[664] Paper

Crude Nukes on the Loose?

Preventing Nuclear Terrorism by Means of Optimum Nuclear Husbandry, Transparency, and Non-Intrusive Fissile Material Verification

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Preface

This is a thesis even more timely than I expected it to be. One year after I commenced my doctoral work, stunned TV audiences across the globe were shocked by live footage of the devastating attacks on lower Manhattan.

The terrorist assaults of 11 September 2001 dramatically altered our perceptions of security. But they did more. Under the rubric of "War on Terrorism", a jagged political focus on international terrorism and a massive hunt for so-called "weapons of mass destruction" was soon instigated. Never before have more resources, political prestige, military power, and human losses gone into the fight against terrorists.

It is in this heated environment and action-packed context this thesis aspires to voice some suggestions on how to best deal with the threat of nuclear terrorism.

The thesis came through during a four-year period starting August 2000. It builds naturally on my book *Atomic Terrorism* (1999). The research was made possible through a grant graciously provided by the Norwegian Research Council.

This assessment of nuclear terrorism has also been a journey on the personal level, where many of my interests and fields of professional expertise have converged in somewhat unexpected ways. My background in nuclear physics and previous work at the Norwegian Radiation Protection Authority to assist in securing and protecting fissile material in Northwest Russia, has helped me to understand the technical aspects of the new nuclear threat. Likewise, my experience in radiation protection and my studies in media science and risk communication have deepened my understanding of the potential of "atoms" as strong tools of terrorist coercion. The efforts of domestic and international NGO communities have showed me the importance of nuclear non-proliferation and disarmament as essential means towards genuine nuclear security.

The Norwegian Institute of International Affairs (NUPI) provided me with a unique chance to merge and further develop these issues into an interdisciplinary research portfolio, in a highly qualified and exciting environment. I am thankful for the opportunities given to me, and I would like to express my gratitude to all my friends and colleagues at NUPI.

This thesis is my own work and views – and so is of course the responsibility for any inaccuracies or errors of analysis of facts. I am, however, indebted to a great many people. Without wishing to leave anyone out, the following persons should particularly be mentioned: Sverre Lodgaard, for always being ready to explore the boundaries of nuclear security wisdom and the inherent opportunities of nuclear arms control. Sverre also served well as my principal advisor. Tore Bjørgo, for familiarising me with the intricacies of contemporary terrorism – and for introducing me to NUPI in the first place. Both of them joined in on the reference group for the doctoral work, where also Knut Gussgård, Steinar Høibraaten, Ole Reistad, Jon B. Reitan, Terje Strand, and Arnfinn Tønnessen participated. I am very grateful to you all.

I would also like to extend special thanks to my co-authors of some of the underlying research papers for the thesis: Annette Schaper, Frank Barnaby, and Roger G. Johnston. Thanks for your willingness to think creatively to further the nuclear terrorism debate and for making nuclear risk assessments and nuclear arms control exciting issues.

Many others have provided useful inputs and comments along the way. Here let me single out Amund Solvi Bremer, as well as Gunnar Arbman, Nils Bøhmer, Ståle Eskeland, Charles Ferguson, Daniel Heradstveit, Alistair Millar, Inga-Britt Mærli, Pernille Rieker, Erik Riul, Andreas Selliaas, Jørn Siljeholm, Heidi Toft, Stein Tønnesson, Lars van Dassen, and Lars Weisæth.

Great appreciation is due to Finn Ingebretsen, for helping to bring back my interdisciplinary research to the spheres of physics at the University of Oslo, where, I hope, it may promote further research and education on nuclear security.

I am indebted to Susan Høivik for her highly professional and swift copy-editing work. Vibeke L. Sand and Liv Høvik are to be thanked for kind lay-out assistance. Ole Dahl-Gulliksen and Ivar Windheim assisted in getting some of the figures into shape. Jan Risvik has helped by providing useful semantic clarifications. The generous support shown by the librarians at NUPI has been invaluable: Dagfrid Hermansen, Hazel Henriksen, Tore Gustavsson and a team of conscientious objectors were always ready to process my literature requests.

A grant from the US–Norway Fulbright Foundation for Educational Exchange enabled me to experience new professional and political environments, and to explore the linkages of technology and security. This triggered a deep interest in the prospects of fissile material verification and allowed me a glimpse into US nuclear security thinking and priorities. Two years in the United States have not only shaped my thinking on international nuclear security relations, including issues related to the threat of nuclear terrorism. They have also given my professional career a boost – and a range of international friends and contacts.

Let me take this opportunity to thank the Fulbright Foundation, as well as friends and colleagues at the Center for International Security and Cooperation (CISAC), Stanford University, and Sandia National Laboratory, California, for those exciting, inspiring and knowledge-packed years. My thanks to all of you for accommodating me and allowing me to talk, repeatedly, about the benefits of cooperative nuclear security and arms control.

It is my hope that the thesis can contribute to diminishing the threat of nuclear terrorism, fuelling a discussion on the role we would like to give nuclear material and nuclear explosives in the 21st century.

Oslo, 24 March 2004

Morten Bremer Mærli

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Executive Summary

This thesis assesses the threat of nuclear terrorism and identifies strategies for diminishing the risk of such incidents. Never before have the material, the technology, the know-how, and, perhaps, the motivations needed to perform acts of nuclear terrorism been more exploitable.

Building on eight research papers, the thesis sets out to answer three principal questions:

- *"Can terrorists possibly perform acts of terror by means of crude nuclear explosive devices based on highly enriched uranium? What are the main barriers to the production of crude nuclear explosives?"*

- *"Is there an optimum way of protecting fissile material from falling into terrorist hands? What role – if any – do transparency and non-intrusive verification play in this regard?"*

- *"Within legitimate security constraints, what kind of measures could be put in place to enhance the transparency and non-intrusive verification of stocks of sensitive fissile material?"*

Answers to these questions may be summarized as follows:

To would-be nuclear terrorists, access to fissile material is the most formidable obstacle to their nuclear ambitions. If non-state actors have sufficient quantities of unirradiated, or "fresh", highly enriched uranium (HEU), the production of crude nuclear explosives could be within their reach. Terrorists will have far less stringent requirements to their nuclear explosives in terms of reliability, safety, security and delivery, than states do.

Once the needed quantities of fissile material have been obtained, it is easier to construct a nuclear explosive device using highly enriched uranium than using plutonium. Technical barriers to the construction of crude nuclear explosives based on HEU should not be regarded sufficient to avoid nuclear terrorism, because:

- HEU allows for the easy and reliable manufacture of crude nuclear explosives;

- perpetrators with access to sufficient quantities of HEU of high enough quality will have good chances of achieving an explosion in the lower kiloton-range, i.e. with a yield comparable to that of the Hiroshima bomb;

- HEU exists in large quantities, in part under unsatisfactory levels of protection, control and accounting;
- HEU detection, e.g. at border-crossings and checkpoints, is demanding due to the low levels of radiation that are emitted;
- radiation levels from unirradiated uranium are low and the handling of HEU involves limited health hazards.

Several implications for countermeasures against nuclear terrorism and protection and control of highly enriched uranium follow from these findings.

There is scant protection against the pressure, heat, and radiation that would ensue from the detonation of even a crudely assembled nuclear device. There would be very few possibilities for meaningful mitigation after a nuclear terrorist attack. Reducing vulnerability by shielding particular or possible targets is neither prudent nor desirable. Accordingly, efforts to thwart nuclear terrorism should aim entirely at prevention.

Detecting illicit fissile material at borders or in a busy urban environment, however, is challenging. The production of crude nuclear explosive devices could go undetected. To stem nuclear terrorism, comprehensive stockpile inventories and stringent norms should be developed to ensure that all stocks of highly enriched uranium are secure and rendered unusable as nuclear explosives. Denying terrorists access to fissile material through satisfactory security at possible sources of supply could be the be-all and end-all of nuclear terrorism countermeasures.

Hence, a key issue for nuclear terrorism prevention becomes how to ensure optimum nuclear husbandry. The past decade has shown some remarkable achievements in the field of practical, cooperative nuclear arms control. Scientists and others whom very few had believed would ever collaborate have worked jointly to secure the excessive stocks of fissile material that were produced during the Cold War arms race. But despite unprecedented efforts, the majority of the security challenges remain. Less than half of the estimated hundreds of tons of proliferation-attractive fissile material in Russia have been secured with international assistance.

The highly enriched uranium, enough for tens of thousands of crude nuclear explosive devices, is managed with very little of the transparency necessary to build confidence that it is safe and secure, or to provide the foundation for deep, transparent and irreversible reductions. Optimal countermeasures against nuclear terrorism thus require significantly more openness on existing holdings of fissile material in the nuclear weapon states. Appropriate schemes for non-intrusive verification of sensitive stocks of HEU are available and ready for implementation.

Keeping a massive shroud of secrecy on stocks of highly enriched uranium can only maintain and exacerbate current uncertainties in fissile material stockpiles and levels of protection and control. This could increase the risk of diversion and, accordingly, elevate the threat of nuclear terrorism. It is not beneficial to the security of any state.

Chapter 1: Objectives and Scope of the Thesis

1.1 Introduction

No terrorist group is known to have developed or deployed a nuclear explosive device, and the severity of the threat of nuclear terrorism remains disputed. Never before, however, have the material, the technology, the know-how, and, perhaps, the motivations needed to perform this specialized terrorist tactic been more exploitable. This thesis assesses the threat of nuclear terrorism and identifies strategies for diminishing the risk of such incidents.

Nuclear terrorism is probably the least understood of all contemporary nuclear dangers. Countermeasures so far instigated may be less than optimal. Contemporary security policies and nuclear threat responses are often driven by worst-case scenarios and perceptions of vulnerability. Moreover, they tend to emphasize *demand*-driven proliferation, e.g. the possible quest for nuclear explosives by states and non-state actors. Consequently, the prospects of deliberate state-to-terrorist nuclear proliferation have come to the fore of our collective attention, as well as of evolving military counter-proliferation strategies.

In parallel, a decisive push for reducing domestic susceptibility to terrorists is developing. "Homeland Security", with its mix of border controls and enhanced emergency response capabilities and domestic surveillance, has preoccupied the US, and to a lesser extent the European, public debate, as well as budget-makers. However, detecting illicit fissile material, or nuclear terrorism plots in the making, could be daunting tasks.

1.1.1 Supply-Side Nuclear Security

Rather than taking a demand-driven, vigilant approach to the challenge of nuclear terrorism, this thesis will look at ways to effectively prevent nuclear terrorism by emphasizing the *supply* side of the problem. To terrorists, difficulty in access to highly enriched uranium (HEU) or plutonium is likely to constitute the single most important obstacle to their nuclear ambitions. Fissile material is an essential component of any nuclear explosive device. Denying terrorists this material through supply-side security could be the be-all and end-all of all nuclear terrorism countermeasures.

Yet, surprisingly little scholarly and political attention has been devoted to threat-reducing activities to secure and control the excessive stocks of Cold War fissile material that are vulnerable to diversion, theft or sale,[1] as well as the effects of such measures in terms of a reduced nuclear terrorist

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1 One important initiative is the US Cooperative Threat Reduction (CTR) program. See Section 4.2.1.1.1.

threat. When grappling with the threat of nuclear terrorism, a key question is how best to deny terrorists access to fissile material. An integral part of this thesis is therefore devoted to the issue of achieving adequate fissile material control and protection through *optimum nuclear husbandry, transparency* and *non-intrusive verification*.[2]

Eight research articles create the scientific backbone of the study. In an interdisciplinary analysis, they create a totality that illuminates evolving nuclear terrorism threats, discusses various threat-reducing approaches, and assesses a range of practical efforts to deny terrorists fissile material. Hence, this thesis is both explorative and normative in character.

1.1.2 The Line of Least Nuclear Terrorist Resistance

To terrorists with access to highly enriched uranium (HEU), crude nuclear explosives of a gun-type design are likely to represent the line of least resistance to their nuclear ambitions.[3] For one thing, it is considerably simpler to make a bomb using enriched uranium than to make one using plutonium, although the critical mass is larger (Bodansky 1996, 271; Falkenrath et al. 1998, 162; Hoenig 2001, 33; Cordesman 2001, 33; Narath 2002, 6).[4] Moreover, highly enriched uranium is easier to handle than plutonium and may thus represent a special nuclear terrorist threat (Falkenrath 1998, 59; von Hippel 2001, 1; Boutwell et al. 2002, 4–7; Committee on Science and Technology for Countering Terrorism 2002, 40).

In consequence, crude HEU weapons represent a particularly relevant item for baseline analysis, for assessing what nuclear terrorists may accomplish – i.e. the minimum requirements for the production of improvised nuclear explosive devices. In order to understand what terrorists might do and what kind of impediments potential perpetrators would encounter when using the most primitive methods available, this thesis has as its principal study objective:

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2 Longman's Dictionary of the English Language (1988, 715) defines "husbandry" as "the management of resources", and the "scientific control and management of a branch (or farming)". A "husband" is a manager or steward, especially one that is prudent and thrifty. Throughout this study, "nuclear husbandry" hence signifies the long-term responsible, careful, and judicious handling, protection and control of fissile material.

3 "Crude" is here used in the meaning of "rudimentary", "rough", and "simple", i.e. technically unsophisticated nuclear explosive devices. The possible effects of a nuclear terrorist explosion in a densely populated area are discussed in Appendix II.

4 If the neutrons from the fission of a nucleus cause the fission of at least one other nucleus, a fission chain reaction is produced. The minimum mass that can sustain a nuclear fission chain reaction is called the "critical mass". A "sub-critical mass" is unable to sustain the chain reaction. If the fission of a nucleus leads to two or more fissions, which in turn lead to another doubling, etc., the process grows exponentially and results in an explosive chain reaction. This system is "super-critical". The fission cross-section and the average number of neutrons per fission are somewhat smaller for U-235 than they are for Pu-239, making the critical mass larger. However, with uranium there is essentially no problem of premature detonation due to neutrons from spontaneous fission (see Appendix III). A number of actinide nuclei can support a chain reaction, but only U-235 and Pu-238 have proven practicable to date. One or more nuclear weapon states may, however, have tested a nuclear explosive using neptunium-237 (Albright and Barbour 1999, 85).

> *To assess the risk of nuclear terrorism associated with highly enriched uranium (HEU), and to identify optimum ways to reduce this terrorism risk.*

This in turn presupposes investigating the competence and the technological sophistication needed to manufacture crude HEU nuclear explosive devices. A first derived study objective is therefore:

> *To assess terrorist pathways to nuclear explosive capabilities, and assess the feasibility of and the barriers to the production of crude HEU nuclear explosive devices.*

To set off a nuclear explosive, terrorists will most likely use a device fabricated from externally acquired fissile material (Arbman and Ringbom 2002, 3; Barnaby 2003a, 2). A second derived study objective is therefore:

> *To assess how the risk of nuclear terrorism may be reduced by introducing specific security measures on highly enriched uranium; further, to consider any limitations and obstacles to the implementation of such security measures.*

On the basis of these study objectives, three principal research questions have been formulated.

1.2 Research Questions

1.2.1 [Q1]: On "Nuclear Terrorism Feasibility"

"Can terrorists possibly perform acts of terror by means of crude nuclear explosive devices based on highly enriched uranium? What are the main barriers to the production of crude nuclear explosives?"

Principal research question number one [Q1] and related issues are explored in papers [P1], [P2], and [P3] (see below). Answers are offered in Section 4.1.

1.2.2 [Q2]: On "Optimum Nuclear Husbandry"

"Is there an optimum way of protecting fissile material from falling into terrorist hands? What role – if any – do transparency and non-intrusive verification play in this regard?"

Principal research question number two [Q2] and related issues are explored in papers [P4] and [P5] (see below), and answered in Section 4.2.

1.2.3 [Q3]: On "Nuclear Transparency and Verification"

"Within legitimate security constraints, what kinds of measures could be put in place to enhance the transparency and non-intrusive verification of stocks of sensitive fissile material?"

Principal research question number three [Q3] and related issues are explored in papers [P6], [P7], and [P8] (see below). Section 4.3 offers some answers.

1.3 Structure

The study encompasses six chapters and seven appendixes. This first chapter presents the rationale, objectives, structure and scope, terminology, and the limitations of the thesis, as well as the underlying research papers. The primary aim of Chapter 2 is to put the threat of nuclear terrorism and research on nuclear terrorism into context. Here, a brief historical outline of nuclear terrorism is presented, together with some observations on the current threat of nuclear terrorism, as well as on threat development. Chapter 3 provides the methodological framework for the analysis: Analytical approaches, tools, and limitations are described and discussed. The chapter starts out with a discussion of some of the dilemmas associated with nuclear terrorism research.

In Chapter 4, key findings of the eight research papers are presented in three principal sections: Understanding the Nuclear Terrorism Threat; Conceptual Nuclear Husbandry; and Nuclear Husbandry in Practise. The latter section uses as a case study fresh naval Russian highly enriched uranium. Each section ends with summary answers to the principal research questions formulated in Section 1.2. The research findings are presented in light of the contextual and analytical framework presented in the two previous chapters, and measured against those of other scholars in the field. As such, Chapter 4 represents more than a mere synopsis of the underlying research articles.

Chapter 5 concludes the analysis and discusses the direct implications of the research findings. Emphasis is on the repercussions for nuclear terrorism countermeasures and practical measures for nuclear arms control. A set of specific policy recommendations on how to meet the threat of nuclear terrorism through optimum nuclear husbandry is presented. The chapter also offers some general considerations on nuclear terrorism risk assessment and model development. Chapter 6 offers some reflections on the research findings. The findings, as well as the implications of the findings, are put into the current political context, with a view to furthering the overall scientific and political discourse on nuclear terrorism risk assessments and nuclear terrorism threat reduction. A critique of the ongoing "War on Terrorism" forms an integral part of the chapter.

Underlying technical issues are presented in the Appendices. A brief assessment of the similarities and differences of "radiological" and "nuclear" terror, two commonly confused forms of terrorism, is presented in Appendix I. The possible effects of a crude nuclear device are described in Appendix

II. Particular challenges associated with the production of crude nuclear explosives are discussed in Appendix III. In Appendix IV, open-source information on Russian naval fuel is presented as background for the case-study research, while Appendix V gives an overview of past thefts of fresh naval fuel in Northwest Russia. Appendix VI presents the status of US support activities to secure fresh Russian naval fuel. Possible spin-offs of the study that could be relevant to nuclear non-proliferation, emergency preparedness, risk communication and education are briefly discussed in Appendix VII.

Key terms are presented in a glossary at the end of the thesis. All supportive research papers are reproduced in full in the Addendum.[5]

1.4 Terminology

The study distinguishes between "nuclear terrorism" and "radiological terrorism" – two related yet distinct forms of terrorism. This is further discussed in Section 1.5.2, as well as in Appendix I.

Throughout the study, a clear distinction is also made between "nuclear weapons" and "nuclear explosive devices". Where states may possess nuclear weapons, terrorist may only be able to produce crude nuclear explosives (see Section 4.1.2.4.2).[6] No attempt, however, is made to discriminate between terms like "crude nuclear explosives" and "improvised nuclear explosives", or simply "nuclear devices". All these terms should be considered as referring to simple nuclear explosives that are possibly within the technical reach of terrorists, as opposed to the more technologically advanced nuclear weapons possessed by states.

For reasons of simplicity, the expressions "fissile material", "direct-use material", "weapons-grade material", or "weapons-useable material" are all used interchangeably as well. Basically, they indicate material that may be applied to construct workable, crude nuclear devices.[7]

Likewise, the study refers indiscriminately to "terrorists" and "non-state actors", simply ignoring any semantic differences between the two, as well as the inherent problems associated with the term "terrorism". Labelling opponents or adversaries as "terrorists" is a common technique to de-legitimize and demonize them (United Nations 2002b, 6) (on these problems, see Bjørgo and Heradstveit 1993, 13–16; Garton Ash 2001, 3w).

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5 References found on the Internet, or the "web", are throughout the text marked with a "*w*" after the page in question. Page numbering may thus be somewhat arbitrary compared to those of book references (generally, the Internet page numbers should reflect the equivalent page numbering for a Word-document).

6 Generally, "nuclear explosives" can be part of a military weapon, terrorists may use it, it may be applied for peaceful purposes, or it can be constructed solely as a part of a research and development project (Swahn 1992, 208).

7 Obviously, this collective jargon is a simplification. According to the International Atomic Energy Agency, "direct-use material", that is nuclear material that could be used for the manufacture of nuclear explosive devices without transmutation or further enrichment, includes plutonium containing less than 80% of Pu-238, highly enriched uranium and U-233. Another category is the so-called "special fissionable material". This category contains "Pu-239, U-233, and uranium enriched in the isotopes U-233 and U-235, or any material containing one or more of the foregoing; and other such fissionable material as the Board of Governors shall from time to time determine" (International Atomic Energy Agency 2002b, 30-31 and 33).

Neither does the study distinguish strictly between "threat" and "risk". As seen in Section 3.4.1, "risk" may be given a fairly concise mathematical definition and is thus in many instances a highly quantifiable and "objective" parameter.[8] "Threat" is not so much a statement of a probability as a (personally) felt or perceived concern about a looming peril. Accordingly, Tønnessen (2002, 7) defines "threat" as "an indication of impending danger".

Moreover, whereas "threat" imports specific consequences, "risk" is based upon measurable losses. These losses can be from an attack, or they can be inadvertent. Hence, whereas a "threat" requires some level of intention, "risk" may not. As such, the two concepts represent quite different ways of describing and interpreting hazards. For a highly non-quantitative study like the present one, however, the somewhat inexact mixing of "risk" and "threat" should cause minimal confusion.

Nor is a stark distinction is made between risk reduction and risk prevention. The terms are interrelated, and may represent a sliding continuum of activities. For instance, time will be needed to complete the work of improving security for fissile material in Russia. Until then, the efforts will be of a risk-reducing character. Risk prevention will be accomplished only when all nuclear proliferation-attractive material is duly secured. As such, risk prevention represents an ideal, and risk reduction a means towards that end.[9]

A recurring phrase in the thesis is "practical arms control measures". This is a general, and admittedly somewhat imprecise, term used for any measures implemented to protect and control nuclear material, e.g. to increase nuclear security. As such, the phrase is more explicit than the widely used "arms control", a term that normally encompasses an entire range of political/diplomatic and verification efforts, often in conjunction with formalized treaties (see e.g. Gallagher 1999).

"Weapons of Mass Destruction" is arduous phrase (see Section 6.2) that is generally avoided. Throughout the text it has been substituted with "chemical", "biological", "radiological", and "nuclear" (or simply "CBRN"), respectively.

1.4.1 Definitions

While the scholarly community in general agrees upon the core elements of a definition of "terrorism", discussion continues on how to delimitate the term. No real consensus as to what should be denoted "terrorism" has yet been established.[10] More than 200 different definitions of terrorism now may be found in the academic literature (Silke 2003, 2). There exists no clear and

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8 Refer for instance to the fields of "Risk Analysis" and "Risk Management". The latter is basically a quantifiable discipline for living with the possibility that future events may cause adverse effects.

9 The author of this thesis owes this point of clarification to Richard Garwin, when he commented on my intervention on "*Terrorist use of nuclear weapons and control of weapons-useable materials"*, at the XV Amaldi Conference on Problems of Global Security, Helsinki, 25 September 2003.

10 This has for instance contributed to slowing down the work for an international convention for the Suppression of Nuclear Terrorism. For a summary of this and other international diplomatic initiatives related to nuclear terrorism, see Potter and Florquin 2002.

concise working or operative definition of "terrorism" – and certainly not of "nuclear terrorism".

For the purposes of this study, "nuclear terrorism" is defined as (based on Maerli 1999, 24):

> *Acts of violence and destruction performed by non-state actors where the means applied are nuclear explosive devices – or threats of such actions – with the purpose of inflicting destruction, creating a condition of fear, getting attention, blackmailing, installing instability, and to affect an audience beyond the victim(s) directly targeted.*

In other words, this study focuses on non-state elements exploring the use or threat of use of nuclear explosives to inflict havoc, fear and a deep-felt sense of insecurity in the population at large, in order to achieve certain goals. This is a narrow definition of "nuclear terrorism" that carries with it several implications.

Firstly, by emphasizing "non-state actors", the definition excludes nuclear terror in the inter-state domain. Terror has for long been adopted by various regimes as an instrument of control and suppression. For decades, nuclear weapons and their destructive powers have been used to constrain and deter opponent states through the logic of mutually assured destruction (MAD). This balance of nuclear terror has been installed despite the illegality of the weapons and the disarmament obligations of the nuclear-weapon states.[11]

Secondly, the definition categorizes even credible *threats* as a form of terror, because of the destructive powers of nuclear explosives and hence the psychological strain that possible use involves. This is also why the study, and the definition, focus on "nuclear terrorism" and not on "nuclear sabotage", as suggested by others (see e.g. Schmid 2001, 16). Sabotage may have additional aims, such as inflicting economic, military or proprietary damage, rather than primarily to install fear and devastation.[12]

1.5 Scope Limitations

With its core foci, the study has inherent limitations. The following section explains what is in the study, and what is not.

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11 Nuclear weapon states are obliged, through Article VI of the Nuclear Non-Proliferation Treaty (NPT), to eliminate their nuclear arsenals. Nuclear weapons are, in accordance with the NPT, temporarily legal in five countries, not illegal in three others, and forbidden everywhere else. Chemical and biological weapons, however, are both legally prohibited by treaty, so the challenge they pose is basically one of enforcement. (Perkovich 2003). In July 1996, the International Court of Justice ruled that the threat or use of nuclear weapons is generally illegal, and that states have an obligation to conclude negotiations on their elimination. See www.lcnp.org/wcourt/opinion.htm (last accessed 30 October 2003).

12 There are overlaps between acts of terrorism and sabotage. Where terrorism rests upon a fear of death or severe harm, sabotage involves additional elements of calculated destruction of properties or installations, with the primary intention to inflict personal or larger economic losses or physical damage.

1.5.1 What is *In*?

The study focuses solely on the possible production of crude nuclear explosive devices by non-state groups, especially the first-generation gun-type design – the simplest and probably the most reliable nuclear device ever produced. Only highly enriched uranium (HEU), and not plutonium, may be used in this design. HEU is hence the core object for analysis throughout the thesis.

The critical mass of enriched uranium increases as the relative amount of U-235 decreases. It is generally considered possible to construct nuclear explosives with enrichment levels as low as 20% (Swahn 1992, 47). When diluted to an isotopic content less than 15–20% in uranium-235, the material cannot be used in a nuclear device, because sufficiently rapid super-critical assembly of the explosive becomes impractical and the critical mass too large (Moniz and Neff 1978, 42).[13]

In consequence, natural uranium has to be enriched if it is to be applied in nuclear explosives. While a small-scale enrichment programme might be hidden through careful facility design and could, in principle, produce enough fissile material for a bomb after several years of operation (Committee on Science and Technology for Countering Terrorism 2002, 41), terrorists are unlikely to enrich material themselves (Cordesman 2001, 30; Schaper 2002, 19; Arbman and Ringbom 2002, 3). Uranium enrichment is equipment-intensive, expensive and time-consuming. In order to manufacture an improvised nuclear explosive device, terrorists would have to steal, buy, or receive sufficient amounts of high-quality uranium.

Highly enriched uranium serves two primary purposes in nuclear-weapon states: As the essential ingredient of nuclear weapons, and as reactor fuel for naval nuclear propulsion.[14] The high enrichment levels establish a natural connection between the stocks. The weapons material may be used as fuel and vice versa: Virtually all high-quality weapons-grade uranium surplus in the USA today is thus kept for naval reactor fuel (Bunn 2000b, 54). As such, increased HEU excess declarations and HEU destruction may call for clarification of the HEU needs and future consumption of the navies. Today this information is classified and beyond the reach of the international community (see Appendix IV). HEU is also used in research reactors and at various research institutions.[15] Current global stocks of HEU are nearly seven times greater than the holdings of weapons-grade plutonium.

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13 Theoretically, uranium enriched to any level above 6% may be used to make a nuclear explosive. For all practical purposes, however, the size of the critical mass required would make this impractical. Frank von Hippel, personal communication with Arbman et al. 2004, 11 September 2003.

14 HEU may be categorised by way of utilization. HEU stocks exist as (based on Schaper 1997, 21–22): (1) military material in operational nuclear weapons and their logistics pipeline, (2) military material held in reserve for military purposes, in assembled weapons and in other forms (e.g. naval fuel), (3) military material in weapons slated for dismantling, (4) military material withdrawn from dismantled weapons, (5) military material declared for transfer to the civilian sector, (6) material currently in reactors (including naval and research reactors, and power reactors) and their logistics pipelines and storages, and finally, as (7) irradiated HEU in spent fuel from reactors, or in vitrified form for final disposal. The primary focus of this study is on unirradiated naval fuel under item (2).

15 According to IAEA estimates, a total of more than 1,300 kg of highly enriched uranium exists in research reactors in 27 countries, sometimes in quantities large enough to make a

Both the material in the nuclear-weapon stockpile and the naval fuel stocks are kept under strict national surveillance, under a shroud of secrecy.[16] So far, the use of HEU in the military sector has attracted little non-proliferation attention. Most non-proliferation analyses of fissile material in recent years have focused on weapons-grade plutonium slated for disposal (Glaser 2003, 34 and 36). But as the international community tries to tighten the noose around stocks of weapons-useable nuclear material to lay the foundation for deeper cuts in nuclear arsenals and optimum nuclear non-proliferation activities, it will, sooner or later, have to deal with the naval stocks of highly enriched uranium as well (von Hippel 1997, 6). Accordingly, stocks of Russian unirradiated naval fuel are here used as a case study for the introduction of transparency and non-intrusive verification on sensitive fissile material.[17]

1.5.2 What is *Out*?

With an exclusive focus on the latter, the thesis distinguishes between possible acts of radiological terrorism, terrorist attacks against nuclear power plants, and nuclear terrorism (see Section 1.4.1). Too often, even radiological terrorism is put under the rubric of "nuclear terrorism" (see e.g. Potter and Spector, 2002; Whittaker 2002, 162; Potter and Florquin 2002, 1; Snowden 2003, 699–713; Steinhausler 2003, 783).[18] While related, these types of terrorism are quite distinct. Mixing them uncritically may add to the current confusion.

Radiological terrorism could inflict damages of both physical and psychological character. It rests upon (the threat of) direct radiation exposure for humans and surroundings. One method involves the mixing of highly radioactive material with conventional explosives to create radiological dispersal devices (RRDs), or so-called "dirty bombs", radioactive material wrapped around high explosives. A dirty bomb could have drastic economic and psychological effects (Levi and Kelly 2002, 81), and its potential for societal disturbance may be considerable. It would not, however, involve the triggering of a nuclear chain reaction. The physical effects of radiological terrorism would be minuscule compared to those ensuing from a successful nuclear terrorist explosion.

The potential terrorist vulnerability of nuclear power plants has also captured the imagination of the public and the media.[19] The psychological impacts of any attacks may be correspondingly strong. Some studies suggest that a terrorist attack on a nuclear power plant could have potentially severe consequences, if the attack is large enough (Committee on Science and

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bomb. The US has been criticized for failing to retrieve its highly enriched uranium dispersed over the last several decades for research purposes (Brinkley and Broad 2004).

16 As nuclear-weapon states under the Nuclear Non-Proliferation Treaty, the states are exempted from international safeguards and control on their nuclear activities. Some voluntary safeguards agreements do, however, exist between these states and the International Atomic Energy Agency.

17 See Section 4.3.1 for a further explanation of the case-study selection.

18 These differences are further discussed in Appendix I.

19 Not least after rumours that one of the planes hijacked on 11 September 2001 was destined for the Three Mile Island nuclear power plant in Pennsylvania.

Technology for Countering Terrorism 2002, 41). But if attacked, no commercial nuclear power plant would produce devastating effects equivalent to those of a nuclear explosive.[20]

Moreover, the strict study-focus on first-generation crude gun-type explosive devices bars any assessments of nuclear explosives using plutonium. As such, the study will not be able to consider the security ramifications of ever-increasing stocks of separated plutonium, the applicability of reactor-grade plutonium in crude nuclear devices, or the possible radiological dispersal-device properties of a fizzling plutonium explosive device. Nor does the scope give an opportunity to assess the security concerns associated with MOX.[21]

The narrow scope of the study also excludes, perhaps somewhat unexpectedly, the seemingly deadly mix of terrorists and intact nuclear weapons. Nuclear weapons may be stolen – for instance during transport, when they are particularly exposed (Valynkin 1996, 16). In the mid-1990s reports of stray nuclear weapons regularly hit the front pages of leading newspapers. Anecdotal reports suggest that nuclear weapons have been lost since the break-up of the Soviet Union (Lee 1999, 123–27).[22]

An array of tactical nuclear weapons was developed and deployed during the Cold War, covering almost every type of military posture (Rogers 2000, 22). There have been specific concerns regarding the security of Russian sub-strategic weapons due to their (often) forwarded positions, the lack of systems to prevent unauthorized use, their large numbers and limited size (Potter and Sokov 2001; Millar 2002; Alexander and Millar 2003).

The need for securing and consolidating tactical nuclear weapons in a transparent manner should not be brushed aside.[23] However, the barriers for terrorists desiring to acquire intact nuclear weapons could prove higher than anticipated. Nuclear weapons are generally subject to more rigorous standards of protection than fissile material (Orlov et al. 2002, 54; Committee on Science and Technology for Countering Terrorism 2002, 40). As a result of unilateral (US and Russian) action,[24] tactical nuclear weapons could now be

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[20] So far, moreover, no attacks against nuclear power plants have resulted in radioactive releases to the surroundings (Bremer Maerli 1999, 57).

[21] Mixed Oxide fuel, i.e. a mix of uranium oxide and plutonium fuel that can be used in (modified) power reactors. Both the USA and Russia now insist that MOX-fuel should be the primary way to dispose of their excess stocks of weapons-grade plutonium, the alternative being immobilisation.

[22] According to (questionable) and recurrent media reports, Osama bin Laden possesses several Russian suitcase nuclear bombs (Rees-Moog 2001; Associated Press 2004). During the war in Afghanistan, the Taliban regime supposedly made contact with Pakistani nuclear weapon scientists and were offered small tactical Russian nuclear weapons (Radio Free Europe/Radio Liberty 2001). In autumn 1998, Arabic news sources claimed that bin Laden had obtained nuclear weapons through links with organized crime in Chechnya and the former Soviet Republics of Central Asia, paying with opium in exchange for nuclear weapons (Pate 2003). The pan-Arab newspaper *al-Hayat* claimed February 2004 that the al-Qaeda organization led by Osama bin Laden bought tactical suitcase nuclear weapons from Ukraine in 1998 and is storing them in safe places for possible use (Reuters 2004, 1w). There has been no independent corroboration of the report, and none of the information has later been confirmed by authoritative sources. For more on the problems of over-reporting, see Section A.7.6. in Appendix VII.

[23] Smith (2003, 23) summarizes this concern vividly: “The Russians no longer need to disperse their nuclear weapons as a means to reduce the effectiveness of an American nuclear attack; rather, they need to consolidate them to reduce the likelihood of theft by terrorists”.

[24] The so-called Presidential Nuclear Initiatives (PNIs) of George Bush (Sr.), Mikhail Gorbachev, and Boris Yeltsin in 1991 and 1992.

as secure as strategic ones (Handler 2003, 32). Most weapons are stored in centralized storage vaults.[25]

The theft of the nuclear weapon itself might not entail sophisticated technology, but would probably necessitate heavy manpower and weaponry. An attack on a nuclear-weapon arsenal would require expeditiously overcoming both passive and active security measures (Mullen 1987, 237). Moreover, permissive action links (PALs) may render any unauthorized use difficult. Removing the fissile material from the weapons may prove hard, as well as highly dangerous. Even if would-be perpetrators manage to overcome all these obstacles, delivery may still pose significant hurdles.

In consequence, without some kind of state cooperation, successful terrorist acquisition and use of an intact nuclear device could be next to impossible (Center for International Security and Cooperation 2003, 3). Hence, it may not be so that a small functioning, tactical nuclear weapon necessarily is "a terrorist's dream come true", as claimed by Couch (2003, 126).

Excluding intact nuclear weapons from the study also precludes any investigation into the mysterious "suitcase bombs". In June 1997, former Russian Security Council chief General Lebed announced that some 52 to 84 Soviet suitcase-size nuclear bombs were missing (Lee 1999, 125).[26] Some Russian officials have confirmed the story; others have refuted it. In terms of size and compactness, advanced nuclear-weapon states, like the former Soviet Union, are probably capable of producing such bombs (Sublette 2002, 1w; Sokov 2002, 10).[27] However, it is questionable whether the nuclear material (plutonium) contained in the explosive device is still suitable for use. The performance of these nuclear explosives, if they exist, may be correspondingly low (Sokov 2002, 11w; Maerli et al. 2003, 703–731).[28]

Situations where states share nuclear technology, and possibly nuclear weapons, with non-state actors cannot be excluded. Any "nuclear sponsoring" could boost terrorists' nuclear abilities. Indeed, this was initially the primary US rationale for attacking Iraq Spring 2003. According to President G.W. Bush, "terrorists will find a shortcut to their mad ambitions when an outlaw regime supplies them with the technologies to kill on a massive scale" (Bolton 2003, 2w).[29] Such scenarios, however, could be unlikely. Even according to Bush's own intelligence assessments, the likelihood of a

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[25] US tactical nuclear-weapon aircraft bombs in Europe are an exception (Handler 2003, 32). The approximately 180 bombs are kept dispersed in weapons storage vaults at ten bases in seven European countries.

[26] Reportedly, the yield of the devices was approximately one kiloton. The suitcases would weigh between 27 and 45 kg and could be armed in 20 to 30 minutes without secret codes.

[27] A related feature is the atomic demolition munitions (ADMs). The munitions were to be buried under their wartime targets before any hostilities and, if necessary, be exploded to hinder advancing Soviet ground troops into Europe. Because of their characteristics, ADMs were denoted "defensive nuclear weapons" (Hutchinson 2003, 86). Other lightweight nuclear weapons include the "David Crockett", a recoil-less rifle or a bazooka in the possession of the US infantry. Its range was between 1,000 and 13,000 feet. Both sides in the Cold War also deployed nuclear artillery shells as short-range tactical weapons, the so-called "atomic cannon" (Hutchinson 2003, 88).

[28] As a rule, nuclear weapon plutonium has to be replaced at given intervals, perhaps every five to ten years. The material in any lost Russian nuclear explosives has certainly not been replaced, rendering the significance of the missing suitcase bombs more doubtful.

[29] The United States has, unsuccessfully, sought to link Saddam Hussein with al-Qaeda (Millar 2002, 1w; Bremer Maerli, 2003b, 24). See for instance State of the Union Address, 28 January, 2003, by President G.W. Bush, www.whitehouse.gov/news/releases/2003/01/20030128-19.html last accessed 10 March 2004).

state sponsor providing such nuclear, biological, or chemical weapons to a terrorist group is believed to be low (United States Department of Defense 2001, 61).

There are several reasons for this. Firstly, any state providing nuclear weapons may face severe retaliation if such a transfer ever becomes known.[30] Secondly, any state leader willing to engage in sponsoring nuclear terrorists may run a particular risk of losing (hard-won) control, by providing the most fearsome power the state ever possessed to non-state actors (Center for Counterproliferation Research 2002, 8; Bunn et al. 2003a, 28–29). Thirdly, nuclear weapons are extremely hard to acquire, even for states. To states, the weapons are regarded not only as military instruments but also as symbols of power, legitimacy and status – demonstrating national capabilities and thus creating the foundations for nationhood building (Bracken 2003, 405). And finally, nuclear weapons are regarded as the ultimate deterrent, and a decisive guarantor for regime survival. States possessing nuclear explosive devices are likely to hold onto them.

This, however, does not exclude state elements from supporting nuclear terrorists, directly or indirectly. Some Pakistani nuclear scientists feel that their country's bomb should be shared with the entire Muslim community, including al-Qaeda (Albright and Higgins 2003, 49). These scientists admit to having met Osama bin Laden in Afghanistan, and may have been able to make contributions to an al-Qaeda nuclear programme. Early in 2004, moreover, Pakistan's top nuclear scientist, Abdul Qadeer Khan, confessed to having leaked nuclear secrets to other states (BBC 2004, 1w).

Involvement of key nuclear scientists in unlawful nuclear proliferation activities may add to the risk of nuclear terrorism, especially if, as suggested by some, weapons-grade material has been passed to al-Qaeda (see Kristof 2004, 1w). Yet, issues of nuclear brain-drain or deliberate or unintended state-to-terrorist nuclear sponsoring will be beyond the primary scope of this study.[31] While any transfers of know-how could boost nuclear ambitions, mere illicit trafficking in for instance nuclear enrichment technology may be of limited use to terrorists. Actors with nuclear ambitions – whether individuals, groups or nations – may well prefer to acquire weapons-useable material externally rather than producing it, as there are significant cost and time expenses related to developing the necessary infrastructure to produce fissile material (Dreicer and Rutherford 1996, 30).

Ultimately, the only effective and sustainable way to prevent the unauthorized use of weapons-useable uranium is to blend existing stocks down to low enriched uranium (LEU), which is not directly useable in weapons (Calogero 2003, 4; Natural Resources Defense Council 2003, 3w). Important efforts have been launched to expedite HEU elimination activities (see e.g.

[30] This problem could be less prominent if a state hires a misaligned group to anonymously deliver a nuclear device for the state in question – an argument sometimes used in the run-up to the Iraq war.

[31] "Brain-drain" is a commonly used expression, normally in the context of the former Soviet Union, to describe the possible flux of (nuclear) weapon scientists and know-how to new states.

Arbman et al. 2004). Considerations in this direction will, however, be outside the scope of the thesis.[32]

The risk that HEU may be applied in crude nuclear weapons has also motivated renewed (and important) emphasis in arms control circles on eliminating the use of HEU in both civilian (research) and military (naval) reactors. Proposals have been made to convert reactors using HEU to reactors using LEU (low enriched uranium) (Bukharin et al. 2002; Bukharin 2002; Kang and von Hippel 2001; Miller 2003).[33] The conversion of naval reactors would entail obvious security benefits. However, a range of factors may hamper its successful implementation and nor is possible reactor conversion assessed in this study.[34]

1.6 Research Papers

Eight research papers constitute the scientific backbone of the study:[35]

1.6.1 [P1]: "Relearning the ABCs"

Morten Bremer Maerli, "Relearning the ABCs: Terrorists and "Weapons of Mass Destruction"", *Nonproliferation Review*, vol. 7, no. 2, Summer 2000a, ww.cns.miis.edu/pubs/npr/vol07/72/maerli.pdf (last accessed 30 October 2003).

Abstract:

Throughout the 1990s, the prospects of biological and chemical terrorism attracted increasing attention, especially in the USA. The article points out some distinct features of non-conventional terrorism and contrasts biological and chemical ter-

32 For a range of reasons is simply assumed that nuclear-weapon states will continue to maintain their stockpiles of nuclear weapons and large (excessive) stocks of fissile material in the foreseeable future.

33 Research reactors may be particularly vulnerable to terrorist attacks and fuel diversion. While operating on limited capacities, many of these rectors are located on university campuses, locations with far less comprehensive security measures and control than traditional sites for nuclear power plants (Bunn and Braun 2003). High-density research reactor fuel is under development, and the prospects for LEU-run research reactors could be good (Miller 2003, 2). Preliminary feasibility studies show that even naval reactor cores, currently fuelled with HEU, may be converted with minimal efficiency losses (Ma and von Hippel 2001).

34 Not only is space tight in naval vessels, particularly in submarines. Naval reactors must operate reliably for long periods of time, under extremely harsh conditions. The use of high-density LEU fuel requires reactor modifications. Any modifications to fuel or reactor may compromise performance and, hence, security. Moreover, modifications would negatively affect refuelling intervals. After half a century of research, the USA has now reached its goal of lifetime reactor cores, using HEU (Bremer Maerli 2001d, 24). In consequence, there is particularly strong US reluctance to redesign the reactors.

35 Research papers [P1], [P2], [P4], and [P7] have all undergone peer-review. [P3] was reviewed at the "New Faces Conference 2000: The Role of Nuclear Weapons in the 21st Century", 12–15 October 2000, Puidoux-Chexbres, Switzerland, prior to book publication (see Bremer Maerli 2001e). An updated version of paper [P6], titled "US-Russian Naval Security Upgrades. Lessons learned and the way ahead", appeared in *Naval War College Review*, Autumn 2003, vol. 56, no. 4. Throughout this study the original paper published in *Yaderny Control* will be used as a point of reference. For the *Naval War College Review* article, please refer to www nwc.navy.mil/press/Review/2003/Autumn/art2-a03.html (last accessed 30 October 2003).

rorism with nuclear terrorism. It discusses various forms of "super-terrorism",[36] its likelihood, and steps and obstacles towards such acts of terror. The differing requirements that terrorists and states may have to nuclear explosive devices are discussed. It is concluded that practical, strategic and possibly even moral constraints will make conventional weaponry and bombs the most likely terrorist means also in the future. Acts of non-conventional terrorism cannot, however, be ruled out. In this regard, nuclear terrorism may prove to be a more feasible option than often perceived, due to the quite limited technical capabilities needed to produce crude uranium explosives.

1.6.2 [P2]: "The Characteristics of Nuclear Terrorist Weapons"

Morten Bremer Maerli, Annette Schaper, Frank Barnaby, "The Characteristics of Nuclear Terrorist Weapons", *American Behavioral Scientist,* vol. 46, no. 6, February 2003.

Abstract:
The risk of nuclear terrorism may be low, but the possible level of physical destruction, fatalities and injuries is so great in and of itself that the potential for terrorist acquisition and use of nuclear devices warrants serious consideration. This article provides some observations on the likelihood of nuclear terrorism and on the technical feasibility of producing crude nuclear weapons. Characteristics of potential nuclear terrorist weapons are discussed and compared with military nuclear-weapon requirements. It is shown that the obstacles to the production of crude nuclear explosives may be lower than anticipated, and that technical barriers should not be regarded as sufficient to avoid future nuclear terrorism. Preventing extremist groups from achieving their goals of large-scale nuclear violence can best be done by denying them access to highly enriched uranium or plutonium, the essential ingredients of any nuclear device. Consequently, adequate protection and control of such material is vital. The gap, however, between the threat and the international response seems to be widening.

1.6.3 [P3]: "Managing Excess Material In Russia"

Morten Bremer Maerli "Managing Excess Material In Russia", in Andreas Wenger and Joachim Krause, (eds.), *Nuclear Weapons and International Security in the 21st Century,* Studies in Contemporary History and Security Studies, Center for Security Studies and Conflict Research, Swiss Federal Institute of Technology, Bern et al. Peter Lang, 2001e, www.fsk.ethz.ch/documents/Studies/volume_8/content.htm (last accessed 30 October 2003).

Abstract:
Proper management of plutonium and highly enriched uranium, the essential ingredients of any nuclear explosive device, is a vital part of non-prolifer-

[36] This is a term frequently used by former Senator Sam Nunn, encompassing nuclear, biological and chemical terrorism.

ation efforts and a prerequisite for deep, transparent and irreversible reductions in nuclear material and nuclear-weapon arsenals. Existing systems of Material Protection, Control and Accountability in Russia may not, however, be up to the task. This article reviews current security challenges associated with the protection and control of weapons-useable material. It is shown that physical security upgrades at Russian nuclear facilities are a comprehensive and complex task, requiring more than quick technical fixes. The article concludes with a set of recommendations for the future management of fissile material.

1.6.4 [P4]: "Safeguarding This and Verifying That"

Morten Bremer Maerli and Roger G. Johnston, "Safeguarding This and Verifying That: Fuzzy Concepts, Confusing Terminology, and their Detrimental Effects on Nuclear Husbandry", *Nonproliferation Review,* vol. 9, no. 1, Spring 2002, www.cns.miis.edu/pubs/npr/vol09/91/abs91.htm#maer (last accessed 30 October 2003).

Abstract:
Words and concepts may have remarkable power, not least in international matters where subtleties and ambiguities in meaning can have major implications for treaty interpretation and compliance. In the diplomatic and political sphere, ambiguity has its uses, such as for attaining consensus or strategic gain. In consequence, hazy concepts may be embraced deliberately by international players seeking to achieve policy goals. But the imprecise use of terms and concepts can also have significant detrimental effects, causing misunderstandings and lost opportunities for practical nuclear arms control. The article takes a critical look at some of the existing nomenclature and concepts in the field of nuclear material, protection, control and accounting. Many current arms control terms are imprecisely defined and often used inaccurately. As an alternative to the current "fuzzy" terminology, Seven Nuclear Husbandry Functions are identified. These have less overlap and a clearer range of application, and may help to avoid technical and political pitfalls. It is concluded that the use of more precise terminology can strengthen both domestic and international efforts to improve nuclear security, whereas continued confusion over basic terms may block further progress.

1.6.5 [P5]: "International vs. Domestic Nuclear Safeguards"

Roger G. Johnston and Morten Bremer Maerli, "International vs. Domestic Nuclear Safeguards: The Need for Clarity in the Debate over Effectiveness", *Disarmament Diplomacy*, no. 69, February/March 2003.www.acronym.org.uk/dd/dd69/69op01. htm (last accessed 30 October 2003).

Abstract:
Several interpretations of the term "safeguards" exist. The international community uses "safeguards" in a different way than for instance the United Sta-

tes, and a clear, concise definition of one of the most central concepts in practical nuclear arms control is still lacking. As a result, there may be a risk not only of mixing the meaning of the different safeguards terms, but also of confusing the disparate goals of practical nuclear security measures. To avoid the far too common "one-size-fits-all" approach to nuclear security, the article explains how and why different forms of nuclear safeguards are quite dissimilar activities. This is done by comparing a set of "real-life" (operational) differences between "international safeguards" and "domestic safeguards". This assessment is followed by a set of concluding remarks on the specific dangers of confusing or mixing domestic safeguards with international safeguards.

1.6.6 [P6]: "US–Russian Naval Security Upgrades"

Morten Bremer Maerli, "US-Russian Naval Security Upgrades: Lessons Learned And Future Steps", *Yaderny Kontrol,* no. 4, Fall, 2002b.

Abstract:
The US Department of Energy is working cooperatively with Russia on several fronts to reduce the threats associated with the Cold War nuclear legacy. One of these activities is the Material Protection, Control, and Accounting (MPC&A) Program.[37] It aims at reducing the threat of nuclear proliferation and nuclear terrorism by improving the security of all weapons-useable nuclear material. The programme has substantially increased security for large amounts of vulnerable nuclear material. However, most security challenges involving Russian nuclear material remain, and programme implementation has been hampered by various practical and political obstacles. The naval MPC&A security upgrades for fresh, unirradiated naval fuel and nuclear weapons in Northwest Russia have clearly been able to deal with these obstacles. This article examines the sources of the extraordinary progress of the naval security upgrades, and attempts to balance justified security concerns with the need for openness. The progress made suggests that valuable lessons can be learned from the US–Russian naval security upgrades, lessons that could contribute to other practical nuclear arms control activities as well, including nuclear transparency and non-intrusive verification.

[37] Broadly speaking, domestic "MPC&A" (Material Protection, Control, and Accounting) systems are intended to protect material against theft or diversion, and to detect such events if they occur. This is explained succinctly in National Research Council 1999, 12: "Physical protection systems should allow for the detection of any unauthorized penetration of barriers and portals, thereby triggering an immediate response. The system should delay intruders long enough to allow for an effective response. Material control and containment systems should prevent unauthorized movement of material and allow for the prompt detection of the theft and diversion of material. Material accounting systems should ensure all material is accounted for, enable the measurement of losses, and provide information for follow-up investigations for irregularities".

1.6.7 [P7]: "Transparency and Non-Intrusive Verification"

Morten Bremer Maerli, "Timely Options for Increased Transparency and Non-Intrusive Verification on Highly Enriched Uranium Naval Fuel", *Journal of Nuclear Material Management,* Vol. 31, no.4, Summer 2003c.

Abstract:

The article explores the technical options and potential pitfalls for increased transparency, and possibly, non-intrusive verification on sensitive fissile material. Fresh Russian naval fuel is used as a case study. The prospects for increased transparency in naval fuel and non-intrusive verification may be better than anticipated and could build upon the progress and solid working relations established during the US–Russian naval MPC&A upgrades. Throughout the article, the importance of openness on stocks of naval fuel is explored. The political and practical challenges associated with transparency in dealing with naval nuclear fuel are assessed, partly in light of ongoing technical work and R&D in related areas of practical arms control. Technical fixes are available for non-intrusive naval HEU verification, if the necessary political will can be established. The measures proposed would not involve the release of any classified or sensitive information. If implemented, they could help in establishing a norm of naval fuel transparency and boost confidence in the non-diversion of fissile naval material for clandestine bomb production, by terrorists and others.

1.6.8 [P8]: "Deep Seas and Deep-Seated Secrets"

Morten Bremer Maerli, "Deep Seas and Deep-Seated Secrets: Naval Nuclear Fuel Stockpiles and The Need for Transparency", *Disarmament Diplomacy*, no. 49, August 2000b, www.acronym.org.uk/dd/dd49/49fuel.htm (last accessed 30 October 2003).

Abstract:[38]

All five declared nuclear-weapon states under the Non-Proliferation Treaty (NPT) possess nuclear-propelled submarines. As nuclear-weapon states they are exempted from international (IAEA) safeguards. Sensitivity concerns and the strategic importance of nuclear submarines have led the nuclear-weapon states to maintain a high degree of secrecy on their nuclear naval operations and stocks of fissile material. The USA and Russia have extensive nuclear propulsion programmes, representing a significant part of the global HEU economy. Eventually, even these stocks may have to be accounted for. Civilian naval uses of highly enriched uranium are, moreover, envisioned. As current safeguards do not meet the proliferation challenges associated with the unirradiated naval fuel cycles, voluntary transparency in naval activities could be introduced as a confidence-building supplement to international control. Promoting a norm for transparency on naval nuclear fuel could limit the risk of evasions of naval material and, hence, raise confidence

[38] This (early) paper carries with it some inherent difficulties, as it mixes "transparency" and "verification". As shown in [P5], these are indeed quite distinct concepts in nuclear security. Still, the paper has been included among the background papers, as its contextual and conceptional considerations on the issue of naval transparency seem to have merits.

in non-diversion. It could, moreover, help to create the conditions needed for deeper cuts in nuclear stockpiles, as well as improved nuclear security. This is a *sine qua non* for reducing the threat of nuclear terrorism.

Chapter 2: Setting the Nuclear Terrorism Stage

The Cold War was a time in history where large parts of the Northern Hemisphere could have been obliterated in a swift nuclear exchange. Today the Cold War is a thing of the past – yet, paradoxically, the nuclear security picture is as unclear as ever. Well-established nuclear-weapon states still hold sizeable nuclear arsenals; juvenile nuclear-weapon possessors are boosting their stockpiles; and a new set of states have revealed disturbing ambitions and a definite nuclear appetite.

Prospects of renewed horizontal, and possibly vertical, state nuclear-weapon proliferation are real.[39] This blurred contemporary nuclear security picture is crested by the interest shown in nuclear explosives by several non-state actors.

2.1 Conditions of Nuclear Terrorism

No information in the public domain indicates that non-state actors ever have managed to develop actual nuclear explosive capabilities. The number of incidents, however, remains classified. Even hoaxes involving nuclear explosive devises are kept secret, in order to avoid panic, fear and possible "copycat" effects (see Section 6.2).

Nevertheless, some general information has been made available on nuclear bomb threats. In the late 1990s, German authorities were responding to an average of some three or four (hoax) incidents a year (Maerli 1999, 62). In the USA, about 100 threats involving alleged nuclear devices or radioactivity have come to the attention of the Nuclear Emergency Search Team (NEST). Since NEST's creation, at least a dozen threats – possibly more than twice that number – have resulted in active deployment of NEST personnel (Richelson 2002, 2w).

For a given mass of explosive material, a nuclear explosion is at least one million times more powerful than a chemical explosion (Harris 2003, 7). In the Second World War, the largest "block-buster" bombs produced an explosive power of about one ton of high explosives.[40] One of the largest conventional terrorist bombings ever was the 1995 attack in Oklahoma City. That attack involved explosive power equivalent to less than three tons of TNT – 4,000 times weaker than the Hiroshima bomb and 17 million times weaker

39 Vertical proliferation refers to qualitative and/or quantitative nuclear weapons development within existing nuclear-weapon states. Horizontal proliferation means the spread of nuclear weapons to new, would-be-nuclear states, or to non-state actors.

40 The bombs got their names by their capability to reducing one city block to rubble (Swahn 1992, 64)

than the largest nuclear device ever exploded.[41] Hence, even the most devastating conventional power may become minuscule compared to that of a nuclear terrorist explosion.[42]

The detonation of even a single crude terrorist nuclear explosive could leave a disaster in its wake. The effects could be devastating, immense and sudden, and even more horrendous than the assaults of 9/11, immediately killing perhaps tens of thousands of people (International Physicians for the Prevention of Nuclear War 1996, iv; Zycher 2003, 11). Others will suffer as first-responders grapple with the radiation, the breakdown in health services and general crisis management.[43] Clean-up, decontamination, and rebuilding costs may be immense, yet easily dwarfed by the expenses of societal disturbance, evacuation and panic, and financial losses.[44]

The power of nuclear explosives was early recognized. On 25 April 1945, US Secretary of War Henry T. Stimson informed President Truman about the existence of the atomic bomb (quoted by Hutchinson 2003, preambular pages):

> *Within four months, we shall in all probability have completed the most terrible weapon ever known in human history, one bomb of which could destroy a whole city.*

With nuclear explosive devices, non-state actors may hence suddenly possess powers superseding those of many states. Against the pressure, heat and radiation from a nuclear blast there is at best only very limited protection. Mitigation and post-exposure prophylaxis could be in vain. In consequence, the terror may move from acting primarily on the psychological level, where the targeted victims are instrumental and additional effects among the public at large are desired, to a definite mass-casualty threat.

Terrorists themselves, however, operate outside the sphere of nuclear deterrence and the carefully crafted logic of mutually assured destruction

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41 It is usual to compare the energy released in a nuclear explosion with the equivalent amount of energy released by a certain mass of the chemical explosive trinitrotoluene (TNT) (Swahn 1992, 47). One kiloton of TNT is a common unit for the yield of nuclear explosives. During the height of the Cold War, the United States and the Soviet Union held between them a firepower equivalent of three tons of TNT per every man, woman, and child living on the planet (Harris 2003). Hence, each and one of us had, in a sense, an allocation of firepower in the nuclear arsenals equivalent to that of the Oklahoma terrorist bombing. The largest nuclear explosive device ever exploded was the Soviet "Tsar Bomba" ("King of Bombs"), detonated with a force of 50 megatons of TNT on 30 October 1961 at the test range on Novaya Zemlya in the Barents Sea (Hutchinson 2003, 119).

42 Three sources of energy were released in conjunction with the 9/11 terrorist attacks against the World Trade Center: Kinetic energy due to the motion of the two aircrafts, exploded jet fuel and gravitational potential energy due to the falling building material. In total, the energy unleashed was equivalent to the detonation of some 0.2 kilotons of TNT (BBC 2001a, 1w). Due to the large mass and height of the towers, the falling material created the major energy component. By comparison, the nuclear blast that devastated Hiroshima was approximately 13 kilotons – some 65 times stronger.

43 The impact of any nuclear attack on the medical infrastructure would be severe, with a high percentage of beds, operating rooms, equipment destroyed and personnel incapacitated (Helfand et al. 2001, 13).

44 Beyond the unprecedented human tragedy of such an event, the sheer economic loss would be staggering. Bunn et al. (2003, 22) estimate the overall costs of a nuclear terrorist bombing at lower Manhattan to possibly be over one trillion USD. Zycher (2003, 21) reckons the annual economic cost of a crude nuclear terrorist attack against a U.S. target to be some 465 billion 2001 dollars, due to a combination of deaths and injuries, property damage, and a reduced GDP.

(MAD) (ElBaradei 2003, 1w). Nuclear terrorism should therefore not be confused with the Cold War concept "balance of nuclear terror", whereby if one side first launched a nuclear attack, the other side would retaliate in kind. As terrorists are elusive, avoiding confrontation and preferring asymmetrical tactics, the role that the military can play in fighting terrorism may be limited (Schmid 2003b, 14).

Nuclear terrorism, if ever carried out, will hence represent something profoundly new. It would challenge our security, and our perceptions of security, in unforeseen and unprecedented ways. The unexpectedness and the sheer magnitude of the destruction could create social and financial collapse. Attention would be widespread and immediate. The norms of nuclear nonproliferation and nuclear non-use could, moreover, be jeopardized (Allison et al.1995, 9).

2.2 Roots of Nuclear Terrorism

For many years, nuclear explosive devices have remained the privilege of a limited number of states. These weapons have been their ultimate security benefit and security provider. The scientists behind the nuclear explosives were the first to warn about their devastating powers (Ruyter 2003, 18) – powers that were to be horrifically demonstrated twice, first in Hiroshima and then in Nagasaki, in August 1945.

It all started with the discovery of the fission of uranium in 1938.[45] This scientific breakthrough led to the development of the atomic bomb under the US Manhattan Project (Rhodes 1986). At the dawn of the atomic era everything regarding nuclear weapons was new. Contemporary cutting-edge technology and a set of highly skilled scientists were needed to explore the splitting and the forces of the atom. Vast efforts had to be put in place to develop the initial nuclear explosive designs and to produce the necessary fissile material. These were efforts that clearly were beyond the reach of any non-state actor (Allison et al. 1995, 54). Thus, the destructive potential of the atom rested in the hands of icy rational state actors (Bracken 2003, 407), entangled in the MAD web.

Within three years after the end of World War II, the United States had an arsenal of 50 atom bombs (Rogers 2000, 13). Tensions were rising as the Cold War took root, and the Soviet Union soon invested vast resources into a crash program to counter the US nuclear monopoly. The Cold War arms race resulted in more than 128,000 nuclear warheads being built (Norris and Kristensen 2002). The doctrine of mutually assured destruction contributed to making the Cold War among the longest periods in history without military confrontation between major states (Waltz 1981, 1).[46] But the unconstrained,

45 This finding earned Otto Hahn the Nobel Prize in Chemistry in 1944.

46 The perceived benefits of the MAD doctrine have led some scholars, most notably Kenneth Waltz, to become nuclear-weapon advocates, arguing that the fear and possibility of mutual nuclear elimination causes states to behave in a more responsible manner. The gradual spread of nuclear weapons is thus seen as preferable, as it is held that this will promote peace and reinforce international stability. See Waltz 1981, or Waltz' follow-up encounter with Scott Sagan (Sagan and Waltz 1995). For similar views in contemporary nuclear policy discussions, see e.g. Payne 1999.

and largely unaccounted, production of fissile material also fashioned today's nuclear terrorist opportunities (see Section 4.1.2).

The possible use of nuclear explosives outside the MAD-web remained largely a non-issue for most of the Cold War. A 1963 US intelligence estimate concluded: "The Soviets almost certainly would not contemplate the use of clandestinely delivered nuclear weapons except as a supplement to other weapons in the context of general war" (Richelson 2002, 1w). Nevertheless, there must have been some simmering concern, or perhaps curiosity, about nuclear terrorism. In May 1964, Lawrence Radiation Laboratory[47] launched its "Nth Country Experiment". The objective was to see if a few capable physicists, unfamiliar with nuclear weapons and with access only to unclassified information, could produce a credible weapon design (Lawrence Radiation Laboratory, 1967).[48]

The researchers, armed with the advantage of knowing that a bomb could be built and having access to the large quantity of open literature on shock waves, explosives, nuclear physics and reactor technology published since 1945, concluded their task successfully (Stober 2003). The final bomb design was deemed workable, without a test. The nuclear explosive was too big to fit on a missile, but small enough to be carried by airplane or truck. Some of the findings were subjected to limited distribution, whereas the full physics description of the Nth Country design was published separately in a classified report.

Still, in subsequent official assessments throughout the 1970s, the issue of nuclear terrorism received only limited consideration and attention (see e.g. the one-page appraisal in United States Office of Technology Assessment 1979, 45). Then in 1987, the pioneering book *Preventing Nuclear Terrorism* spelled out the growing possibility that terrorists could acquire nuclear weapons or engage in other forms of nuclear violence, and presented important measures and initiatives for preventing this.[49] However, these preventive measures were followed up only to a very limited extent. The findings of the task force were, moreover, qualified in the sense that if nuclear terrorism were to occur it would require substantial efforts, expertise and competence on behalf of the perpetrators.[50]

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47 Today better known as the Lawrence Livermore National Laboratory, California.

48 The National Security Archive has made a censored version of the original report available at: www.gwu.edu/%7ensarchiv/nsa/NC/nuchis.html#usnhdp (last accessed 3 November 2003).

49 Leventhal and Alexander 1987. The task force behind the book made several recommendations to limit the risk of terrorists resorting to nuclear forms of violence. These recommendations included fitting all tactical nuclear weapons with self-protective systems, protection and minimization of use of some proliferation attractive nuclear fuels, and better protection of nuclear installations.

50 The report concluded, for instance, that "it is exceedingly unlikely that any single individual, even after years of assiduous preparation, could equip himself to proceed confidently in each part of this diverse range of necessary knowledge and skills, so that it may be assumed that a team would have to be involved. The number of specialists required would depend on the background and experience of those enlisted, but their number would scarcely be fewer than three or four and might well have to be more. The members of the team would have to be chosen not only on the basis of their technical knowledge, experience and skills but also on their willingness to apply their talents to such a project, although their susceptibility to coercion or consideration of personal gain could be factors. In any event, the necessary attributes would be quite distinct from the paramilitary capabilities most often supposed to typify terrorists." (Mark et al. 1987, 58–59).

2.3 Prospects of Nuclear Terrorism

This conditional conclusion, and the fact that nuclear terrorism has not occurred, may have led many of today's analysts to conclude that while chemical, biological, or even radiological terrorism is likely, nuclear terrorism is improbable. Notions have it that nuclear terrorism is too difficult, requiring a huge infrastructure and vast investments (see e.g. Betts 1998, 32; Cameron 2000; Orlov et al. 2002, 54).[51] In combination with technical hurdles, the risk of large-scale nuclear terrorist violence in specific countries has also been dismissed on the grounds of internal factors such as geography and politics (Anet et al. 2000, 56). Some scholars dismiss nuclear terrorism as merely "an overrated nightmare" (Kamp 1996), claiming that even vagabonding fissile material would only "slightly increase the likelihood of nuclear terrorism" (Kamp 1998–99, 170).

Others, however, maintain that unless radical steps urgently are taken, it will not be a question of whether non-state actors will perform acts of nuclear terrorism, but when (International Physicians for the Prevention of Nuclear War 1996; Falkenrath et al. 1998; Curtis 2001; Potter 2003; Ferguson et al. 2004). Some Western intelligence analysts believe that it is plausible that a small nuclear device may be detonated in Europe or the United States within the next decade (Hutchinson 2003, 195). According to these views, the absence of shocking TV images in the wake of successful nuclear terrorist activities is merely due to the "lack of means, rather than a lack of motivations" (Bunn et al. 2002, 1).

Such perceptions seem to be founded upon the conviction that the scenes from lower Manhattan on 11 September 2001 are only the beginning. These spectacular live-catastrophe attacks were performed with conventional means, providing a dire reminder of the destructive powers of contemporary terrorism.[52] The magnitude, crudeness and efficacy with which these actions were carried out could point in the direction of future large-scale terrorist uses of chemical, biological, nuclear or radiological (CBRN) weapons.[53] More people died in one day on 11 September than in 35 years of sub-state terrorism in Western Europe (Wilkinson 2001, 5). On 11 March 2004, Europe got its dreadful share of large-scale terrorist violence. The multiple assaults in Madrid killed more than 200 people.

As terrorists are known to have already stockpiled and used chemical and biological weapons, nuclear explosive devices may be the next logical step on the ladder of terrorist violence.[54] The inherent "need" for violence escala-

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51 The belief that chemical and biological weapons in the hands of terrorists represents a greater threat than nuclear devices may emanate from the misperception that fresh fissile material is so radioactive that it would fatally harm anyone who stole and assembled it into nuclear explosives, in addition to the complexity of manufacturing military nuclear weapons.

52 The term "live-catastrophe attacks" is borrowed from Beck (2003, 141).

53 The multiple attacks that day spurred a tidal wave of rumours of imminent large-scale terrorist attacks, including low-flying terrorists using crop-dusters filled with biological material, and trucks full of nasty toxicants destined for city centres. And indeed, letters containing anthrax were soon mailed to several US recipients, fortunately with a limited number of casualties, but with a psychological damage radius far exceeding that of the physical impact.

54 A chronology of CBRN terrorist/hoax incidents identifies 175 incidents in 1999 (Cameron et al. 2000). Most of the incidents involved biological (95) or chemical (82) substances. Only 10 involved radiological or nuclear material. Nearly 100 of the incidents were hoaxes, planks or still at the plotting stage. Only 39 involved the actual use of an agent.

tion could in itself force terrorists along a route leading inescapably towards nuclear havoc (Harris, undated).

Chapter 3: Analytical Approach

The primary aim of this chapter is to create an analytical framework and a methodological foundation for the analysis. The point of departure is a simple risk-assessment model in which each of the steps towards acts of nuclear terrorism will be analysed. For each of these subsequent steps there is also an opportunity for intervention, and hence risk-reduction measures. Risk assessments, identifying and evaluating threats on the basis of such factors as capability and intentions, as well as the potential impact of an event, are essential to effort aimed at risk management.[55]

Latour's model for the rendering of science is then presented and discussed as a theoretical foundation for the introduction of nuclear transparency and non-intrusive verification on fissile material. Transparency and verification are two key elements of optimum nuclear husbandry (see Section 4.2.1.1).

The chapter starts out by discussing the inherent dilemmas of nuclear terrorism research, and by explaining the explorative, normative, and interdisciplinary character of this study. The analytical limitations of the study, hereunder restrictions in empirical data, are presented at the end of the chapter.

3.1 Dilemmas of Research on Nuclear Terrorism Risks

The highly politicised and publicized setting surrounding the risk of nuclear terrorism poses particular challenges to scholars. On the one hand, the risk could indeed be growing. Falkenrath (1998, 45) maintains that, in view of their potential severity, future acts of nuclear, biological or chemical terrorism should be regarded as likely enough for them to be counted amongst the most serious challenges to national security faced by modern liberal democracies.

If so, our perceptions of the risk should then commensurate with the real probability of such acts of violence, and with a realistic common understanding of its seriousness if nuclear terrorism should occur (Weisæth, undated). This in itself calls for qualified analysis as well as proper risk communication (see Section A.7.8 in Appendix VII). The development of a qualified public opinion requires an educated and informed citizenry, and a free flow of communication (Habermas 1991, 200).

[55] Risk management is a systematic and analytical process for considering the likelihood that a threat will endanger an asset, and for identifying actions that can reduce the risk and mitigate the consequences of an attack (United States General Accounting Office 2002, 3). Since 1996, the United States General Accounting Office has produced more than 60 reports and testimonies on the US government's efforts to combat terrorism. Several of these reports have recommended using a risk-management approach for understanding the threat and developing proper countermeasures. Other elements of risk management include vulnerability and criticality assessments, aimed at identifying and eliminating societal and structural weaknesses that may be exploited.

Here academia may have a special responsibility. As knowledge-providers, scholars should engage in dialogue and "contribute to the development of knowledge-based assets and should enthusiastically participate in the social, cultural, economical and technological developments of society" (University of Oslo 2000, 1w). Translated to the field of nuclear terrorism risk assessment: Educated, informed discussion should create the foundation for a common understanding of the nuclear terrorist threat and directions for sensible political action. Such scholarly activities are not merely academic; they could have direct policy implications (Busch 2002, 88).

On the other hand, any embellishing of the risk may serve to exaggerate the threat, and could lead to over-reactions and inappropriate short-term fixes. Research findings and science may be misused, suppressed, or distorted to suit political and ideological goals (United States House of Representatives 2003, 33; Union of Concerned Scientists 2004, 29).[56] Scientists, or their findings, may be handpicked, misappropriated and then used to give political decisions the appearance of objectivity.[57] By controlling access to scientific studies, officials and others may dismiss any citizens' objections as uninformed and irrelevant.

Another problem relates to the fact that even restrained scholarly assessments could inspire and assist perpetrators (Calogero 2003, 7; Putnam 2002, 13). Potential nuclear terrorists could start off significantly higher on the learning curve after studying some of the available papers and reports on nuclear explosive devices (Albright 2000, 59).

This leaves scholars working on nuclear terrorism threats with a dilemma. Undertaking and publishing research on the phenomenon of nuclear terrorism could exacerbate the risk; but not doing so could lead to under-estimation of the threat and failure to identify optimum countermeasures. The call for analysis and assessments by Jayanatha Dhanapala, former UN Under-Secretary General for Disarmament Affairs (2001, 3), could give some encouraging guidance on how to deal with this research quandary:

> *The danger of terrorism involving weapons of mass destruction needs to be assessed realistically so that appropriate precautions can be taken. Objective facts require that we be neither alarmist sowers of panic, nor complacent do-nothings. No doubt, the consequences from the use of one weapon of mass destruction by terrorists would be devastating. We need, however, to examine whether and in what quantities materials are available; the technology needed to weaponize these materials and, finally, what delivery methods could be used. This analysis would help strengthen existing legal norms and to create new ones to block any loopholes.*

56 After the G.W. Bush Administration came into office, the scientific committee that had advised the US State Department on technical matters related to arms control was for instance dismissed (Union of Concerned Scientists 2004, 25).

57 As a response, this has given rise to the field of "public interest science", where qualified scientists and researchers provide independent technical analysis and present their findings directly to the public, either through media or at public hearings. Frank von Hippel, who has emerged as the leading proponent and practitioner of public-interest science, describes himself as a "citizen-scientist" (von Hippel 1991).

Correspondingly, clear- and level-headed analysis and examination of the threat of nuclear terrorism seems essential as an important step towards risk reduction.

3.2 Explorative and Normative Research

Ultimately, all research is concerned with crafting information into new knowledge. The resulting level of knowledge will vary, as will the methods used to reach it. The methods applied may depend on the primarily goal of the analysis. *Explanatory* research aims at providing reliable insights into a given subject, explaining what has happened and what is happening and, importantly, providing an opportunity to predict what will happen in the future (Silke 2001, 1). Prerequisites for this kind of research are exploratory and descriptive studies, working at initial levels to identify and describe the main forces and connections at work. Here, case studies are often applied, and the methods commonly used are not overly concerned with issues of validity and reliability (Silke 2001, 1).

The present study belongs to the category of exploratory research. It investigates the threat of nuclear terrorism and ways to optimise protection against such acts. The analysis identifies possible nuclear-security options more than it dissects them. Once the necessary political awareness and interest have been established, further follow-up and in-depth studies in the field should be initiated. An important element of this explorative analysis is a case study on nuclear transparency and non-intrusive fissile material verification (Section 4.3). Case-study research is particularly applicable for research questions formulated as "how", and "why", with a focus on contemporary events (Yin 1994, 6).

The study is, moreover, of a *normative* character. Normative research aims at improvements, and usually includes an evaluation of the present state of affairs, as well as of the direction of future development. Accordingly, normative research differs from purely descriptive studies because the aim is not only to gather facts, but also to point out in which respects the object of study may be improved.[58] Normative studies are expected to help point out the optimal or the most acceptable strategy to be used for subsequent practical operations (Routio 2003, 1w).[59]

3.3 Interdisciplinary Research

Different branches of science may yield different concepts of reality, in accordance with the core premise(s), or rather how the science in question itself explores reality (Krogh, 2001,15). This means that we may have to live with differentiated senses of reality, leaving us, as Krogh puts it, as "happy squirrels on different boughs of the great Christmas tree of science". Inter-

58 A critique of normative theory as an underlying analytical tool will be beyond the scope of the study.

59 Hence, a set of policy recommendations for optimum nuclear terrorism countermeasures through improved nuclear husbandry is formulated in Section 5.2.

disciplinary science may therefore have to be defined, and even developed, on the basis of the need for communication that develops between different sciences. As a tactic for innovative knowledge-gathering, however, this may not appear very fruitful.

Another and somewhat more pro-active approach would be to regard interdisciplinary science as a process of convergence in which new insights evolve through interaction (Liestøl and Morrison 2001, 2). A daily-life analogy may clarify this. We humans usually look at things by aiming both eyes at the same object(s) at the same time. This may seem like a wasteful use of busy sense organs: After all, one eye could suffice. However, from this arrangement, two sorts of advantages occur (Bateson 1980, 78). Firstly, the viewer is able to improve resolution at the edges and contrast, making it, for example, easier to read when the print is small or the lighting is poor. Secondly, and perhaps of particular importance for this study, information about depth is created. In effect, this double perspective nurtures new qualities in our experience of our surroundings – and, it is to be hoped in our case, new knowledge about nuclear terrorism and appropriate countermeasures.

On the basis of their knowledge of general patterns, social researchers can, at best, make broad projections concerning the possibilities of future events and developments (Ragin 1994, 39). Natural scientists may, on their side, provide in-depth technical analyses of specific phenomena. By combining these approaches, risk assessment may foster in-depth examination in new and unforeseen ways, creating by itself renewed sensitivity. This phenomenon, which Bateson denotes “double description”, forms the methodological basis for this assessment. What the study may risk losing in terms of quality from a one (eyed)-discipline assessment, it should gain by combining disciplines traditionally labelled as “social science” and “natural sciences”. The overarching framework for such an interdisciplinary approach is a simple risk-assessment model, as presented below.

3.4 Analytical Tools

As was seen in Chapter 2, the current literature is divided on the issue of whether terrorists may be able to develop and use viable nuclear explosives.[60] Not surprisingly, recommendations for government responses to the threat vary accordingly (Center for Counterproliferation Research 2002, 10).

If, as one school of thought argues, the likelihood of CBRN attacks is high and probably increasing, it is urgent that governments should allocate all needed resources for a range of countermeasures, since there is near-certainty that catastrophic acts of terror will occur. In the aftermath of a mass-destruction attack, elected leaders who were not interested in hedging against the threat, may, moreover, find themselves accountable for their nations’ failed preventive efforts (Falkenrath 1998, 61).

60 For a good overview of recent articles on CBRN-related topics, see the “Threat Reduction Literature Quarterly Bibliographic Review”, Spring 2003, of the Defense Threat Reduction Agency, available online at www.dtra.mil/news/nw_lit_review.html (last accessed 30 October 2003).

If, however, as argued by others, the terrorist scene will remain dominated by low-level attacks resulting in limited casualties, injuries and damages comparable to conventional bombings, comprehensive countermeasures may be not only futile but also a waste of money. In this second camp, the limited effects of the chemical attack of the Aum Shinrikyo cult in 1995 and of the US anthrax outbreaks in autumn 2001 are often taken as demonstrating that terrorists lack sufficient CBRN capabilities (Center for Counterproliferation Research 2002, 10).

A third – and for this analysis a preferred – viewpoint takes a middle-ground approach, incorporating elements from the other two. Here, it is acknowledged that the likelihood of large-scale terrorist attacks may be limited. The possible consequences of such attacks, however, are potentially so severe that serious consideration should be given to the threat. Thus, the threat of nuclear terrorism merits judicious risk assessments that allow for threat understanding and for proper countermeasures to be installed, without catering to hysterical doomsday fears or arguments that deny any validity to the prospects of CBRN terrorism (Center for Counterproliferation Research 2002, 10).

3.4.1 A Simple Risk Assessment Model

There is no universal definition of "risk". To describe a situation involving risk, we must refer to the probability that it will actually occur, and the possible consequences if it occurs (Lindell 1996, 157). Mathematically, risk (R) may be expressed as a function of probability (P) times possible outcome (Q), i.e. consequences:

$$R = P \times Q$$

Hence, high-probability/high-consequence events represent the greatest risk. However, even low-probability events may represent a comparable risk to more frequently occurring incidents if the potential consequences are particularly severe. Low-probability/low-consequence effects, on the other hand, will always represent a limited risk to society.[61]

The "probability"(P) of a terrorist act is directly proportional with the threat level. The threat of nuclear terrorism depends upon a combination of a group's motivation (M) to perform such actions, and their capability (C) to actually do so (see e.g. Bjørgo 1990). The threat, and hence probability (P), is thus a function of both motivations (M) and capabilities (C):

$$P = P\left[f(M, C)\right]$$

61 A related concept is "vulnerability". Operationally, vulnerability could be defined as "a function of the reciprocal multiplicative relationship between risk and preparedness" (Hedge 1987, 148–149). In more popular terms, vulnerability may be regarded as the (societal) ability to recover from damage. Society is most vulnerable when risk is high and preparedness is low; by the same token, it is least vulnerable when risk is low and preparedness high. However, due to the potential scale of the consequences of nuclear terrorism, and, hence, the very limited room for post-attack mediation, these aspects are given limited consideration throughout the present study.

High motivation combined with high technical capability raises the likelihood of successfully performed acts of nuclear terrorism. Equivalently, low motivation plus low capability would represent a low probability of nuclear terrorism (Maerli 2003d, 1). Obviously, without any intentions and/or capabilities to perform acts of nuclear terrorism there would be no such violence. Similarly, even though a group may be (highly) motivated to perform nuclear terrorism, lack of capabilities may severely hamper their chances of carrying out such acts of terrorism.

3.4.2 A Model of Nuclear Terrorism Pathways

A model of the successive steps towards a successful act of nuclear terrorism, presented by Bunn et al. (2003a, 26) provides a useful framework for understanding both the motivational and the technical aspects of this possible form of terror (see Table 3.1).[62]

Table 3.1: Successive steps towards acts of nuclear terrorism

Step	Action	Index
S1	Form a highly capable group with extreme objectives	M1
S2	Decide to escalate to the nuclear level of violence	M2
S3	Steal nuclear weapons-usable material	C1
S4	Acquire nuclear weapons-usable material	C2
S5	Smuggle nuclear weapons-usable material to safe haven	C3
S6	Construct nuclear explosive	C4
S7	Smuggle nuclear explosive into target country	C5
S8	Transport nuclear explosive to target location	C6
S9	Detonate nuclear explosive	C7

(Based on Bunn et al. 2003a, 26)

The steps towards nuclear terrorism are both of a motivational, or intentional, character, and of a capability strengthening character. The total risk, R_T, is:

$$R_T = R_M \times R_C$$

where R_M and R_C are the motivationally-based and capability-based nuclear risks, respectively. The motivationally-based nuclear risk (R_M) encompasses the first two steps, i.e. the formation of a highly motivated and capable group with extreme objectives and then the decision within the group to pursue a

62 The original Bunn-model covers nuclear terrorism steps involving both intact nuclear weapons and nuclear weapons-useable material. Here, however, focus will be on the latter with a scenario where non-state actors possibly produce their own improvised nuclear explosives. A critique of the model and proposals for further development are presented in Section 5.3.

nuclear option. The capability-based risk (R_C) involves a series of subsequent technical steps that any aspiring nuclear terrorists have to go through.

According to the model, each of these steps must be performed in the order indicated, and each rests upon the previous one. Accordingly, derived from Table 3.1, the total probability of a nuclear terrorist attack, P_T, may be expressed as the product of the probability of all the single steps S1, S2, …, S9:

$$P_T = P(S_1) \times P(S_2) \times P(S_3) \times .... \times P(S_9) = \prod_{i=1}^{9} S_i$$

With reference to Section 3.4.1 and the indices from Table 3.1**,** the total risk, R_T, of nuclear terrorism may be expressed:

$$R_T = P \times Q = P[f(M,C)] \times Q = [P(M_i) \times Q_i]_{i=1,2} \times [P(C_j) \times Q_j]_{j=1,7}$$

Each of the steps S1–S9 is a prerequisite for nuclear terrorist havoc. In consequence, the total probability P_T may be severely limited, even reduced to zero, if one or more of the partial probabilities $P(S_i)$ becomes minuscule or zero. This is an essential point: The risk of nuclear terrorism could be drastically reduced, even eliminated, if terrorists are prevented from carrying out one or more of the steps. They are hence barred from advancing throughout the nuclear terrorism chain.

The model shows, moreover, that different countermeasures could be tailored for the specific terrorist step in question. This could allow for comparative "cost–benefit" considerations to determine where investments are likely to yield the highest gains, in terms of reduced probability of nuclear terrorism.

3.4.3 Latour's Model for the Rendering of Science

Any arms control measures are likely to encounter a mixture of technical, political, and bureaucratic problems (Gallagher 1999). The extent of opposition will usually depend on the amount of change, resources, and inherent risks involved. Resistance to new arms control measures can be strategic in nature, where the changes are opposed due to politics and/or security concerns, or of a subtler organizational (structural), cultural, psychological, or personal nature (Maerli and Johnson 2002, 69).

To members of the defence community in particular, increased openness may be viewed as a threat to sustained military strength.[63] Releasing information may increase vulnerability and lessen the (political) strength of the nation as well, as sensitive technical information could be revealed. Divulging such information has been seen as being on a par with the surrender of status, and has thus often been viewed as defeat (Schaper and Frank 1999,

63 Indeed, nuclear deterrence depends critically upon the ambiguity of retaliatory attacks.

59). Hence, secretiveness has traditionally been accorded a special status within nuclear-weapon complexes.

Consequently, nuclear arms control practitioners may face numerous pitfalls in their endeavours to improve nuclear security. In one bold attempt to understand and assess the problems of sensitivity and systemic inertia, and thus make headway in the jungle of obstacles to practical nuclear control measures, non-intrusive fissile material verification is viewed as a novel scientific discipline about to be implemented in a state. As will be seen, this somewhat exotic coupling has various merits, with fewer methodological difficulties than might be anticipated.

The introduction of the "science" of non-intrusive verification may be tracked using Latour's models of how political questions are transformed into questions of technique, and vice versa, and how mixtures of humans and non-human agents are mobilised during controversies (Latour 1999, 98–98). This could make it possible to pinpoint relevant technical-political relationships in practical nuclear arms control, and could assist in identifying how nuclear arms control practitioners and experts may better influence policymakers. It could also allow for deeper understanding of the role of key security actors involved in the process.

According to Latour, there are five types of interrelated activities that need to be considered simultaneously in the process of understanding what any scientific discipline is up to. These are: "Mobilization of the world", "Autonomization", "Alliances", "Public representation", and finally, "Links and knots". In society, these work together in generating mutually dependent loops (see Figure 3.1).

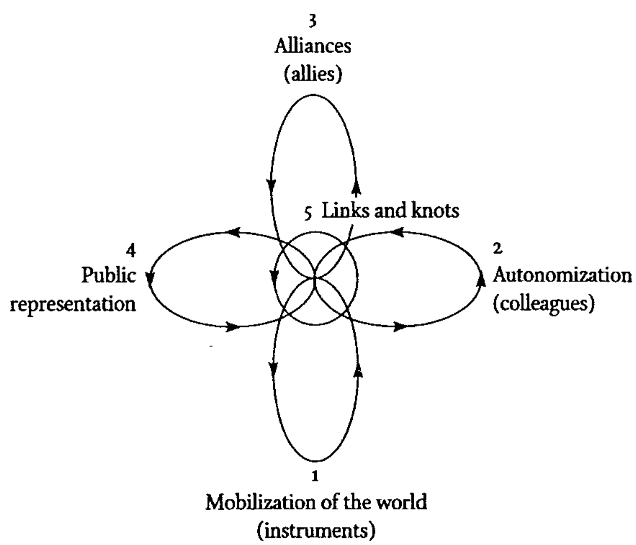

Figure 3.1: Latour's five loops for the rendering of science

(From Latour 1999, 100)

Mobilization of the world refers to all the means by which non-humans are progressively loaded into public discourse, to lay the foundation for interaction and dialogue. The "non-humans" in question could be instruments or equipment developed or recently made available. In the field of non-intrusive verification, a prime example is emerging equipment with information barriers to protect sensitive information during nuclear arms control measurements.[64] Or, it could be information-gathering expeditions, or simply surveys that make new data available. Studies like this one may serve as an example. Ideally, this set of new science opportunities should be gathered at openly available sites to ensure its optimum use and mobilization of potential users and actors.

As with other fledgling disciplines, the foundations for non-intrusive verification need to grow strong on their own. In Latour's model, *autonomization* concerns "the way in which a discipline or a profession becomes independent and forms its own criteria of relevance" (Latour 1999, 102). All scientists (and arms control practitioners) are gradually becoming experts though a learning and educational process that makes them more and more specialized within their fields of work. Eventually, a separate, autonomous "discipline" may evolve – in our case, optimum nuclear husbandry, in which e.g. non-intrusive verification will be an essential element.

Alliances. To ensure that the new discipline is able to exist and endure, arms controllers may have to place it within a large and secure context. This may mean that new groups of people with little or no contact in the past suddenly have to interact. In our case, both the military and members of the legislative assembly may for instance have to become interested in the opportunities (and physics) of nuclear verification. To many of them, this could be a new field. Depending on the circumstances, these alliances between the new set of actors can take a wide variety of forms. But this inclination has to be created. To put it bluntly, there is no natural connection between a politician, a military officer and the gamma rays emanating from highly enriched uranium inside a container. Some level of persuasion and assistance is needed. As Latour (1999, 104) explains, the world has to be worked on to "make these alliances, in retrospect, inevitable".

To create a foundation for new types of practical arms control measures like non-intrusive verification, the potential opportunities and, not least, the possible benefits of such measures have to be known, to the public at large and to a range of audiences. The novel techniques and procedures of non-intrusive verification have to be socialized into the collective through *public presentation*, as a fourth loop of the science rendering. According to Latour, it would be astonishing if this were not so: "For what is science if it is not to modify the associations of people and things?" (1999,105).

Finally, the new system of science "bloodstreams" needs to be connected through a set of mutually supportive and necessary set of *links and knots*: "If one takes the content on one side and the context on the other, the flow of science becomes incomprehensive, and so does its source of the oxygen and

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64 For this purpose, a range of different verification schemes have been developed that use so called "information barriers" to protect sensitive information. Generally, an information barrier must both prevent the release (accidental or intentional) of any classified information, and at the same time provide confidence that the measured systems are functioning correctly and that the unclassified display (output) reflects the true state of the measured item. This is often referred to as the "authentication problem". For more on this, see Section 4.3.3.2.1 and research paper [P7].

nutriment, as well as their means to entering the bloodstream" (Latour 1999, 107). This is both the unifying loop and the blood-pumping cycle. Without the fifth loop, it would be hard to mobilize the world, annoyed colleagues and new allies would soon lose interest, as would the general public – after expressing either disbelief or indifference to the opportunities and threat-reducing potentials of non-intrusive nuclear verification in society.

The Latour model is an interesting tool for understanding the many challenges of practical measures for nuclear arms control. However, an inevitable question is how valid the coupling between "science" and "non-intrusive verification" is. From a methodological perspective, equating the two may be an overly simplified approximation. Firstly, "verification" may seem more like a measure, procedure or approach than a defined science discipline. Secondly, validity losses may occur, as the Latour model here is (presumably) used in a quite extended way, beyond Latour's own case studies. Latour analysed the introduction of so-called "big science" in society, and specifically the instigation of atomic physics and civilian nuclear power in France after the Second World War.

On the other hand, these problems may prove less substantial than anticipated. Post-war "big science", like nuclear power, was indeed characterized by teams of researchers, all in new settings with latest experimental devices. Researchers would typically work in a multidisciplinary way, with an array of newly developed and specialised equipment, often with governmental funding (American Institute of Physics, undated). The similarities to post-Cold War nuclear verification activities are striking. During non-intrusive verification of sensitive fissile material, a (new) set of tools will have to be introduced in a highly multidisciplinary approach by a new set of actors (technicians, military, policy-makers etc.), facing a range of obstacles on the individual, structural, political and technical levels (Maerli and Johnston 2002, 67–69).

Important similarities between "science" and "non-intrusive verification" may be found on the ideological level as well. Science has three important functions: An instrumental function, where the development of science brings development and benefits to society; a critical function, where science may act as a corrective and guidance in society; and finally, a cultural function, where science describes, analyses and changes our culture (Kaiser 2000, 29–30). Equally, the successful implementation of non-intrusive verification into society may bring (instrumental) development and societal benefits in terms of increased security; it may correct government policies and attitudes, thereby lessening hostility, and it may change individual and organizational customs and habits. As such, non-intrusive verification contains many of the features of a fully-fledged science discipline.

As argued by Silke (Section 3.2), moreover, atypical methodological steps, with less concern with issues of validity, may be taken at the explorative study level in order to illuminate both technical and political aspects of the case in question. Despite possible validity losses, the Latour model will therefore be used, with caution, as a structuring element for the analysis of the practical implementation of key concepts of nuclear husbandry like transparency and non-intrusive verification of fissile material.

3.5 Analytical Limitations

As to the "who", "why" and "how" of nuclear terrorism, the analytical focus of study will be primarily on the latter, with a focus largely on (technical) capabilities (i.e. steps S3-S9 in Section 3.4.2).

However, as the majority of terrorist organizations world do not seem to have an interest in nuclear explosives (Rapoport 2001, xv), understanding motivational aspects become particularly important; excluding terrorist intention from the assessments could result in a general over-appreciation of the threat. For this reason, general terrorist motivations, as well as the usability of crude nuclear explosives for terrorists, will have to be briefly assessed. However, it is beyond the scope of this study to undertake in-depth analyses of the motives and capabilities of specific terrorist movements, to identify groups most likely to acquire nuclear explosive devices.[65]

Nor has the impact of suicide bombings, a method increasingly adopted as the ultimate strategic weapon (Randstorp 2003a, 74), been taken into consideration. Defence against such attacks is extremely difficult, as the timing, location and target ranges could be drastically increased, and any threat of nuclear terrorism might be correspondingly amplified. However, the assertion that suicide bombings could fuel large-scale terrorism with chemical, biological or nuclear weapons could be based on an unfounded generalization of the phenomenon of suicide bombing (Dolnik 2003, 32). The possible emergence of nuclear suicide bombers is probably best understood by assessing psychological processes on the group and/or individual level, which in again turn calls for specialised studies.

Terrorism today is increasingly moving away from the hierarchal structures, national contexts and traditional modes of state sponsorships and is characterised by a move towards ad hoc constellations and international networks (Randstorp 2003a, 74). However, within the analytical framework applied here, there has been no room for assessing the impact of communications technology on terrorist capabilities. Terrorist finances and economic resources will have to be left unattended as well.[66] Neither does the analysis address in any depth the nexus of organized crime, arms trade, and terrorism. No apparent links to organized crime have been identified (Zaitseva and Steinhausler 2004, 6w), but nuclear smugglers could use drug trafficking routes.[67] Some of these actors are highly skilled, well-organized and resourceful, which would make any nuclear trafficking operations particularly hard to detect (Williams and Woessner 2001, 321).

Nor does the analytical approach chosen allow for a thorough assessment of perceptions of the risk of nuclear terrorism, another sadly under-investi-

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65 The sheer complexity surrounding the range of root causes of terrorism calls for separate and specialized studies on these issues. There exist many preconditions and precipitants for the emergence of various forms of terrorism (see Bjørgo 2003, 2).

66 The events of 9/11 have heightened concerns about the ability of terrorist organizations to use the global financial system to support their activities. In response, international initiatives to combat terrorism have focused on preventing and suppressing the collection and movement of terrorist funds. These issues are assessed by the project "Targeting Terrorist Finances", at the Watson Institute at Brown University, Rhode Island: see www. watson-institute.org/projectdetail.cfm?id=51 (last accessed 16 January 2004).

67 In February 2002, 1.5 kg. of uranium smuggled from Tajikistan through Uzbekistan was seized in the southern region of Kazakhstan together with a large cache of heroin (Zaitseva 2002, 9).

gated topic. The fear of radiation is deep-seated among the world's populations (Slovic 1996; Maerli 1996), and nuclear worries about radiation do not necessarily parallel (objective) assessments of the risk in question (Reitan et al. 1996, 155; Tønnessen 2002, 7). Strong responses in the population to any (possible) exposure from radioactivity could result, making atoms and nuclear explosives a particularly powerful terrorist tool (Maerli 1999, 65).

Finally, to natural scientists, the analysis could appear to have its technical limitations. For instance, promising schemes for non-intrusive verification on sensitive fissile material (naval fuel) are presented (Section 4.3.3.2) without any calculations that would take into consideration such critical factors as shielding, gamma-ray attenuation, measurement set-up and measuring times. Possible approaches for verification and key parameters are discussed in general terms only.

Readers should, however, bear in mind that this thesis is of a highly exploratory character (see Section 3.2.). Rather than providing fully-fledged solutions for practical nuclear arms control, one of the underlying aims has been to explore the highly interwoven political and technical aspects of specific nuclear security challenges. Many of the practical problems encountered will have to be further investigated, once the necessary political resolve and openings have been generated.

3.5.1 Data Limitations

Due to secrecy considerations, especially in Russia/the former USSR, this study has struggled with both direct data acquisition problems and access to primary information sources in conjunction with the case study for transparency and non-intrusive verification on classified stockpiles. Very little is officially known about Russian naval fuel, and the limited information available is mostly channelled through NGO sources.[68] While studies of civilian–military relations always encounter methodological challenges, this may be a particular problem in Northwest Russia, one of the most highly militarised regions of the world (Hoenneland and Joergensen 1999, 3).

Mutual sensitivity concerns may also play a role. It took nearly four months of consideration by the US Department of Energy (DOE) before the author of this study was granted permission to interview one of the US team members in the joint US–Russian naval material protection, control and accountability programme. As a precondition, anything written after the interview was to be subjected for review, prior to publication. As such, this represented a form of potential censorship and was hardly the best way to ensure free and equitable research. In the end, however, the DOE abstained from providing any official comments on the text. The person interviewed was granted anonymity.

There is a reluctance to talk about non-classified issues related to naval fuel. All this would seem to indicate a deep-felt concern on both the US and the Russian side that anything written about such a sensitive topic as fresh

[68] The most prominent ones being the Center for Nonproliferation Studies' Database on the Russian Navy, available at www.nti.org/db/nisprofs/russia/naval/overview.htm, and the Norwegian Bellona Foundation, www.bellona.no.

naval fuel could endanger cooperation and progress in security upgrades. The author's past professional experiences of fresh and spent fuel handling practices and nuclear security in Northwest Russia have made this less of a problem compared to the barriers other scholars may have encountered.

Not only has data *input* proven challenging. Even the *output* of research findings could be an act of balance. The analyses would not only assist governments in meeting the threat and in identifying optimum countermeasures: Studies like this also risk *increasing* the threat by inspiring, and perhaps guiding, potential terrorists in their pursuit of innovative, media-attracting and hard-hitting tactics. Accordingly, considerable care should be taken when presenting and disseminating research findings. For this reason, in this study only general and limited technical calculations on crude nuclear explosive devices have for instance been presented (Appendix III). References to Internet sites with open but possibly sensitive information have generally been omitted.

Yet, even the caution shown may apparently not be enough. Concerns about assisting potential nuclear terrorists were cited as the reason why the editor of *Nonproliferation Review* found it necessary to replace some references in one of the research papers of this study, thusly: *"[Editor's note: In order not to make it easier for unwanted actors to find information about how to build a nuclear bomb, the individual's name and specific references provided by the author have been removed from this endnote]*".[69]

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[69] The research paper in question was [P1] (Maerli 2000a). For more on this story, see Larsen 2002 or Hanley 2002.

Chapter 4: Research Findings

This chapter presents key findings from the eight research papers [P1] to [P8] presented in the Addendum. The chapter encompasses three main sections: Understanding the Nuclear Terrorism Threat; Conceptual Nuclear Husbandry; and Nuclear Husbandry in Practice. Each section ends with summary answers to the principal research questions formulated in Section 1.2. The analytical approach presented in Chapter 3 serves a structuring element and an overall methodological framework for the presentation of the research findings.

Where appropriate, the research findings are presented in concert with those of other scholars in the field. This will help to put the findings of this thesis in context, and also add on to the cumulative knowledge in the field, furthering the general understanding of the nuclear terrorism threat and pertinent countermeasures. Accordingly, the chapter will be more than a mere synopsis of the underlying research papers. However, only highlights of the underlying research papers will be presented. Readers wishing more in-depth considerations should consult the research paper(s) in question.

To make it clear when the findings of one of the research papers [P1]–[P8] is applied throughout this text, specific reference (e.g. [P3]) to the relevant paper is made.

4.1 Understanding the Nuclear Terrorism Threat

Using the model of Bunn et al. on nuclear terrorism pathways (Section 3.4.2), a series of questions regarding the terrorist threat will be investigated in the following. In particular are the various technical barriers to the production of crude nuclear explosives scrutinized, inter alia by looking at the potential availability and the possible use of highly enriched uranium, and the respective "standards" of military and terrorist nuclear explosive devices.

The first principal research question, [Q1],[70] is taken as the point of departure for studying the feasibility of producing crude nuclear explosives and the utility of such devices as a terrorist tool. The findings of research papers [P1], [P2], and [P3] are of primary importance for this analysis.

4.1.1 Terrorist Interest in Nuclear Explosives

Nuclear explosives could be the ultimate terrorist weapons. With crude nuclear devices, terrorists may suddenly possess powers far exceeding those of many states. They could be used to destroy an enemy's centres of power and

70 *[Q1]: "Can terrorists possibly perform acts of terror by means of crude nuclear explosive devices based on highly enriched uranium? What are the main barriers to the production of crude nuclear explosives?"*

finance in a spectacular way, and at the same time be more territorially confined than the less predictable and less reliable biological or chemical weapons ([P2], 114–115). Moreover, terrorists might possibly view nuclear weapons as somehow "cleaner" and merely a more powerful extension of traditional explosives, whereas biological and chemical weapons might be seen as representing a new and more vicious kind of destruction (Laqueur 1999, 255).

Generally, the public has greater fear of events and consequences that are confirmed, catastrophic, and imperfectly understood – and these are all common features of a nuclear threat (Maerli 1995, 115; Tønnessen, 2002, 61). Past nuclear explosions and nuclear accidents, limited public understanding and knowledge of radiation, and the human inability to sense potential exposure may have cultivated (disproportionately) negative perceptions of radiation (Maerli 1999, 51–52). Nuclear detonations could therefore inflict a radius of psychological as well as economic damage far exceeding that of actual injury and death ([P2], 730).

Terrorists who capitalize on the inherent fear of radiation amongst the population are likely to have a strong impact ([P2], 730). In contrast to the silent, invisible death of biological and chemical substances, a nuclear blast would create unexpected, immediate, and widespread attention ([P1], 116). According to Tønnessen (2002, 241), "nuclear threat inflicts upon the public a feeling of insecurity about possible adverse health effects, is closely related to dreaded Armageddon schemata, and is perceived as a threat from which one cannot protect oneself".[71] The psychological and political impact of any nuclear explosion would hence be vast, regardless of the actual damage it inflicted (Cordesman 2001, 40), adding on to the post-attack confusion, fear and panic ([P1], 116). The strong impacts may, however, also stand a risk of overshadowing the cause – if any – that terrorists are trying to make a case for (Maerli 1999, 7).

Nuclear explosive devices may be particularly useful for maximizing damages, augmenting crisis, and destabilizing societies or economies ([P1], 116). Actually detonating a nuclear device could set a terrorist organization apart from any other group, and could compel governments to take that organization seriously (Carmeron 2000). Proven nuclear capabilities may, moreover, serve as a strong tool for terrorist blackmailing. Even a credible hoax – for example, where terrorists provide workable designs of nuclear explosive devices together with samples of high-quality fissile material – could challenge proper governmental responses ([P2], 730).

While the number of terrorist attacks has remained fairly constant or even declined, the terrorist mortality rate is on the rise, with more indiscriminate killings (Stern 1999). The death-toll from the World Trade Center attacks represented a quantum leap in terms of terrorist casualties, in itself suggesting that there will be future acts of large-scale terrorism (Maerli 2001a, 214).

71 This is confirmed by surveys. August 2003, 32% of Russian respondents saw international terrorists as a nuclear threat (Agence France-Presse 2003). As many as 66% of the Russians believe that terrorists may obtain access to the Russian nuclear arsenal (Orlov and Khlopkov 2001, 8). In 1998, 67% of 1502 Canadian respondents put nuclear terrorism on top of all contemporary nuclear threats, regarding this as a "serious threat", Bremer Maerli 1999, 53.

Particularly in the USA, there has been unprecedented concern that the next terrorist attack could involve a nuclear explosive or a radiological bomb (Collina and Wolfsthal 2002, 1w). When Tom Ridge, the Bush Administration's head of the Office of Homeland Security, was asked what he worried the most about, he simply said "nuclear", with reference to nuclear terrorism (Keller 2002, 2w).

However, there have always been enormous gaps between the potential of a weapon and the will to employ it by terrorists (Rapoport 1999, 51). In the past, non-state actors desiring so have managed to kill large numbers of people without employing exotic technologies like nuclear weapons. Conventional means could still more than effectively serve their goals and are likely to remain the terrorist weapons of choice. Besides, inflicting massive human casualties does not serve the objectives of most non-state groups (Falkenrath et al. 1998, 45).

New means and methods of violence with unknown outcomes and new technical requirements (and thus an increased risk of failure) could also be less appealing for non-state actors. Unsuccessful or failed actions may waste resources, kill members of the terrorist groups, increase the risk of revelation and retaliation, embarrass the terrorist organization, or reduce support amongst followers – all putting at stake the very existence of the group, and its cause.

Terrorists, moreover, operate in contexts of enormous uncertainty and anxiety, and may prefer known means. If one target is regarded as too challenging, other targets may be chosen, while the tactics of the group remain the same. Alternatively, conventional tactics may be further developed, as horrifically evidenced in the events of 9/11. The use of nuclear, biological, or chemical weapons could, moreover, stigmatize the terrorist group, rendering it hard for them to accomplish any political aspirations. The constraints against the use of such weapons are particularly severe for terrorists who are concerned with their constituents, as in the case of social revolutionary and national separatist terrorists (Post 2001, 9).

A less pronounced barrier, in addition to the practical and strategic constraints, might be moral considerations. For a terrorist group to be able to use biological, chemical or nuclear weapons, its members would have to be morally disengaged from the consequences of their actions (Stern 1999, 80). Typically, terrorists do not view themselves as psychic madmen and killers, but simply as political or military units (Hoffman 1998, 29). Killing many innocent people may not be consistent with terrorists' own perceptions of themselves as respected liberators or "freedom-fighters". Coupled with the fact that most conventional means will serve the terrorist purpose(s) well, these considerations could probably go far in explaining why there so far have not been any acts of nuclear terrorism.

4.1.1.1 Forming a Highly Capable Group With Extreme Objectives

Most terrorists are in a sense conservative. It may be hard to establish a sophisticated, capable, and well-financed terrorist group that also had the kinds of extreme objectives that would make it a candidate for pursuing nuclear explosives (step S1, Section 3.4.2). Groups may not simply take what may be "available" in terms of weaponry. They are more likely to seek weapons or agents that best suit their needs.

Examination of past mass-casualty attacks shows that the perpetrators did not opt for unconventional weapons, but preferred known means (Parachini 2001, 402). If a group chooses unconventional weaponry instead of conventional means, this choice will be influenced by many more factors than only the perceived potential for inflicting mass casualties.

However, while most terrorist groups are likely to stick to traditional terrorist means and known tactics, some groups may be ready to escalate up to a new level of violence. In the wake of the events of 9/11, the notion that "terrorists want a lot of people watching and listening, not a lot of people dead" (Jenkins 1975, 15) should be in for review. As seen in Section 3.4.1, the greatest danger of large-scale killing occurs when the group or individual is not only motivated, but also has technical capabilities, easily exploitable opportunities, and a minimum of restraints (Falkenrath et al. 1998, 169; Parachini 2003, 46). As Jessica Stern (1999, 8–10) points out, a mix of at least five interrelated developments may point in this direction.

First of all, terrorist motivations are changing. Today's new breed of terrorists appears more inclined than terrorists of the past to commit acts of extreme violence. The set of new terrorists may include everything from ad hoc groups motivated by religious conviction or revenge, to violent right-wing extremists, and apocalyptical cults. Secondly, chemical, biological and nuclear weapons could be especially valuable to terrorists who are not pursuing traditional political goals, but are seeking divine retribution, to display prowess, or just to perform large-scale killings.

Thirdly, terrorists will generally choose their technology to exploit the vulnerabilities of a particular society. Modern and densely populated societies are particularly susceptible to weapons capable of killing many people at one time. Moreover, as governments implement sophisticated security measures against terrorist attacks, terrorists may find more powerful weapons appealing, as a way to overcome such countermeasures.

Fourthly, with the brake-up of the Soviet Union and corrupt nuclear scientists in states on the fringes of international law,[72] black markets may now offer unprecedented access to weapons, components and know-how. Technological (weapons) development may add on to this. Fifthly, copycat efforts, where new groups both find inspiration and ideas from previous large-scale terrorist violence, may spur additional terrorist attacks.

Moreover, international terrorism is becoming more lethal. Terrorists themselves may have become less dependent on state sponsorship, gradually turning more non-secular, and more suicidal. Increasingly, they tend to organize themselves in loosely affiliated groups (Schmid 2003a, 2). Failed states could serve well as terrorist breeding grounds. None of these developments means good news for nuclear terrorism prevention; the use of crude nuclear explosives could indeed increase terrorism lethality, and a lower dependence on state sponsorship could reflect more technically competent and independent terrorist groups.

72 Early in 2004, Pakistan's top nuclear scientist, Abdul Qadeer Khan, confessed to having leaked nuclear secrets to other states, see Section 1.5.2.

There are few reasons why extreme religious considerations should be a constraining factor for nuclear terrorism. Any linkages with organized crime can only improve access to black markets of technology and fissile material. Finally, more loosely organized networks should not be regarded as a real impediment to nuclear terrorism, particularly not if the individuals involved are firmly committed and capable.

4.1.1.2 Deciding to Escalate to the Nuclear Level of Violence

The formation of a highly capable group with extreme objectives is in itself not enough to create nuclear havoc. As Bunn et al. point out (Section 3.4.2), the group needs to be ready to step up to the level of nuclear violence (step S2). A range of factors determines whether a group or an individual will seek to acquire and use non-conventional weapons for terrorism. These factors could differ from group to group. Religion is an important factor, but only one of many (Parachini 2003, 46).[73] Tucker (2000, 255–269) has identified a set of characteristics associated with terrorist groups that have used biological or chemical weapons. These groups are characterized by:[74]

- paranoia and grandiosity;
- lack of political constituency;
- closed cult or splinter group;
- charismatic, violence-prone leader;
- apocalyptic ideology, cult of death;
- escalatory pattern of violence;
- technical and tactical innovation;
- fascination with poisons, plagues.

Groups marginalized and distanced from society may be particularly prone to violence escalation. Often in cults, in closed environments with limited interactions with the outside world, such groups are open to strong influences from a charismatic leadership. Extreme images of right and wrong, images that not only call for but also justify, the use of extreme violence, may be easily cultivated. Groups that place themselves outside society and outside societal mores may have scant moral difficulty deciding to employ

73 Calls from religious or political leaders for nuclear explosives regularly surface. For instance, December 26th 2002, the moderator of the radical Islamic Internet forum www.al-mojahedoon.net, Abu Shihab al-Qandahari, published a short article entitled "The Nuclear War is the Solution for the Destruction of the United States" (Paz 2003).

74 One obvious limitation to this comparison is that while terrorists' uses of nuclear weapons will result in a massive, abrupt disaster of catastrophic dimensions, chemical and biological weapons are invisible, odourless, tasteless, silent, and insidious. There are in other words profound differences between the different means (Bremer Maerli 2000, Bremer Maerli 2003a). Terrorists attracted to the shock, drama and drastic effects of a explosion may be particularly drawn to bombings, conventional or unconventional.

chemical, biological, nuclear, or radiological means. Groups that lack an "audience" among the public may be less constrained in CBNR use, and particularly difficult to deter. Without a political constituency, they will not have to justify their goals or means to any outsiders – other than perhaps their God.

In sum, only the most extreme and least rational groups, or those motivated not only by distinct political aims but by apocalyptic visions or by pan-destructive beliefs are likely to employ nuclear, biological or chemical weapons (Laqueur 1999, 70). Among such groups, associations to nuclear Armageddon do occur, both by way of "cleansing" and as sheer retribution (Maerli 1995, 92).

The views that terrorist could be on the nuclear path have, particularly in the USA, been strengthened by the sarin attacks in Tokyo in 1995, the Oklahoma City bombing the same year, the 2001 anthrax outbreaks, and, obviously, the attacks of 11 September 2001. Some groups that have shown a proven interest in acquiring nuclear explosive capabilities have, moreover, been granted considerable media attention. Prime examples are the Aum Shinrikyo cult, and, of course, the near-mythical bin Laden ([P1], 110; Bergen 2001b, 431; Resch and Osborne 2001, 4–7; Parrish 2002, 1w).

The Aum Shinrikyo cult had indeed an apocalyptic worldview, in which the use of nuclear, biological and chemical weapons would catalyse a future world where they would rule. The cult's pursuit of nuclear explosive capabilities, however, proved fragmented and opportunistic, and, consequently, unsuccessful (Cameron 1999). The nuclear material and technology purchased by the cult seem to reflect what was available on the market, rather than being the result of a carefully crafted strategy.

The worldview of Osama bin Laden does not depend upon the use of non-conventional weapons, unlike Aum Shinrikyo's apocalyptic vision of the future (Parachini 2003, 43). Questions have hence been raised about the likelihood of a sanctioned nuclear attack by the group (Raufer 2003, 397). Findings in Afghanistan have revealed neither a nuclear capability nor any nuclear material. In the raids against former al-Qaeda hideouts, only simple sketches of nuclear devices were found (CNN 2002, 2w).

But bin Laden and al-Qaeda have shown an incontestable interest in nuclear explosives. Proven nuclear efforts included attempted uranium purchases in Sudan in 1993/94 and then in Germany in 1998. The latter attempt resulted in the arrest of bin Laden's aide Mamdouh Mahmud Salim (Resch and Osborne 2001, 4). bin Laden may have been a "patient shopper" (Kluger 2001, 2w). His intentions in this regard may have come to the fore with the events of 9/11. In the first interview given by Osama bin Laden after the attacks, the terrorist leader claimed to possess nuclear weapons (BBC 2001b, 1w). He has further maintained that by acquiring nuclear explosives, he would be carrying out a religious duty (Frontline 1995, 2w).

However, while al-Qaeda may have acquired rudimentary nuclear material, it remains highly uncertain whether the group has been able to weaponize any of this material (Bergen 2001a, 85 and 231). Despite extremely high media publicity, evidence of any of al-Qaeda's non-unconventional weapons capabilities remains fragmentary (Albright et al. 2002, 23; Parachini 2003, 40). Their nuclear intentions may hence still be stronger than any nuclear capabilities.

4.1.2 Technical Barriers to Nuclear Terrorism

Countless non-state actors with hostile intent have arisen in the past decade, but only very few, most notably the Aum Shinrikyo cult, have combined the technological capability needed to mount a terrorist act involving real CBNR capabilities with intent of doing so. As illustrated by the Bunn model (Section 3.4.2), the initial technical, or capability-building, steps on the nuclear terrorist ladder involve stealing fissile material (step S3) and then gaining access to the stolen material (step S4). The materials that make possible nuclear bombs are those few isotopes capable of sustaining an exponentially growing chain reaction. Two isotopes of uranium, U-233 and U-235, and all isotopes of plutonium (most importantly Pu-239, Pu-240, Pu-241 and Pu-242) fit this description, and thus are denoted directly useable nuclear material, or "direct-use material".[75]

Unirradiated fissile material, especially HEU, is only mildly radioactive, with a limited level of toxicity in solid form. The material is not radioactive enough to deter theft and handling of them ([P3], 49). Such material becomes hazardous only if finely divided, dispersed and ingested into the lungs. Only after the uranium has undergone fissions, will strong radiation (from the fission products) be present.[76] Due to the extreme density of the material, a critical mass of weapons-grade uranium occupies only small volumes – about the size of a grapefruit (Harris 1999, 82).

The small volumes needed and the low toxicities and radiation levels could make stealing and smuggling of near-critical amounts of fissile material relatively uncomplicated.

4.1.2.1 Stealing Fissile Material

There have been multiple documented cases of theft of kilogram-quantities of weapons-useable material, especially in countries of the former Soviet Union ([P3]; Bukarin and Potter 1995; Ewell 1998; Ewell Daughtry and Wehling 2000; Parrish and Robinson 2000; Stone 2001). In February 2002, US intelligence confirmed to Congress that weapons-grade and weapons-useable nuclear material had been stolen from some institutes in Russia (Collina and Wolfsthal 2002, 1w).

75 For fission explosives, nuclear weapon designers prefer a U-235 fraction of more than 90%, normally denoted "weapons-grade uranium". For plutonium, more than 90% Pu-239, denoted "weapons-grade plutonium", will normally be preferred in the designs, although virtually all combinations of plutonium isotopes can be used to manufacture nuclear explosives. An exception is plutonium containing substantial quantities of Pu-238, which generates so much heat and gamma radiation that it is not practical to make nuclear explosives out of it. Even reactor-grade plutonium is considered by the International Atomic Energy Agency as direct-use, i.e. weapons-useable, material. Recently declassified US documents reveal that in 1962 a nuclear test explosion was carried out with reactor plutonium, producing a significant, but still classified yield. For an assessment of nuclear explosive devices based on reactor-grade plutonium, see Swahn 1992, 59–65.

76 Because of the long half-lives of the isotopes, the dose rates from fresh material are several orders of magnitude below the dose rates from spent uranium fuel when it is unloaded from a reactor.

A serious incident occurred in December 1998 ([P3], 52), when the Russian Federal Security Services intercepted an attempt to divert 18.5 kg of "radioactive materials that might have been used in the production of nuclear weapons" (Bukharin et al. 2000, 5; Bunn 2000b, 17; Parrish and Tamara 2000, 112). Russian officials confirmed this attempt in November 1999. Later it was acknowledged that the material was highly enriched uranium. This makes this case the largest documented attempt to steal weapons-useable material in the former Soviet Union (Bunn 2000b, 17). It is, moreover, the first confirmed case that apparently involved a conspiracy to steal enough material for a bomb at a single stroke. The then Russian president, Boris Yeltsin, ordered a radical overhaul of security at the site, where more than 30 tons of highly enriched uranium were stored (Hutchinson 2003, 184).

Naval fuel has been particularly exposed to theft in Russia (see Appendix V); especially prior to the installation of US-funded security upgrades (see Appendix VI). At least six cases of attempted thefts of highly enriched uranium from the Northern Fleet took place in the Murmansk and Arkhangelsk region in the period from 1993 to 1996, at storages and shipyards for construction and maintenance of nuclear submarines. But even more recent cases have occurred. August 2003, Alexander Tyulyakov, Deputy Director at Atomflot, the naval base for Russian civilian icebreakers in Murmansk, was arrested on charges of smuggling nuclear material (Diggens 2003b).[77] The material seized allegedly contained uranium-235, uranium-238 and radium (Bellona 2003). The case is particularly worrying, as it involved senior management of a facility handling such material (Badkhen and Sterngold 2003, 2w).[78]

A Murmansk newspaper claims Tyulyakov planed to sell fuel assemblies from a nuclear icebreaker for USD 50,000. The case may be indicative: Perpetrators apparently steal the material without having a buyer at hand, routinely asking for sums that are hundreds or thousands of times higher than the market value of the fuel.[79] Interpol's Stockholm office reported a case in which the smugglers wanted USD 700,000 for one kg of natural uranium (Lee 1997, 3w). The asking price for some 5 kg of 20% enriched fresh naval fuel stolen in the Murmansk area in 1993 was USD 50,000 (Allison et al. 1995, 25).

The unclassified literature on weapons design could lead many to exaggerate the amount of fissile material needed for a nuclear explosive device. Outdated sources of information indicate that 50% to 200% more fissile material is required than is really needed for a modern nuclear explosive of advanced design (Cordesman 2001, 33). For a technically advanced gun-type device (see Section 4.1.2.1.4), Cochran and Paine claim (1995, 9) that 2.5 kg of HEU may suffice to produce a one-kiloton yield. According to the same authors, a functioning, crudely assembled device with neutron reflectors could require as little as 8 kg.

77 According to the regional Ministry of Internal Affairs (MVD), Tyulyakov was arrested after a search of his home allegedly revealed "an arsenal" of guns, as well as unknown a "strategic substance that could be radioactive".
78 These are the kinds of thefts hardest for any security system to prevent.
79 Current uranium fuel (LEU) prices are generally in the range of USD 25–35 per kg of material (Bunn et al. 2003b, 23).

If, so the “Significant Quantities” (SQ) of the IAEA may have to be reviewed.[80] According to IAEA, “the approximate amount of nuclear material for which the probability of manufacturing a nuclear explosive device cannot be excluded” is 25 kg of U-235 (International Atomic Energy Agency 2002b, 23). This is ten times the quantity suggested by Cochran and Paine for sophisticated devices, and three times the amount possibly needed for crude nuclear explosives.

To ensure a nuclear chain reaction, however, amounts in excess of the critical mass of uranium-235, e.g. above 50 kg, are ideally needed.[81] This is partly due to the fact that barely a critical mass would not release much energy, and partly as material losses may occur during the production of the device ([P2], 736). The inevitable presence of impurities would further increase the required amounts (Narath 2002, 4). The quantities needed to produce a crude nuclear explosive device are still minuscule compared with the total amounts of fissile material produced.

4.1.2.1.1 HEU Production, Control and Accountability[82]

As the quantity of weapons-useable material increases, so does the proliferation risk (Dreicer and Rutherford 1996, 30). The probability for losing control over nuclear material depends on the amount of material to be secured, the number of storage sites, and the level of physical protection provided by the facility operators (Zaitseva and Steinhausler 2004, 1w). While much of the fissile material worldwide is duly protected and accounted for, the huge amounts produced during the Cold War could make proper control challenging. The stockpile inventories are not static (Bukharin et al. 2000, 7),[83] and clear information on all fissile material stockpiles is essential to ensure optimum fissile material handling and control by states.

On a global scale, more than 3,000 metric tonnes of highly enriched uranium and plutonium are now stockpiled in various military and civilian programmes (Albright et al. 1997, 396; Albright 1999, 6). While production has ceased in well-established nuclear-weapon states, it continues in the juvenile ones.[84] At least 1,750 tons of HEU have been produced for military purposes since the dawn of the atomic era, most of this by the United States and Russia (Albright et al.1997, 397).[85] These two countries, in their capacity as declared nuclear-weapon states, are exempted from international control. Ac-

80 Significant Quantities are used in establishing the quantity component of the IAEA inspection goal. The Significant Quantities take into unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses.

81 The critical mass of a bare solid sphere of U-235 is approximately 50 kg.

82 The section is in part based on (Arbman et al. 2004), a text to which the author of this thesis contributed.

83 Tens of tons of fissile material are recovered from nuclear weapon dismantlement annually, and tons of HEU are disposed of or used in (naval) reactors. As Russia dismantles some 2,000 strategic nuclear warheads each year, the stockpile, however insecure, will grow even greater (Hutchinson 2003, 185).

84 Most notably India and Pakistan (Bremer Maerli 2001c).

85 The United States and Russia have now declared 174 tons and 500 tons, respectively, of HEU in excess to their national security needs. These quantities will be down-blended for use as commercial reactor fuel or disposal. The ongoing HEU deal between the United States and the Russian Federation is covering the 500 tons of HEU currently declared excess by Russia. No further excess declarations are currently envisioned by either side. It should, however, be observed that the initial Russian excess declaration of 500 tons happened only after the USA offered economic incentives.

cordingly, only some 1% of all HEU globally is currently under International Atomic Energy Agency (IAEA) safeguards.

Today more information about military nuclear stocks is available than only a few years ago, but still, with some noteworthy exceptions, no official figures exist on the military inventories of HEU in the nuclear-weapon states ([P3], 55).[86] Whereas Russia's contribution to overall fissile material production has been substantial, its total quantities are largely unknown ([P3], 53). No official figures on Russian stocks exist. Estimates involve large uncertainties, varying by several hundreds of tons (see Table 4.1). This makes it difficult to assess the ratios of prevented to non-barred thefts (Orlov 1999, 170). The material is distributed at more than 300 buildings at more than 50 civilian or military sites in Russia ([P3], 57).

Much of the nuclear accountancy that in fact took place has proven to be deficient at several of the installations in the former Soviet Union ([P3], 55). The quantities of nuclear material were often given in tons, or even in relation to the value of the rouble (Kulik 1995). Inflation and devaluation make this type of "accountancy" untenable. Obviously, the practice complicates any detailed control of the material.[87]

Table 4.1: Estimated quantities of highly enriched uranium in Russia according to different sources

Source	Quantity of HEU outside weapons	Total quantities of HEU, including in weapons
Mikhailov (1993) [88]		1,250 tons
Albright et al. (1997, 399–400, 414)[89]	825 tons	1,050 ± 300 tons
Bunn and Holdren (1997, 413)[90]	825 tons	
Bukharin (1996, 70)		1,300 tons
US Department of Energy (1998)	600 tons	
Albright (1999, 11)[91]		1,010 tons
CSIS Task Force (2000, 20)		1,040 tons
Cirincone et al. (2002,115)		Up to 1,500 tons

(Based on [P3], 54)

These discrepancies signify the importance of an overall fissile material accountancy exercise and the creation of a "baseline" of all stocks of fissile material. 1,500 tons of Russian HEU represents the upper limit of these esti-

86 Inventories of all nuclear material on hand have not been declared by any nuclear weapon state, except the United Kingdom.
87 This lack of accountability should, however, not be mistaken as sole Russian problem. A US historical account of its total plutonium production revealed 2.8 tons in "losses", that is, material unaccounted for (United States Department of Energy 1996). An equivalent historical UK plutonium survey finalized in April 2000 found 300 kg Pu in excess, theoretically enough for some 50 to 60 bombs. A long-promised US HEU historical account is pending due to the difficulties of keeping track of the uranium production and production tails.
88 Quoted in Albright et al. 1997, 94.
89 Based on 10,000 operational warheads. HEU figures given in weapons-grade equivalents.
90 Again assuming a stockpile of 10,000 warheads (see the preceding footnote).
91 The HEU figure is given in weapons-grade equivalents.

mates, a quantity possibly enough for some 30,000 crude HEU nuclear explosives.[92] Today these vast stocks are managed with very little of the transparency needed to build confidence that they are safe and secure, or to provide the foundation for deep, transparent and irreversible nuclear arms reductions ([P3], 57).[93]

4.1.2.2 Getting Access to the Stolen Material

To get hold of the required quantities and qualities of fissile material, non-state actors would need to steal or buy the material (step S2). If they try to steal it themselves, the terrorists risk blowing not only their cover, but also their tactics and future plans. Moreover, stealing material could take terrorists into new fields of criminal activity, where they have less competence and thus a higher risk of failure ([P1], 110).

Alternatively, they could get the material from a seller or a middleman. This involves other risks, as the group will have to explore the market and expose themselves to new people and environments – and possible sting operations. Moreover, sellers and buyers may have problems in connecting. No final buyer – only sellers and middlemen – has been identified in what seems to be a persistent black market for fissile material (Belyaninov 1994, 8w). This could be due to a lack of purchasers, or, possibly, more professionalized smuggling networks (see below).

According to the IAEA's Illicit Trafficking Database,[94] about 600 illicit trafficking incidents have taken place since January 1993. Of these, about 400 incidents have been confirmed by states. Slightly less than half of the confirmed cases (175) involve nuclear material, including 18 cases with highly enriched uranium or plutonium (Anzelon 2001). By combining state-confirmed information with unconfirmed open source data, the number of highly-credible trafficking incidents involving weapons-useable nuclear material amounts to 25 since 1992 (Zaitseva and Steinhausler 2004, 2w).

None of the quantities of seized nuclear material was in itself enough to produce a workable nuclear explosive. Intercepted plutonium accounts for less than one percent of the 39 kg of fissile material seized in the 25 incidents known. HEU may hence have been subject to diversion and smuggling to a much higher degree than plutonium (Zaitseva and Steinhausler 2004, 2w). However, the extent to which undetected smuggling has occurred is unknown. The dark figures could be high. One successful transfer of high-quality nuclear material could be one too many, and the seizures produce a disturbing picture ([P1], 114).

92 This is a very rough estimation, assuming that slightly above 50 kg of HEU will suffice for a crude nuclear explosive device. The number depends on the kind of nuclear explosive in question. Using the 8 kg figure given by Cohran and Paine (Section 4.1.2.1) as a point of departure for the nuclear explosive, gives for instance a stockpile figure enough for nearly 200,000 crude nuclear explosives.

93 The considerable uncertainties in fissile material inventories have been deemed to be the major obstacle to meaningful reductions (Fetter 1996, 15; Zarimpas 2003, 10).

94 This database is part of an information exchange programme among IAEA member states, with some 70 states participating. The member states report and confirm incidents of illicit trafficking on their territories, and provide background information to the cases. Additional information from open sources is included when appropriate.

4.1.2.2.1 Russian HEU Security

Reponses from Russian officials on the matter of physical security deficiencies and insufficient control of nuclear material vary – from denial (see e.g. Sinitsina 2003) to some concessions, acknowledging to a certain extent that there are security problems. In August 2003, the board of the Russian Federal Inspectorate for Nuclear and Radiation Safety, Gosatomnadzor (GAN), concluded that there have been deviations in the control and accounting of nuclear material (Nuclear.ru 2003, 1w; RIA Novosti 2003, 1).

The conclusions were reached after a revision of the activities within the state system for nuclear material control and accounting of as well as results of regulatory control over the physical protection of nuclear and radiation hazardous facilities. According to the board, many violations have been registered (Aale 2003, 6). Russian officials now claim to have taken steps to correct these. However, establishing a state system of accounting and control for nuclear material in Russia is a slow process (Dmitriev et al. 2001).

The primary threat against the security and the control of nuclear material in today's Russia may be a knowledgeable and corrupt insider, possibly acting in collaboration with external participants ([P1], 114; [P3], 56; Bukharin and Potter 1995, 49; Bukharin 1998, 320). Soviet-era physical security systems were built on a philosophy of "guards, guns and Gulag" (Bunn et al. 2002, 35). Morale in the nuclear-weapon complex then was high, and insiders were not really a threat, as personal surveillance was tight and potential buyers of stolen fissile material absent.[95] Post-Soviet experiences have proven otherwise ([P3], 52).

Recent developments in Russia, resulting in burdensome transformations of both military and civilian nuclear entities and cuts in wages and former privileges for the employees, seems to have lowered the thresholds for theft and diversion of material ([P3], 56). According to a study performed by GAN, personnel working within the nuclear industry were involved in all the thefts that were analysed in 1992–94 (Koupriyanova 1999). These perpetrators were all without a previous criminal record.

Hence, although fissile material security in the former Soviet Union has often been treated as a technical problem, it may actually be more of a "people problem" (Daughtry and Wehling 2000, 108). Living conditions and political turmoil in Russia are factors of great importance to nuclear security (Allison et al. 1995, 28–29). Domestic upheavals can only increase the risk of "nuclear leakage" (Busch 2002, 46). The system of fissile-material security at former Soviet nuclear facilities was severely weakened after the collapse of the Soviet Union (Busch 2002, 73). Sustainable nuclear security and safety cannot be developed in a vacuum.

95 In the past, insiders were never considered a major threat ([P3], 57). Close screening and surveillance of employees, strong penalties and closed borders and the absence of external buyers of any diverted material was considered sufficient. Hence, portal monitors for fissile material at nuclear facilities would be a rare feature in Soviet designed systems of physical protection. Sometimes simple wax seals were used to indicate if doors or containers have been opened or tampered with. These seals do not meet international standards and also do not guarantee the quick discovery of thefts (Bunn 2000).

Stable political, societal and economic conditions are paramount, and these aspects need to be taken into consideration when discussing nuclear security.[96]

4.1.2.2.2 Joint International Efforts to Secure Russian HEU

During the past decade, unprecedented cooperative work between the USA and Russia has been carried out to secure fissile material ([P6], 38). Many of the challenges, however, remain. Hundreds of metric tons of nuclear material still lack improved security systems. As of March 2003, the USA, according to the United States General Accounting Office (2003, 25), had assisted Russia in protecting about 228 metric tons, or some 38%, of its weapons-useable nuclear material.[97] Most of the buildings where the Americans have been granted access and where security systems have been installed are at Russian civilian sites and at naval sites, not at Russian nuclear complex (see Table 4.2).

The Department of Energy (DOE) plans to complete its work at naval fuel storage sites in 2006, at civilian sites in 2007, and at the nuclear weapons complex in 2008 (General Accounting Office 2003a, 24–25 and 29).[98] As of January 2003, US teams had obtained or anticipated obtaining access to thirty-five of the estimated 133 buildings in Russia's nuclear-weapons complex with nuclear material. At the remaining buildings (74% of the total), the US Department of Energy (DOE) had no access to design or confirm the installation of security systems. In reality, therefore, progress has been limited for much of the most proliferation-attractive material, located in the nuclear-weapons complex ([P6], 38).

Table 4.2: Buildings to Which US Teams Lack Physical Access in Russia, percentage, as of January 2001

Civilian Sites (%)	Naval Fuel Sites (%)	Nuclear Weapon Laboratories (%)	Overall (%)
12	0	73	41

(From US General Accounting Office 2001, p. 8)

In stark contrast to this, the US team working on security upgrades for the Russian Navy reports access to all sensitive facilities having fresh highly enriched uranium fuel (see Table 4.2). Building upon the fresh fuel security upgrades, the team is now engaged in securing the nuclear weapons of the Russian Navy and expects to finish security upgrades for four thousand naval nuclear warheads by 2005 (Abraham 2002, 3w).

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96 The assessment by Hansen and Tønnessen (1998) may be useful point of departure for such an analysis.

97 A key US official in part contrasted these figures September 2003. According to Energy Secretary Spencer Abraham (2003, 3), security has been improved "at over 70% of the original MPC&A (Material Protection, Control and Accounting) sites in Russia". It is unclear, however, what is meant by "original sites", and the figure presented says nothing about the amount of material actually covered, to what level of security.

98 DOE has, however, scaled back its plans to assist operational naval sites, which support deployed nuclear weapons, to comply with January 2003 US interagency guidelines that preclude assistance to most operational sites (General Accounting Office 2003a, 32).

The US–Russian naval MPC&A Program has clearly been more successful than other cooperative programmes in overcoming distrust and dealing with sensitivity issues ([P6], 46–47). As such, it could be a particularly interesting candidate, or perhaps even a springboard, for increased transparency ([P6], 48).[99] Important lessons from this collaboration could, moreover, be applied to other cooperative nuclear security efforts.

Other elements of the US–Russian MPC&A Program have run into several fundamental problems. From the beginning, access to sensitive Russian nuclear sites has been a significant stumbling-block for cooperation on fissile material security and nuclear weapons ([P3], 59). There has been a lack of clarity on both sides as to the kinds of access needed, when, for whom, and most importantly, for what purposes (Holgate 2001). As a result, all new security contracting at the most sensitive nuclear-weapon complex has been suspended since autumn 1999, pending decisions and agreements on access ([P6], 38). Most assessments of joint US–Russian cooperative threat-reduction programmes or fissile-material security upgrades have hence stressed that improved transparency is essential for continued success (Busch 2002, 90).

The scale of the security challenges has, moreover, proven far greater than anticipated ([P3], 58). New insights into the size and diversity of the Russian nuclear weapon complex have led US experts to revise their initial threat assessments and cost estimates. In 1999, the risk of theft or diversion of directly useable material was deemed "considerably greater" than just three years earlier, due to more extensive dispersion of the fissile material and more pervasive inadequacies in the physical protection system (National Research Council 1999, 1).

There are also operational problems associated with the MP&A equipment installed with US support. The equipment needs continuous supervision and maintenance, which in turn presupposes dedicated and well-trained (and paid) personnel. Sustainability is obviously an aspect requiring more attention ([P3], 63). The fact that the joint US–Russian nuclear material security upgrades may be effective against casual thefts, but less effective against the insider threats mentioned (Committee on Science and Technology for Countering Terrorism 2002, 40), also merits close consideration.

4.1.2.3 Smuggling the HEU to a Safe Haven

If the country of origin of the fissile material is different from the planned country of destination for the nuclear explosive device, the material will have to be transferred across international borders (step S5). To customs and other law-enforcement officers, this represents an opportunity for intercepting the material. Unfortunately, the low radiation signatures of HEU complicate such seizures, as do the need for specialized customs training and equipment. Prevention of illicit trafficking in nuclear material is further challenged by the large number of legitimate border crossings, and limited opportunities and resources to control all travellers and goods.

Every day, more than 15 million cargo containers are moving around at sea or land, or await delivery. Inspectors examine only two per cent of these containers, and often only after these have travelled long distances *(Econo-*

99 These are issues that will be thoroughly investigated in Section 4.3.

mist 2002). Experiences with the interdiction of drugs and other trafficking suggest that seizures represent as little as 10%, and a maximum of 40%, of the goods actually being smuggled (Williams and Woessner 1995, 2; Zaitseva and Steinhausler 2004, 5w).

Assuming, probably far too generously, that customs and others should be able to seize 60 to 70% of the nuclear goods, this would still leave one third of the illicit nuclear material outside the hands of law-enforcement officials. Experiences from drug trafficking, moreover, suggest that when law enforcement is increased along one route, this simply leads to a re-routing along new paths that involve fewer risks for the perpetrators (Williams and Woessner 1995, 3). Since 1994, reported illicit trafficking incidents in Europe have declined. Simultaneously, however, since 1999 there has been a revival in such incidents in the Caucasus, Central Asia, and Turkey (Stone 2001; Zaitseva 2002).

Illicit trafficking in nuclear material hence remains an international problem. While tests show that border monitoring of nuclear and radioactive material is possible with acceptable expenses, there is ample room for improving detection capabilities at border crossings in many states (Beck undated, 5 and 15–16). Sweden, a state with nuclear-power activities, may serve well as an example. A 2001 survey concluded that the national technical ability of Sweden to detect illicit trafficking in nuclear and other radioactive substances is highly limited (Ringbom and Spjuth 2001, 18). Existing equipment is not sensitive enough, and improved training for customs officers is needed. A figure of zero seizures of radioactive and nuclear material in Sweden could therefore stem from poor detection capabilities, rather than from a lack of incidents.

4.1.2.4 Constructing a Crude Nuclear Explosive Device

After having acquired the needed amounts of high-quality uranium and smuggled the material to a safe haven or into the target country, terrorists may be ready to construct the actual nuclear explosive by assembling the various weapons components (step S6). To construct a workable nuclear explosive device, any actor – a state or a non-state group – must follow a series of complex technical steps ([P2], 731).

Aspiring actors must:

1. develop a design for its nuclear device or obtain such a design from a weapon-holding state;

2. produce the fissile material for the core of the device or obtain it from an external source and then machine the fissile material to fabricate the nuclear parts of the explosive;

3. fabricate, or obtain from outside, the non-nuclear parts of the device, including the high-explosive elements and triggering components that will detonate the nuclear core;

4. verify the reliability of these various elements individually and as a system;

5. and, finally, assemble all of these elements into a deliverable nuclear explosive, commonly referred to as "weaponization" (Carnegie 2001, 1w).

Consequently, building a nuclear device capable of producing mass destruction may represent significant challenges for terrorists, as indeed even for states with well-funded and sophisticated programmes (Cordesman 2001, 30). Such endeavours would have to include technical skills, specialized brain-power (e.g. metallurgical experts and specialists on explosives and electronics), money, facilities, equipment, and fissile material (Milhollin 2002, 8w).[100] Aspiring nuclear bomb-makers would, moreover, have to study how to optimize the design. Although the basic scientific and technical principles of making nuclear weapons are relatively well-known, details and "tricks" can be very hard to duplicate in practice (Albright 2000, 58).

All demonstrably successful efforts by states to develop nuclear weapons have to date thus been major enterprises, involving several years of work, with large design teams and recourses devoted to the development of nuclear devices ([P2], 731). The South African nuclear-weapon programme spent significant resources to develop adequate knowledge to design and manufacture crude, deliverable fissionable weapons. Success was measured in years rather than months.[101]

These technical challenges could, coupled with unsuccessful large-scale state nuclear weapon programmes (e.g. that of Iraq), be why some scholars prematurely and uncritically also dismiss the risk of nuclear terrorism. For instance, it has been claimed that "significant technical hurdles stand in the way of practicing nuclear terrorism in any form" (Cameron 2000, 157). But all the well-documented efforts by states of nuclear weaponization since 1945 seem to have been created as stepping- stones to increasingly sophisticated arsenals. Most of the resources have been put on the production of fissile material (MacKenzie and Sinardi 1995, 84).[102]

The need for extensive know-how may be circumvented by a modest programme aimed simply at producing a limited number of crude nuclear explosives; terrorists would have lower technical weapons requirements than would states ([P2], 731–732). The technical difficulties are highly dependent on the complexity of the device a non-state group chooses to develop (Narath 2002, 2). As the complexity of the nuclear design decreases, so do the technical challenges associated with the design of auxiliary components.

4.1.2.4.1 Types of Terrorist Nuclear Explosive Devices

Two basic designs of crude nuclear explosives are likely to be adequate for most purposes of a terrorist group intent on nuclear terrorism ([P2], 732). Both designs were used in the first generation of nuclear weapons produced,

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100 Additional technical challenges include issues of material purity, uniformity, stability and compatibility (Narath 2002, 12).

101 For more on the South African nuclear devices, see Appendix III.

102 Even the Iraqi nuclear weapon programme was over-dimensioned in terms of simply producing a crude nuclear device (MacKenzie and Sinardi 1995, 85).

and could almost certainly be fielded without a nuclear testing programme (Zimmerman 1993, 354). By contrast, it is unlikely that terrorists will have access to enough know-how and information to construct sophisticated weapons like small boosted fission devices or small staged thermonuclear devices (Narath 2002, 15).

One of the designs is a so-called *gun-type nuclear explosive device,* similar to the nuclear weapon that destroyed Hiroshima.[103] This is the simplest crude device to design and construct, and it is quite reliable ([P1], 115).[104] As such, it is the most likely one to produce a powerful nuclear explosion by less qualified actors. The risk of pre-ignition, and hence an effect (significantly) below the design yield, is limited due to the low neutron background in the HEU (see Appendix III). This design can use only highly enriched uranium as fissile material, not plutonium.[105]

In the gun-type design, one piece of sub-critical HEU could be propelled into a larger mass of uranium – whether by means of conventional explosives, prompt retardation or compression, or simply by gravity (Alvarez 1987, 125). Terrorists could possibly do this by using a thick-walled cylindrical barrel to force two sub-critical masses of HEU together with the use of high explosives ([P2], 733). A sketch of a gun-type device is presented in Figure 4.1.

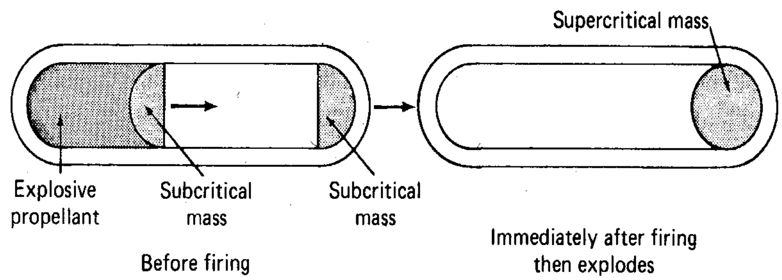

Figure 4.1: Schematic diagram of the gun-type assembly principle

(From Craig and Jungerman 1986, 182)

Because of the required characteristics of the gun itself, as a large mass of high density must be accelerated to a high speed in short distances, the gun-type design may be harder to master than it initially appears. Moreover, impurities in the fissile material would reduce the yield and should, ideally, be removed. This could further complicate the manufacturing of the crude nuclear explosive device (Falkenrath et al. 1998, 133). Potential perpetrators would face hazards such as those arising from the handling of the conventional explosives, the possibility of inadvertently initiating a chain reaction,

103 The nuclear explosive were never stockpiled, and only five assemblies were completed with this design. They were retired by November 1950.

104 The bomb dropped on Hiroshima, "Little Boy", had a gun-type design. It was never tested before deployed. Appendix III offers some general considerations on the feasibility of producing a crude highly enriched uranium explosive device.

105 The relatively long insertion time would allow for spontaneous neutron fissions in the plutonium. Accordingly, a chain reaction may be initiated prematurely, leading to early termination of the fission reaction and a (drastically) reduced yield.

and radio-chemical toxicity of the material used (Barnaby 1996, 10). However, these production challenges and hazards should not be exaggerated.

While by no means straightforward, designing and fabricating a functioning nuclear gun-type explosive is unlikely to confront non-state actors with insurmountable difficulties (Narath 2002, 7). A gun-type design can be considerably simpler both to design and to construct, if the length and weight of the design are not constrained by the traditional requirement that the nuclear device be deliverable by air (Falkenrath et al. 1998, 162).

With the exception of the HEU, and possibly high-strength steel for the barrel, a gun-type device does not have to rely on exotic material. In fact, it could be quite easy to produce all the needed material (again with the exception of the HEU) and perform the fabrication and assembly operations without attracting much attention (Narath 2002, 8). Most non-nuclear components of nuclear explosive devices are available in international commerce (Goldblat 2002, 116). The machining operations to produce the device are not particularly complex.[106] Besides, the use of uranium oxide may lessen many production challenges, though at the cost of a less efficient device and, hence, a reduced yield.

Poorly assembled nuclear explosive devices would produce lower yields, as the chain reaction will abort as the system expands. The yield will vary accordingly, but a crude HEU device should explode with an explosive power equivalent to that of several hundred to a few thousand ton of TNT (Barnaby 1996, 7). Even a device in the lower kiloton range would wreck havoc vastly greater than that hitherto inflicted anywhere by a terrorist attack (Arbman et al. 2002; Narath 2002, 14).

A sketch of an implosion-type device, the other first-generation nuclear design, is presented in Figure 4.2. In contrast to HEU devices, plutonium explosives need to have a fast compression due to the higher fraction of spontaneous neutrons. The need for a rapid and simultaneous compression of the fissile material requires a more challenging implosion design (Narath 2002, 9), and preferably, but not necessarily, advanced computerized analysis to optimize the yield ([P2], 734).

The needed quantities of fissile material will be lower than for a gun-type design, and both plutonium and highly enriched uranium may be applied. But generally, in addition to lower design and performance confidence, the fabrication of an implosion-type device is more demanding than that of a gun-type one (Narath 2002, 10).

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[106] Possible hardening of the uranium may pose some production challenges, and the fact that the uranium is pyrophoric could cause additional problems (Zimmerman 1993, 348).

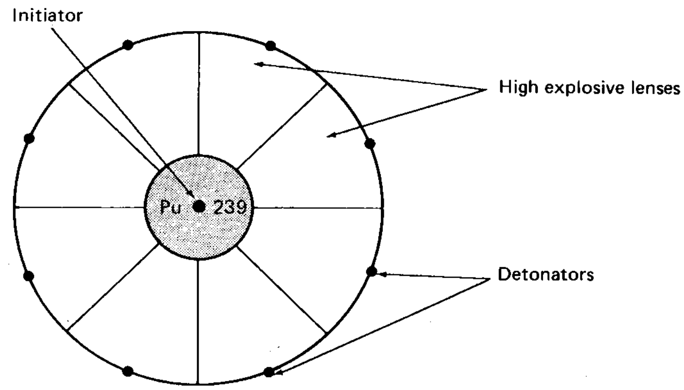

Figure 4.2: Schematic diagram of the implosion type assembly principle

(From Craig and Jungerman 1986, 182)

The gun-type design is inherently inefficient, and requires a larger mass of fissile material than for implosion designs ([P2], 736).[107] The weight and bulkiness of device may increase accordingly. However, the performance of any nuclear explosive devices may be improved and the critical mass reduced by fairly simple measures ([P2], 736). For example, a reflector that returns escaping neutrons back into the fissioning assembly could surround the nuclear device. This would make more neutrons available to produce fissions, and less fissile material would be needed. The reduction can be considerable. According to Mark (1991) only some 25% of the initial critical mass is needed when a beryllium reflector is placed around a mass of uranium containing 93% of uranium-235. This provides corroborating evidence for the findings of Cochran and Paine (Section 4.1.2.1).

Moreover, to assure high neutron flux the instant the system goes critical, a strong neutron source that becomes active as soon as the pieces come intro position can be introduced. The burst of neutrons will then boost the fissioning of uranium atoms, and, hence, increase the yield. For gun-type uranium weapons, this can be done for instance by placing one radium source at one uranium piece and a beryllium source on the other, so neutrons are produced only when the pieces are close to the proper relative position (Serber 1992, 51).

4.1.2.4.2 Terrorist Nuclear Explosive Standards

For states, the technical barriers to weaponization of fissile material come down to designing and proving the explosive sets needed to assemble the supercritical mass, producing a reliable initiator, coping with the physical and chemical properties of the material, and performing the necessary proof testing of the designs (Zimmerman 1993, 348). Terrorists, however, would not have to meet many of the extremely tight military specifications and

[107] Situations were nuclear perpetrators do not possess enough material for a gun-type design, and they hence are left with no other option than trying to construct the less mass-demanding implosion device, could be envisioned.

weapon tolerance standards ([P1], 112; [P2], 731–732; Mark et al. 1987, 63; Falkenrath et al. 1998, 100). A crudely assembled nuclear device, while less efficient than a state military weapon, could very well serve the needs of a terrorist group.

The highly differing requirements for performance and delivery could make weapons designed to meet the "Terrorist Nuclear Explosive Standards" less technically challenging to produce than traditional state nuclear weapons ([P1], 112; [P2], 731). The manufacturing of a single crude terrorist uranium bomb might, moreover, not produce many of the "signatures" that intelligence agencies look for, or a noisy testing programme (Milhollin 2002, 8w).

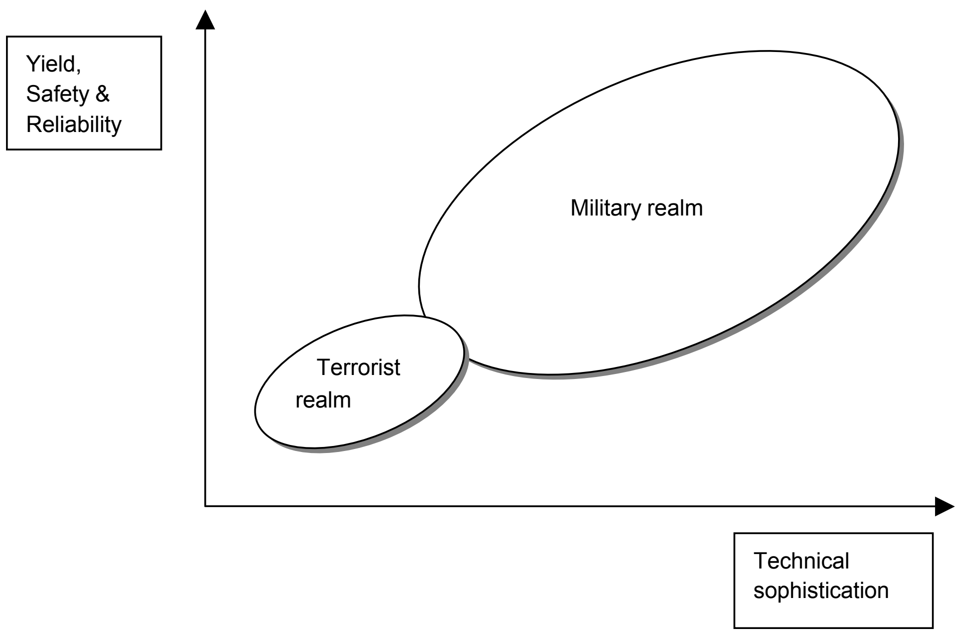

Figure 4.3: Terrorist and state military nuclear explosives compared

(*From [P1], 112*)

As schematically illustrated in Figure 4.3, a state would be at least as concerned with the nuclear device *not* going off during storage and transportation, as with optimizing the yield and detonation of the device. To states, nuclear-weapons safety is essential.[108] While safety is a must for states, such concerns might well be less important to terrorists, especially groups with strong leanings to martyrdom (Maerli 2001a, 216).

Secondly, the reliability concerns may be correspondingly low amongst terrorists. While an ignition failure or a fizzle yield would be unfortunate from the viewpoint of terrorists, it could have profound impact on the secu-

108 One example is the so-called "one-point safety" requirements of the USA to prevent accidental detonations of nuclear weapons. This set of strict requirements is designed to ensure that a nuclear explosion will not result if the conventional explosive that surrounds the fissile material were accidentally detonated.

rity of a state, e.g. in a nuclear offensive mode ([P1], 732).[109] Moreover, to be able to forecast damages, perform nuclear planning, and estimate the number of warheads needed, states are looking for fairly predicable and accurate yields.[110] The result is, again, more technically advanced designs for state nuclear weapons. For terrorists, however, devices that explode with only a fraction of the design yield could be more than enough to serve their purposes (Arbman et al. 2002, 13).

Thirdly, weapons for military uses are normally required in fairly large numbers, and they must be delivered by conventional military means like missiles or mortars ([P2],112).[111] Terrorists, on the other hand, will aim at a limited arsenal and unconventional delivery. The major constraining factors for state nuclear weapons are often the weight capacity of the delivery vehicle and the space available to carry the explosive (e.g., the diameter and length of a nosecone or the length and width of a bomb bay). Developing reliable delivery systems and slender nuclear explosives is technically challenging and expensive, even for states ([P1], 732).

Crude terrorist nuclear devices, however, will easily fit into a van, or even an automobile, for possible detonation in a densely populated area ([P2], 112). Other non-military means of delivery could involve trucks, hot-air balloons, ships, or simply a complete assembling of the nuclear device inside a garage or an out-of-the-way residence (Botuwell et al. 2002, 3).

4.1.2.4.3 Availability of Relevant Bomb-Making Information

The design and production of nuclear weapons today is a far simpler process than it was during the Manhattan Project (Military Critical Technologies 1997, II-5-1). The rapid spread of technological knowledge could advance terrorists' weaponization attempts ([P2], 111). Indeed, in a 1960s experiment conducted by the US government, three recently graduated students were instructed to develop a nuclear explosive design using only publicly available information. The students reformed their task successfully. In the ensuing years, much more information has entered the public domain, probably making similar efforts today even simpler (Maerli 2002c, 5w). As one US veteran weapon designer has noted, "the scientific knowledge and computational expertise required for nuclear weapon design is now widely dispersed" (quoted by Hoenig 2001, 32). Nearly 60 years after Hiroshima and Nagasaki, this should hardly come as a surprise. Knowledge of nuclear-weapon design is so prevalent that trying to maintain a shroud of secrecy around it no longer offers adequate protection (Deutch 2001, 68).

Relevant information on the production of nuclear explosives can be found in the technical literature.[112] *The Los Alamos Primer: The First Lectures on How to Build an Atomic Bomb* was declassified and published in 1992 (Serber 1992). The book originated as a series of five lectures, given to the physicists of the Manhattan Project at its commencement, outlining the

109 I.e. in a nuclear exchange, where it would be essential to destroy enemy warheads before they are launched.
110 Technically advanced states have even introduced nuclear weapons with variable yields, or "dial-a-yield" measures, where each bomb's explosive power can be custom adjusted right before it is launched.
111 Nuclear mines are a notable exception.
112 See for instance Lovins 1980 and Mark et al. 1993.

theoretical foundations of the bomb-making. Also within the information swamp on the Internet, potential producers of nuclear explosives can find useful sites. While these are not likely to be "step-by-step" descriptions, parts of the openly available information are likely to assist and even guide potential bomb-makers in the process ([P1], 111).[113]

4.1.2.5 Smuggling a Nuclear Explosive Device Into a Target Country

After a workable nuclear device has been constructed, it will have to be transferred to the location of planned detonation (step S7). This process could involve border crossings, and hence new challenges for the perpetrators as well as new opportunities for interceptors. The sheer size and weight of the explosive device could render clandestine transport and smuggling difficult, making detection more probable than in the case of transfers of fissile material.

However, (sleeping) cells in shipment and receiver countries could be activated, to ease and ensure the transfer. As Schmid points out (Section 4.1.1.1) contemporary terrorism is becoming more trans-national and more linked to organized crime. Professionalized nuclear smuggling networks may evolve. Moreover, for assembled nuclear explosives, radiation signatures from the fissile material are likely to be better masked due to the metal casing of the explosive device, making radiological detection harder (Cordesman 2001, 35).

As a test, a 6.8 kg cylinder of depleted uranium metal was smuggled, on two occations, into the United States without being detected (Natural Resources Defense Council 2003, 2w). Depleted uranium has a lower specific activity than HEU,[114] but it seems clear that also weapons-grade uranium quite easily could have passed through US Customs without being detected, despite recent security upgrades at the borders and elsewhere.

Blocking nuclear smuggling has been a major part of the US Homeland Security measures. In the wake of rumours about al-Qaeda's alleged progress toward obtaining a nuclear or radiological explosive device in Afghanistan, hundreds of new and sophisticated radiation detection sensors were deployed to US borders, overseas facilities and points around Washington DC. The ability of these sensors to detect nuclear material, however, may be limited (Glanz, 2002).

Generally, technologies designed and used to detect nuclear material operate over fairly short ranges. For a hidden or smuggled crude nuclear explosive device, the shape, material composition, and shielding will be unknown. This could further challenge detection.[115]

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113 Such sites are deliberately not presented here.

114 The specific activity (the radioactivity per unit mass) of the uranium isotopes in depleted uranium is about 15 million becquerel per kg (15×10^6 Bq/kg). This is approximately 40% lower than that of naturally occurring uranium (25×10^6 Bq/kg) and about 150 times less than that of enriched uranium (approximately 2.3×10^9 Bq/kg).

115 However, as seen in Section 4.1.2.1, crudely assembled nuclear explosives may require extra quantities of fissile material. This could increase radiation levels, and thus ease the delectability. If possible nuclear perpetrators only get hold of material with intermediate enrichment levels, say 50 to 60% enriched in U-235, this could also raise the neutron background and thus the probability of detection, compared to material with higher enrichment levels. If close enough, a crude nuclear device could probably be detected within a few minutes of measuring time with a hand-held monitoring device (Arbman et al. 2002, 9). Generally, it is easier to detect plutonium devices than uranium devices, due to higher radiation levels (Arbman et al. 2002, 7).

4.1.2.6 Transporting the Nuclear Explosive Device to Location

The first nuclear weapons produced were robust and sizeable and not easily transportable.[116] However, a crude nuclear explosive HEU device capable of delivering a kiloton yield could weight no more than 300 kg, with a length of one meter (Barnaby 1996, 7). Others maintain that the most primitive gun-type devices would be at least 2 to 2.5 m. long and weigh roughly half a ton (Cordesman 2001, 34). Yet even a device of the latter size could fit in the back of a truck or inside a cargo container. Hence, the number of terrorist means of delivery into or against a country is potentially quite large ([P1], 112).

This level of relative mobility, coupled with weak gamma-ray radiation from the device, could make it very difficult to detect a nuclear explosive in a busy urban environment (Harris 1999, 83).

4.1.2.7 Detonating the Nuclear Explosive Device

The final step for terrorists would be to detonate the nuclear device, releasing its devastating blast, heat and radiation. The ease of detonation depends upon the technical sophistication of the device, hereunder for instance the use of neutron triggers (Serber 1992, 51). The device may fail or fizzle, producing a limited yield (see Section 4.1.2.4.1). Once potential terrorists have the necessary material, however, the actual construction of the ignition for the nuclear explosive device may be comparatively easier (Schaper 2002, 19). As far as is known, no nation that has attempted to detonate a nuclear explosive device has failed on its first attempt (Zimmerman 1993, 354).

Compared to having stolen an intact nuclear warhead, terrorists who construct their own crude devices could have an easier task detonating the device. No safeguards to prevent unauthorized uses of the device (PALs) would have to be bypassed, and the perpetrators would know the device inside and out.

Even at this stage, governments may put in place measures to prevent terrorists from successfully performing their planned acts. In terms of detection, however, law-enforcement officers and others will encounter the same challenges as their customs-officer colleagues are facing at borders. And now time has really become a critical element.

4.1.3 Summary Answer to Principal Research Question [Q1]

> **[Q1]:** *"Can terrorists possibly perform acts of terror by means of crude nuclear explosive devices based on highly enriched uranium? What are the main barriers to the production of crude nuclear explosives?"*

Strategic, practical and perhaps even moral considerations make conventional weaponry the means of choice for the vast majority of terrorist groups. However, if given the opportunity, some groups may stand ready to escalate to the level of nuclear violence. To would-be nuclear terrorists, access to

[116] The "Little Boy" bomb, dropped on Hiroshima, weighed 4,400 kg. It was more than 3 m. long and 70 cm. across.

fissile material of sufficient qualities and quantities is the most formidable obstacle to their nuclear ambitions.

If terrorists have access to sufficient quantities of unirradiated, or “fresh”, highly enriched uranium, crude nuclear explosives could be within their reach. Terrorists will have much less stringent requirements to their nuclear explosives in terms of reliability, safety, security and delivery than states. Technical barriers to the construction of nuclear explosives should thus not be regarded as sufficient to prevent nuclear terrorist havoc.

Once the needed quantities of fissile material have been obtained, it is easier to construct a nuclear explosive device using HEU than using plutonium. Acquisition of unirradiated HEU is by far the most direct shortcut for any actors seeking nuclear explosive capabilities, because:[117]

- HEU is the only material that allows for the easy and reliable manufacture of crude nuclear explosives;
- perpetrators with access to sufficient quantities of HEU of high enough quality will have a good chance to achieve an explosion in the lower kiloton range, i.e. with a yield comparable to that of the Hiroshima bomb;
- HEU exists in large quantities, in part under unsatisfactory levels of protection, control and accounting;
- HEU detection, e.g. at border-crossings and checkpoints, is demanding. due to the low levels of radiation emitted;
- the radiation levels from unirradiated uranium are low and the handling of HEU involves limited health hazards.

If an assembled nuclear explosive reaches its country of destination, it may be too late for detection. Unless sting operations and national intelligence agencies are able to penetrate the terrorist group, it seems likely that any assembling of crude nuclear explosive devices would go undetected (Narath 2002, 14). Denying terrorists access to highly enriched uranium through optimum nuclear husbandry at its sources of origin could therefore be the be-all and end-all of nuclear terrorism countermeasures.

4.2 Conceptual Nuclear Husbandry

The second principal research question, [Q2],[118] is taken as a point of departure for studying how best to prevent terrorist access to fissile material.

In the following, this question will be investigated by means of conceptual analyses of contemporary approaches to the husbandry of nuclear mate-

117 The summary is based on Arbman et al. 2004, a text to which the author of this thesis contributed.

118 [Q2]: *“Is there an optimum way of protecting fissile material from falling into terrorist hands? What role – if any – do transparency and non-intrusive verification play in this regard?”*

rial. Here, the meanings and implications of common nuclear security concepts like safeguards, material protection, accounting and control (MPC&A), verification and transparency are assessed. Particular consideration is given to the two latter concepts and their relevance for preventing nuclear terrorism: Verification is a veteran, yet persistently contested and highly politicized, issue in international nuclear security. The potential of the more recent feature of nuclear material transparency may not yet have been fully utilized. The findings of research papers [P4] and [P5] are of primary importance for the analysis.

A central part of the analysis will also involve looking at possible obstacles to optimum nuclear husbandry. Are there, for instance, any differences between domestic and international nuclear husbandry? If so, what are the implications for practical arms control measures? What are differences between transparency and verification? How could these best be used to optimize nuclear husbandry, and consequently limit the risk of nuclear terrorism? What about their relationship to secrecy? Could for instance nuclear secrecy and transparency possibly co-exist?

4.2.1 Foundations for Optimum Nuclear Husbandry

Deliberate inaccuracy and fuzzy concepts may be embraced purposefully by political actors seeking to achieve policy goals. Such ambiguity, while possibly beneficial in the political or diplomatic sphere, could easily confuse and lead to misunderstanding on the technical arms control arena. Clarity is thus essential, though surprisingly often an alien feature in discussions on practical measures for nuclear arms control ([P4], 54).[119] Practical arms control measures may be introduced without a proper or shared understanding of its meanings, intentions or ramifications. Often an overly simplified "one-size-fits-all" approach to nuclear security measures seems to prevail ([P4], 56; [P5], 3). This is hardly the best starting point for optimum nuclear husbandry.

Fuzzy concepts have not only contributed to errors in planning and implementation of arms control measures. As an important input to the political arms control discussions, technical inaccuracy may obscure opportunities for sound political action, thereby limiting the fulfilment of the true potential of specific practical nuclear arms control measures ([P4], 54).[120] Too often nuclear security equipment is fielded without a serious assessment of its intended purpose, overall context, expected performance, or vulnerabilities. This may cause unrealistic or flawed expectations to monitoring hardware and security systems, and failure to appreciate critical security vulnerabilities ([P4], 55–56). Many of these problems can be avoided with an understanding of the different characters and nature of the various arms control func-

119 The lack of careful thinking may not be as obvious in the literature as in real-world arms control efforts.

120 One example is ongoing discussions on a future Fissile Material Cut-Off Treaty, where technical considerations go hand in hand with political discussions on the level of intrusiveness and the confidence in verification and control. So far, the international community has failed to commence negotiations on such a treaty. For more on the FMCT, see Bremer Maerli 2003e.

tions. Yet, these issues often seem to be overlooked, with potentially detrimental consequences for nuclear security.

Even something as fundamental as the disparate goals of "P", "C", and "A" in nuclear Material Protection Control and Accounting ("MPC&A") are not always well recognized.[121] Much of this confusion rests within US arms control communities, even amongst actors working in the field of nuclear security ([P4], 55). As such, it may have far-reaching consequences for international arm control because the USA is extensively engaged in nuclear security consulting and technical assistance abroad, and the country is a recognized leader in MPC&A technology. Confusion is particularly common over the practical differences between international and domestic "safeguards" – concepts with distinctly different meanings and implications ([P5], 9).

4.2.1.1 Key Concepts in Nuclear Arms Control

In research papers [P4] and [P5], existing concepts of nuclear arms control and terminology are pragmatically examined to clarify inherent differences and identify how the current confusion may influence practical control measures. One important result of this exercise is the identification of Seven Nuclear Husbandry Functions – related yet sovereign activities for the responsible management of fissile material. These will be presented in the following.

First, however, three widely applied nuclear arms control concepts are scrutinized: "Safeguards", Verification" and "Transparency".

4.2.1.1.1 Safeguards

The International Atomic Energy Agency safeguards system constitutes the most important example of multinational nuclear treaty monitoring.[122] IAEA safeguards comprise an extensive set of technical measures by which the IAEA Secretariat independently verifies the correctness and the completeness of the declarations made by states about their nuclear material and activities ([P5], 3).

The US government, however, uses the word "safeguards", sometimes together with "security", to cover a wide range of *domestic* nuclear nonproliferation activities, from physical protection and containment to accounting of nuclear material, conveniently grouped under the heading of Material Protection, Control & Accounting (MPC&A).

As a result, there may be a risk not only of mixing the meaning of the different safeguards terms, but also of confusing the distinct goals of each nuclear security measure installed ([P4], 57; [P5], 3). For some time now, the IAEA has been using domestic (usually US) safeguards technology and approaches with little or no modification for use in its safeguards ([P5], 3). Technical assistance provided by the United States and other countries to the IAEA, moreover, typically involves personnel who are primarily experts on domestic safeguards.

121 To explain the differences of different nuclear security functions, [P4] offers some simple everyday analogies for nuclear husbandry ([P4], 62).

122 According to article III of the Non-Proliferation Treaty (NPT) each non-nuclear-weapon state party to the treaty undertakes to accept safeguards, as set forth in an agreement to be negotiated and concluded with the International Atomic Energy Agency (IAEA) in accordance with its statute and safeguards system.

In the IAEA context, the purpose of such safeguards is to verify the fulfilment of the state party's obligations under the NPT, to prevent diversion of nuclear material from peaceful uses to nuclear weapons or other nuclear explosive devices. Traditional IAEA safeguards involve a set of techniques and technologies depending less on sophisticated hardware than on an elaborate set of record-keeping and administrative techniques (Krass 1985, 89).

Treaty monitoring, like international safeguards, works on the international arena and in a multinational setting. The potential "foe" for international safeguards is the very state being monitored and inspected. International safeguards, moreover, do not involve any physical protection requirements. They do not, even where they are fully in force, offer assurance against theft, seizure or unauthorized acquisition of nuclear material within the state (Curtis 2001, 4).

Under the heading of Material Protection, Control and Accounting (MPC&A), domestic US safeguards, in contrast, consist of a set of preventive, protective, or deterrent measures to be put in place for the primary purpose of avoiding non-state diversion of nuclear material ([P5], 4). A state operates domestic safeguards inside its own borders and facilities, and does so largely for its own benefit and purposes.

Hence, the two types of international and domestic safeguards do not only serve different purposes: They also operate in quite different contexts ([P5], 5–9). A state attempting to cheat would possess vastly more resources than non-state actors planning to divert fissile material from an installation under domestic MPC&A.

For the case of IAEA safeguards, the facility and items monitored will be owned by the potential perpetrator, and personnel working at the installation could, perhaps, work at cross-purposes to the safeguard control. This would influence the operational environment, and the atmosphere and implementation of the security measures. It could, moreover, raise concerns about espionage and tampering of the monitoring equipment ([P4], 5–9). Besides, response patterns and possible sanctions would differ quite significantly between the two types of safeguards.

Another important distinction should be made between international (IAEA) safeguards and cooperative MPC&A. To meet nuclear proliferation challenges, the United States has for the past decade engaged in a defensive Cooperative Threat Reduction Program with Russia and other Newly Independent States.[123] A significant part of this cooperation is carried out under the "US/FSU Program of Cooperation on Nuclear Material Protection, Control and Accounting", of which Naval MPC&A security upgrades are an integral part (see Section 4.1.2.2.2). This programme includes providing technical assistance, consulting, training, and hardware to Russia. However, despite its international focus, it is not a system of international safeguards – and not even international MPC&A, which (as yet) does not exist.

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123 The programme is designed to help the countries of the former Soviet Union destroy and protect nuclear, chemical and biological material and weapons, and associated infrastructure. The programme emanates from the Soviet Nuclear Threat Reduction Act of 1991, championed through Congress by Senators Nunn and Lugar. For more on the CTR program, see www.dtra.mil/ctr/ctr_index.html or www.defenselink.mil/pubs/ctr/ (last accessed 16 January 2004).

Under these programs, the USA does not perform any MPC&A functions for the Russians. While the USA may act on a consultative and supportive basis, Russian MPC&A is a Russian responsibility and an activity undertaken by Russia on its own soil, using Russian personnel and increasingly more equipment bought in Russia ([P4], 57). It is, in other words, still a domestic, and not an international, nuclear security provision.

4.2.1.1.2 Verification

The term "verification" may give a positive sense of security and control. As an absolutist assurance connotation, however, it poses several problems. Firstly, the very nature of arms control makes absolute verification difficult, if not impossible ([P4], 59). It will be in the interest of a sovereign state to limit any kind of intrusive revelations on its defensive or offensive nuclear capabilities. Moreover, if sanctions are likely, those states engaged in undesirable behaviour will have few incentives to supply accurate information themselves (Mitchell 2000, 189).

Consequently, states will want the level of intrusiveness to be kept as low as possible. This conflicts with the initial verification goals and expectations ([P7], 20). Verification activities are further complicated by the fact that new monitoring technologies tend to be quite intrusive and may therefore actually work against acceptable verification solutions, as they might reveal details about nuclear secrets (Rinne 1999).[124]

Secondly, the verification process itself involves a series of steps, each one with costs and vulnerabilities as well as the potential for failure and cheating (Krass 1985, 7–8).

The interpretation of the data output would involve another element of uncertainty and, consequently, a potential for political wrangling: Does an observed event or collection of results signify a violation or not, and with what probability? While "verification" may raise confidence that a promise is violated or kept, it therefore cannot provide 100% assurance of either noncompliance or compliance ([P4], 59).

In international negotiations, one fundamental question has therefore been whether verification regimes must control capabilities by making noncompliance impossible, or whether they should have the realistic (but less tangible) objective of making defection less attractive than cooperation. This distinction is particularly important as the inherent limitations of verification are often embraced by political opponents seeking to kill undesired inspection regimes (Gallagher 1999, 56; Butler 2003, 138).

Accordingly, verification should not be considered a binary function where there is either absolute proof of compliance or absolute proof of cheating. Verification should be viewed as a probabilistic, interpretive activity that involves both evaluating the evidence and attempting to understand its meaning (Cheon and Fraser 1988, 39; Thompson 1990). To achieve a common understanding of such verification norms, it is crucial to have a

[124] Even radiation measurements outside sealed canisters containing the plutonium "pit" of a nuclear fission trigger could reveal classified information (von Hippel 1997, 6). Accordingly, if sensitive nuclear components are to be put under international surveillance, the International Atomic Energy Agency would have to compromise the intrusiveness of its monitoring. These aspects are further explored in Section 4.3.3.2.

clear and common understanding of the concept and the implications for practical nuclear arms control.

4.2.1.1.3 Transparency

No universal understanding of the meaning of transparency exists within the arms control communities (Center for Strategic and International Studies 2000, 54). Transparency has come to be a "grab bag" concept that encompasses all kinds of unrelated nuclear monitoring and disarmament activities. Nevertheless, the concept has merit – as long as the meaning and implications are unambiguous and understood ([P4], 60).

The general aims of transparency to contribute to confidence- and security-building, and to foster public and political support by explaining the rationale of a specific nuclear policy and posture (NATO 2000, 25). In the nuclear realm, transparency can corroborate that no clandestine activities are taking place, bolster the validity of material accounting, confirm that nuclear material is adequately protected, and verify that non-proliferation obligations are being met.[125] As a result, lifting secrecy serves to reduce tensions and nuclear dangers (Zarimpas 2003, 10). As seen in Figure 4.4, predictability is a key element in this process.

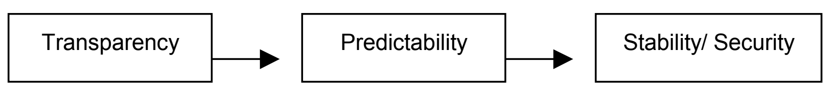

Figure 4.4: Transparency as a stability and security-building tool, through predictability

Transparency is a process in which information about governmental actions, preferences, intentions, and capabilities is made available – or more properly, allowed to flow – to citizens and the international community (Finel and Lord 2000, 3). A more predictable, and hence more stable, environment may evolve.

While the transparency process can involve elements of cooperation and mutual negotiability, transparency is decided and performed by a sovereign state on its own territory ([P4], 60). A nation does not need the assistance, cooperation, or permission of another states to engage in transparency, nor to decide the timing or degree of openness that will be allowed.

Ideally, transparency surpasses required activities, such as reporting or verification obligations mandated by treaty. Transparency is more than a mere description or detailed specification of a nuclear programme, specific site, or ongoing activity, and more than merely providing data mandated by treaty or law. *Voluntary release* is the true meaning of transparency: Taking extra steps of openness beyond expectations or promises is the true test (Senazaki et al. 1997, 2–3). Such extra steps are likely to promote higher levels of trust. Transparency is "permitted knowledge" (Center for Strategic and International Studies 2000, 54). On the other hand, providing false in-

[125] Here it is assumed that states with an attitude of openness are prone to have benign and defensive nuclear intentions. In the absence of crisis, this seems to be a fair assumption. Any offensive nuclear intentions are likely to raise tensions significantly, possibly to the extent that the state may face a (preventive) (nuclear) attack. From a security point of view, this is not likely to be a desired development for any state.

formation is not transparency, but plain disinformation. Hence, "faking" transparency is not an option.

Note that despite being unilateral in nature, transparency can still be negotiable. States or the international community can request or demand more openness in return for other considerations. They can encourage, cajole, threaten, or even horse-trade for increased transparency from the other side. Transparency may also evolve as a more or less inadvertent "spin-off" of certain state activities.[126] But in essence, transparency remains the decision of a single state ([P4], 60). Because there usually will be no specific formal agreements concerning unilateral acts of transparency, breaking-out is not generally relevant.

Even if transparency is formalized in a treaty, "verification" and a set of monitoring equipment should not automatically be expected as part of the deal. Typically, transparency does not involve monitoring equipment or negotiated schemes for monitoring. The more established transparency becomes, however, the more it is self-corroborating because there of the increasing number of channels of information that cross-check each other (Mitchell 2000, 189). As such, the insight and information acquired in during any appurtenant and formalized verification activities will also feed into, and expand, the existing pool of (international) knowledge about the nuclear intentions and activities of the state monitored.

With this feedback, initial levels of transparency may be effectively enhanced (stippled lines), as schematically presented in Figure 4.5.[127]

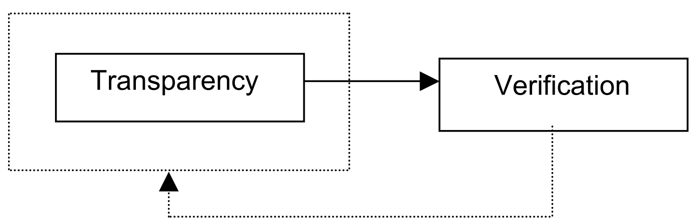

Figure 4.5: The interdependent and potentially self-reinforcing relationship between transparency and verification

Transparency may be viewed as small "peephole" made available to the international community into the priorities of states, revealing some of their practices and preferences. Through these vantage points, external actors may increase their general understanding of a nuclear programme. They may also become better equipped to negotiate later specified verification deals and goals (e.g. reductions in strategic nuclear arms). As such, the transparency–verification relationship is mutually interdependent, as well as potentially self-reinforcing.

126 Examples include increased international trade (e.g. adherence to the WTO), large international events (like the 2008 Olympic Games in China), or simply the development of information technology (in particular the Internet).

127 A prominent example of the interwoven relationship between transparency and verification is in the process denoted "International Audits" in Section 4.2.1.2. As part of the Additional Safeguards Protocol (International Atomic Energy Agency 1997), states are obliged to present comprehensive initial declarations of past and present nuclear activities, as well as of any nuclear facilities (Goldschmidt 1999, S–5).

Referring back to Figure 4.4, both transparency and verification could increase predictability and hence increase and contribute positively to stability. One factor working in its favour is that transparency, once well established, is difficult to reverse ([P4], 60). Fully established and total transparency is and will remain an ideal, however. After all, every nation has secrets that legitimately should not be released to the world. This is probably why leading nuclear-weapon states do not feel obligated to pursue transparency, despite strong international calls and treaty commitments.

The importance the international community attaches to nuclear transparency was highlighted at the 2000 Review Conference of the Nuclear Non-Proliferation Treaty. By consensus, the NPT states then agreed upon "Increased transparency by the nuclear-weapon States with regard to the nuclear weapons capabilities and the implementation of agreements pursuant to Article VI and as a voluntary confidence-building measure to support further progress on nuclear disarmament" (2000 Review Conference). This established the concept of transparency as a permanent element of nuclear diplomacy (Grand 2003, 35). Yet, the current political commitment to nuclear transparency is precariously low (Walker 2003, 15). If, in the longer term, greater nuclear disarmament is to become a common objective, these positions will need to change (Höhl et al. 2003, 47).

Transparency may be viewed as the opposite of secrecy ([P4], 60). Secrecy means deliberately hiding intents, capabilities, and actions; transparency means deliberately revealing them (Florini 2000, 13). Secrecy may well be justified from the perspective of national security and international non-proliferation obligations.[128] Releasing classified information will be unlawful and could potentially harm national and international security. Thus, increased transparency could be seen as making it easier for criminals and sub-national groups to divert fissile material unlawfully, if for instance details of the physical protection systems and quantities and qualities of fissile material at facilities were to be made available.

Openness could hence add to the nuclear terrorist threat, enabling non-state actors groups to acquire information relevant to their (planned) acts.[129] Proponents of particular transparency measures must therefore demonstrate that it will not (inadvertently) lead to the disclosure of useful information to would-be proliferators (Grand 2003, 37).

Transparency and secrecy, however, are not either/or conditions. As ideals, they represent two ends of a continuum, and two societal conditions that never may be fully accomplished. In practice, transparency and secrecy will have to operate in parallel. Especially weaker nuclear states, like China, have embraced nuclear ambiguity for its perceived security benefits. To these sta-

128 Nuclear weapon states have an obligation under the Nuclear Non-Proliferation Treaty not to disseminate proliferation-attractive or proliferation-encouraging information. For instance, in accordance with Article II of the NPT, "Each nuclear-weapon State Party to the Treaty undertakes not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly; and not in any way to assist, encourage, or induce any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices". The treaty text is available at http:// disarmament. un.org/wmd/npt/npttext.html (last accessed 30 October 2003).

129 Particularly sensitive information could for instance encompass quantities, and qualities of fissile material stored at specific installations, as well as the level and procedures for security and control.

tes, unintended openness may become particularly costly if opponents manage to identify weaknesses in their (limited) nuclear arsenals, war-plans, or (future) capabilities. Still, due to the perceived security benefits, even China has been pursuing a range of nuclear transparency options, hereunder clarification of its nuclear activities and acceptance of site visits (Bin 2003, 50).

In sum, transparency is based on voluntary measures. It permits outsiders to accumulate released data from a wide range of sources, over an extensive period of time, to build confidence that the behaviour of a country or a collection of countries is consistent with agreements and norms (Senazaki et al. 1997, 2–3). Ideally, such voluntary measures will generate increased confidence, hence reducing tensions and the perceived need for secrecy. Accordingly, there exist several interrelated incentives for increased transparency on all stocks of fissile material (based on Maerli 2002a, 8):

- to gain confidence in non-diversion;
- to maintain constructive security dialogues;
- to create the foundation for deeper cuts in nuclear arms;
- to raise awareness of international non-proliferation challenges;
- to identify the best and most sustainable options for nuclear security.

Greater transparency in the management of nuclear material and warheads would genuinely contribute to strengthening international security and reducing nuclear-related threats (Zarimpas 2003, 253). Hence, transparency has been, and will continue to be, an indispensable device for limiting the dangers posed by nuclear explosives (Walker 2003, 29).

4.2.1.2 The Seven Nuclear Husbandry Functions

It is common to consider “safeguards”, “verification”, and “transparency” as comprising *the* key nuclear security and arms control measures. As pointed out, however, these concepts may be vague, too general, and potentially misleading. They could encompass a variety of unrelated activities. Clarification of the concepts and specification of the tools applied (if any) for each of them is therefore both necessary and desirable to be able to meet contemporary fissile material security challenges. A set of specified and better defined functions in the spectrum of nuclear husbandry activities will therefore be identified in the following. These are ([P4], 61):

- domestic nuclear physical protection;
- domestic nuclear control/containment;
- domestic nuclear accounting;
- domestic nuclear auditing;

- international nuclear auditing;
- monitoring of international treaties and agreements;
- nuclear transparency.

These seven functions fit into the two broader categories of domestic and international husbandry, respectively, as illustrated in Table 4.3.

Table 4.3: The Seven Nuclear Husbandry Functions

Domestic				International		
Physical Protection	Control	Accounting	Auditing	Auditing	Treaty Monitoring	Transparency

(*From [P4], p.61*)

US "domestic safeguards" is split into its three respective functions of "physical protection", "containment and control" and "accounting". Physical protection measures may have the greatest immediate impact in reducing the immediate risk of theft. By contrast, material accounting can at best detect thefts after they have occurred. It does little to actually prevent thefts. Physical protection security upgrades are often less sensitive as they require less understanding of a facility's operations and are less technically complicated (Bukharin et al. 2000, 23).

Accounting, on the other hand, could be the only way to confirm that no thefts have occurred, and that the system of physical protection and control has performed as intended. Accounting could prove crucial in detecting and deterring thefts by insiders with knowledge of the weaknesses of a facility's security systems (Bukharin et al. 2000, 23).

"Domestic auditing" means monitoring adherence to domestic laws and regulations, not to international treaties, by internal revision. "International auditing", basically a more flexible and focused way of doing treaty monitoring, is still a novel feature in international arms control. Its evolving incarnation can be seen in the strengthened international safeguards system, as expressed in the "Model Protocol" (International Atomic Energy Agency 1997). The category of "Treaty monitoring" here simply encompasses NPT safeguards, i.e. what has been denoted "international" or "IAEA" safeguards above. As it is normally directed to an international audience, nuclear transparency is included amongst international nuclear husbandry functions.

By assessing the means applied, the adversaries to defeat (i.e. the type of hostility of the operational environment), and the potential obstacles that each of the nuclear security activities may encounter, it soon becomes clear that these Seven Nuclear Husbandry Functions are quite disparate ([P4], 64–70). Research paper [P4] offers an attempt to quantify of the differences. Each attribute ("Means", "Adversaries", and "Obstacles") is then given a (numerical) contribution score, according to its relevance for the function in question. For instance, locks and barriers are important means for physical protection and are given a high contribution score (+2). These means, however, play no role in nuclear transparency, so their appurtenant contribution score is consequently low (–2) ([P4], 65 and 69–70).

Likewise, a domestic system for nuclear accounting aims at deterring insiders from diverting fissile material. The system is, however, of much less importance for international treaty monitoring. Hence, in the first case the contribution score is set high (+2), and in the latter, low (–1). Similar argumentation may be introduced for the obstacles to the husbandry functions. The various activities may encounter different types of resistance, especially when they are initially implemented or when they are expanded ([P4], 67). Negative perceptions to change could, for instance, be a more constraining obstacle for nuclear transparency than for the instalment of domestic security measures in a domestic setting. Hence, a high contribution score in the first case and a low one for the latter.

Table 4.4: Overall linear correlation coefficients (r) for each of the Seven Nuclear Husbandry Functions versus the others, based on the relative contribution scores

	Domestic physical protection	Domestic containment and control	Domestic accounting	Domestic auditing	Internat. auditing	Treaty monitoring	Transparency
Domestic physical protection	1	0.66	0.30	0.51	–0.29	–0.37	–0.33
Domestic containment and control		1	0.84	0.50	–0.06	–0.11	–0.36
Domestic accounting			1	0.47	0.07	0.04	–0.23
Domestic auditing				1	–0.05	–0.27	–0.17
International auditing					1	0.73	–0.09
Treaty monitoring						1	0.17
Transparency							1

(*From Table 5 in [P4], p. 71*)

By combining all attributes, there are a total of 44 different relative contribution scores for each of the Seven Nuclear Husbandry Functions ([P4], 71). In this exercise, all contribution scores are weighted equally, regardless of whether they fall within the "Means", Adversaries" or "Obstacles" categories. The differences between the respective functions may then be explored by calculating Pearson linear coefficients for each nuclear husbandry function (see [P4], 69–73).[130] The findings are summarized in Table 4.4.

The correlation coefficient provides a measure of how interconnected one husbandry function is to another. The correlation coefficient, *r*, assumes a value from – 1 to + 1, where a value of $r = +1$ signifies perfect correlation. The two nuclear husbandry functions in question are then in other words identical. A correlation coefficient of $r = 0$ indicates that the two functions are orthogonal, and completely uncorrelated and dissimilar.[131] The resulting coefficients accentuate the dissimilarities of the respective functions.

The correlation analysis reveals that international treaty monitoring is indeed quite different from any of the domestic functions (P, C, A, or domestic auditing). These results should warn against the tendency for instance to insist that US domestic nuclear security means and procedures make the most sense for IAEA safeguards or treaty monitoring ([P4], 76; [P5], 9); a comparison of domestic and international nuclear auditing reveals more dissimilarities than similarities.

However, Table 4.4 also indicates several related features amongst the respective nuclear husbandry activities ([P4], 69). As may be expected, domestic physical protection, for instance, appears to be somewhat related to domestic containment and control, and both these functions seem again to be related to domestic accounting. Though the means applied differ, the implemental obstacles to overcome and the adversaries to defeat are probably quite similar for the three domestic MPC&A activities.

On the international arena, there is some correlation between international nuclear audits and traditional treaty monitoring. International auditing is strongly related to treaty monitoring, another type of international husbandry function. This makes sense, as the former could be viewed as basically a more comprehensive and aggressive form of the latter ([P4], 74). The potential adversary, the inspected state, is, moreover, the same. Hence, the strengthened safeguards system (future nuclear audits) should be based more on the traditional safeguards system – i.e. treaty monitoring – than on domestic auditing or domestic MPC&A. The shared attributes of treaty monitoring and (future) international nuclear auditing should be examined in detail, so that the international community can utilize what is already known about treaty monitoring for developing effective international nuclear auditing.

There is, however, a lack of correlation between transparency and any of the other six nuclear husbandry functions (Figure 4.6). Transparency is thus quite unique. Its features (in terms of what, when and where to reveal) will be up to the state itself, depending on the intentions behind the act of transparency ([P4], 75).

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130 Admittedly, the contribution scores and numerical figures chosen will be subjective. Inputs in the correlation matrixes are based on (and coloured by) the experiences of the authors of the research paper [P4]. As such, the assessments will carry with it inherent and unfortunate biases. Accordingly, others are encouraged to perform similar exercises, with their preferred inputs. Given that the inputs are fairly reasonable, this, however, should not alter the results significantly: Minor changes to the scores show to have little effect on the overall findings ([P4], 72).

131 A value of $r = -1$ indicate that the functions are completely anti-correlated, e.g. like the two series (–2, –1, 0, 1, 2) and (2, 1, 0, –1, –2). One series has a large number when the other has a low, and vice versa.

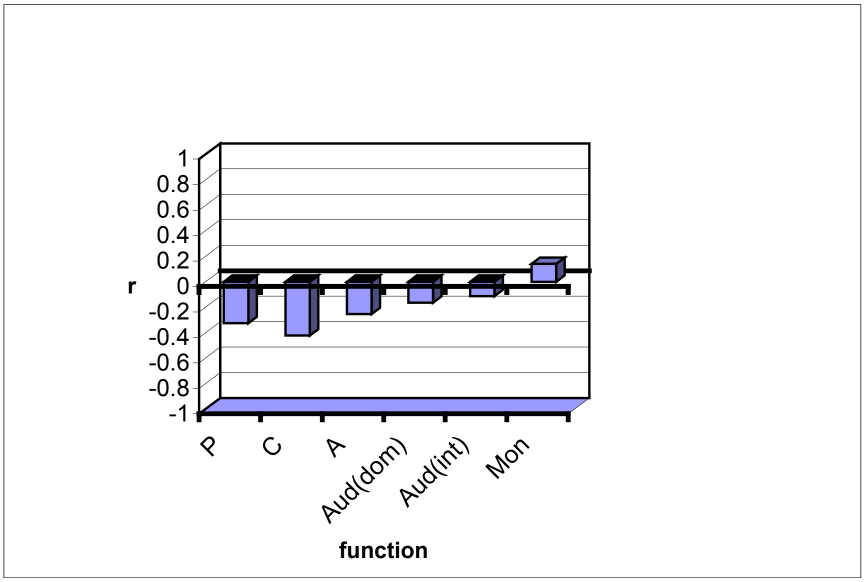

Figure 4.6: Weak correlation coefficients for transparency versus the other six Nuclear Husbandry Functions

However, once the political decision to proceed has been made, transparency is likely to be fairly easily implemented. It requires minimal cost and no or limited technology, in stark contrast to verification, and to domestic and international safeguards. For transparency, readily available information distribution channels can be used. Possible positive trade-offs include international recognition, an informed citizenry and neighbours, and potentially a more stable nuclear international security environment. Accordingly, transparency may be an important supporting element to practical nuclear arms control.[132]

4.2.2 Optimizing Nuclear Husbandry

These findings have several implications for nuclear security and practical measures for nuclear arms control. One is that it is particularly important not to confuse and mix international and domestic nuclear husbandry functions. While this may be tempting from an economic, and perhaps even a habitual, point of view, it should be avoided. International and domestic nuclear husbandry are distinctly dissimilar. The means to be applied, the adversaries to meet, and the obstacles to overcome all differ considerably ([P4], 76, [P5], 9).

There may, moreover, be a range of practical constraints. As indicated, nuclear husbandry functions can encounter various types of resistance. The extent of the political, military, technical, diplomatic, or bureaucratic opposi-

[132] Transparency may become a particularly powerful and imperative in the context of unilateral and non-verified nuclear arms control ([P4], 75), as well as for bilateral nuclear security cooperation.

tion will usually depend on the amount of change, resources, and inherent risks involved ([P4], 69). The resistance can be strategic in nature, where changes are opposed due to security concerns, or of a more subtle organizational (structural), or a psychological/cultural (individual) nature.

As a result, even if and when (attributable) differences are fully appreciated, there can be substantial problems in transferring domestic MPC&A hardware, methods, and know-how between different (international) settings. Different countries have very different cultures of physical protection and safeguards (Bunn 1999, 3). Despite their expertise, US nuclear security consultants could face profound challenges when assisting in the upgrading of Russian domestic MPC&A systems.[133] The US Department of Energy alone now administers in Russia more than a dozen distinct non-proliferation programmes designed to reduce the risk of nuclear material or expertise falling into the hands of terrorist organizations and states ([P6], 39).[134]

In its MPC&A assistance to Russia, the USA has been very slow to appreciate the variety of different nuclear custodians in Russia (Potter and Wehling 2001, 187).[135] There is, moreover, little understanding of Russian organizational structure, peculiarities, and decision-making processes. Assisting the Russians in strengthening their MPC&A can neither be effective, nor sustainable, without a thorough understanding of these problems (Potter and Wehling 2001, 183; Bunn 2000b, 84).

Cultural differences in attitudes about security may hence create serious impediments (Bunn 2000b, 150). Transparency in particular is likely to be deeply affected by cultural beliefs and attitudes towards openness. In situations where the nature and advantages of increased openness are not properly understood, the anticipated benefits will be underestimated ([P5], 69). This is likely to result in less interest and thus less emphasis on implementing or expanding certain nuclear husbandry functions. National pride, legal restrictions or bureaucratic inertia can also be serious obstacles to nuclear security activities (Smith 2003, 16).

The latter is often seen as an insistence on over-classifying documents, data, and perceived secrets (Albright 2000, 60; Hafemeister 2003,110). Traditions of secrecy may be another challenge. As Liddell Hart wryly observes, “the only thing harder than getting a new idea into the military mind is to get an old idea out” (quoted by Smith 2003, 23). Secrecy can hence be detrimental to scientific and technical progress. It can also undermine public confidence in government by limiting citizens’ ability to scrutinize their government’s action or be fully informed on public issues (Albright 2000, 60). A more general consideration is that democracy requires an informed citizenry, and secrecy undermines this goal (see Section 3.1).

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133 New settings often present unexpected technical problems; workforce conflicts; novel kinds of adversaries; unique issues of licensing, environmental surroundings, exports control, tariffs, and liability; and other obstacles to the practical implementation of MPC&A systems (Potter and Bukharin 2001; Baker and Cutler 2001, 25; Bunn 2000, 81–82).

134 For an overview and discussion of the programmes, see e.g. (Hoehn and Fieck 2001; Spector 2001; and Roston and Smigielski 2003).

135 After nearly a decade of cooperation (in 2000), both the Department of Defense and Department of Energy had for instance very incomplete information on the number and location of non-MINATOM sites possessing direct-use material.

4.2.3 Summary Answer to Principal Research Question [Q2]

> **[Q2]:** *"Is there an optimum way of protecting fissile material from falling into terrorist hands? What role – if any – do transparency and non-intrusive verification play in this regard?"*

The past decade has shown some remarkable and unprecedented successes in the field of practical, cooperative nuclear arms control. Scientists whom very few believed would ever cooperate have worked jointly to secure stocks of fissile material to reduce Cold War nuclear threats. But a range of difficulties, some of which seem to emanate from a lack of conceptual understanding, hamper ongoing efforts to optimize nuclear security.

For any corroborative nuclear security activities (e.g. the United States' MPC&A assistance to Russia), a range of practical and political impediments will arise. A fundamental prerequisite for avoiding these pitfalls is to have a clear understanding of the goals, implications and limitations of the instigated activities. Domestic and international nuclear security activities should not for instance be uncritically mixed.

Seven Nuclear Husbandry Functions that span the spectrum of current and future nuclear security activities have been identified. These are: Domestic nuclear physical protection, domestic nuclear control/containment, domestic nuclear accounting, domestic nuclear auditing, international nuclear auditing, monitoring of international treaties and agreements, and, finally, nuclear transparency. Some of these are related, however, as they are distinct, discriminatory, and operate with little overlap, less confusion should arise, both on the conceptual as well as on the practical level.

Nuclear transparency is a novel and under-utilized husbandry function. Its potential may not have been fully exploited. Transparency may not only lessen any offensive nuclear tensions amongst states. Ideally, it could lay the foundation for and advance international nuclear security cooperation, and possibly develop the (global) norms needed for responsible nuclear husbandry and non-intrusive verification of fissile material. Hence, it is a precondition for reducing the threat of nuclear terrorism.

Transparency normally precedes verification. Without nuclear transparency, verification can hardly be achieved (Arbman 2003, 116). The means and mechanisms at work, however, are quite different, as are their objectives. Mixing transparency and verification in practical nuclear arms control could mean that their respective features will not be effectively recognized, implemented, or nurtured. Transparency, using existing channels of information, may be easily instigated, and quite hard to reverse, once the political openings have been established. Verification, on its part, normally requires carefully negotiated procedures, agreements, and equipment that monitor (only) data acceptable to all parties involved. Once implemented, however, verification will feed into, and expand, existing levels of transparency.

At first glance, transparency and security may seem to be incompatible and conflicting interests. Openness may be at odds with the to need to maintain ambiguity in military strength. Each nation has, moreover, both a right and an obligation to protect classified and sensitive information. Some of the objections to transparency are hence well founded and justified. Others, however, may be outdated and exaggerated. Transparency and secrecy may very well work in tandem, as none of them are either/or conditions. As a general rule, transparency measures should not release information that could be damaging to the very non-proliferation interests it seeks to promote.

Keeping a massive shroud of secrecy on stocks of fissile material can only maintain and exacerbate current uncertainties in fissile material holdings and protection. This could increase the risk of diversion and, accordingly, elevate the nuclear terrorism threat. It is not beneficial to the security of any state.

4.3 Nuclear Husbandry in Practice

Having explored the underlying concepts for improving security on stocks of fissile material, the time has come to look at practical ways to implement optimum nuclear husbandry, in particular nuclear transparency and non-intrusive verification. This section will thus address the third principal research question, [Q3],[136] based on research papers [P6], [P7], and [P8].

This section presents the results of a case-study assessment of nuclear transparency and non-intrusive verification on unirradiated Russian naval fuel. For this material, transparency has remained a particularly alien feature. The material is still kept completely outside international control, despite its proliferation attractiveness and possible applicability in crude nuclear explosive devices.

Possible schemes for enhanced openness while protecting sensitive information are presented and discussed. Related issue that will have to be addressed concern the foundation for such practical measures for nuclear arms control, and their limitations. What kinds of practical measurements are feasible, and who are the key actors involved? What kind of information on fresh naval fuel is justifiably withheld, from a security perspective? If it is successfully implemented, could lessons be drawn from naval fuel transparency and non-intrusive verification to other practical activities in nuclear arms control, and vice versa?

Latour's model on the rendering of science from Chapter 3 is used as a facilitating tool for introducing the novel discipline of non-intrusive verification on sensitive stocks of fissile material. Technical background information on Russian naval fuel is given in Appendix IV.

First, however, the rationale for choosing naval fuel as a case study is further explained. As will be seen, many of the challenges associated with fresh naval fuel go to the crux of contemporary fissile material protection and control issues.

[136] [Q3]: *"Within legitimate security constraints, what kinds of measures could be put in place to enhance the transparency and non-intrusive verification of stocks of sensitive fissile material?"*

4.3.1 Unirradiated Russian Naval Uranium Fuel as a Case Study

There are several reasons for using unirradiated, or fresh, Russian naval fuel as a case study. Firstly, the enrichment levels of naval fuel make it highly proliferation-attractive. Secondly, the fuel cycle, still shrouded in secrecy, involves a large portion of global HEU stockpiles. Thirdly, existing and possibly future arms control agreements do not fully meet the proliferation challenges posed by these fuel cycles.[137] Fourthly, R&D for non-intrusive nuclear verification may in general benefit from looking at new schemes and material, outside the traditional nuclear weapon stockpiles. And finally, naval fuel consumption is likely to decrease in the coming decades (Maerli 2002a, 26).[138] This, and the close working relation forged between different actors under the naval MPC&A security upgrades, could affect states' willingness to engage in naval fuel transparency and non-intrusive verification.

Directly or indirectly all of these factors will determine the future fissile material holdings by states, norms of fissile material transparency, and the level of (international) control and security of these stocks. As such, these aspects are of direct relevance for the prospects of nuclear terrorism, and will be briefly elaborated upon in the following.

4.3.1.1 Naval Fuel Security Challenges

Specific attributes make the naval fuel cycle potentially less proliferation-resistant than other uranium fuel cycles. To achieve increased efficiency and higher energy output while keeping naval cores compact, higher enrichment rates of HEU are used in the reactors ([P8], 14). The high enrichment and the low radioactivity levels of fresh naval fuel make the material highly proliferation-attractive.

As explained (Section 4.1.2.1.4), highly enriched uranium is the only material that allows the easy manufacture of a crude and reliable nuclear explosive device ([P1], 117; [P2], 733). In consequence, due to their high enrichment levels, the naval fuel cycles could constitute a back door to clandestine nuclear explosive capabilities, by states or by non-state actors.[139] Russian

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[137] In non-nuclear weapon states, institutionalized international control, i.e. international safeguards, is in place to limit possible diversion of any (potentially) weapons-useable material. However, these arrangements do not properly cover the naval fuel cycles ([P8], 16). International safeguards do not prohibit the non-explosive use of nuclear material, equipment or technology for a military purpose such as the propulsion of naval ship. The material can simply be withdrawn from international safeguards, evoking this formal exception. New guidelines and a new regime have been proposed to limit the potential impact of the current HEU loophole in the Non-Proliferation Treaty, so far without significant political support (see e.g. Moltz 1998).

[138] Overall US naval fuel requirements will be reduced mainly due to the introduction of lifetime reactor cores and a limited decline in the number of operating reactors. By 2020, with the successful launching of all the planned new SSNs with lifetime cores, the annual lifetime integrated naval HEU fuel consumption of U-235 for US attack submarines will be some 60% of the levels for the year 2000 (Bremer Maerli 2002b, 32). Russian naval HEU consumption will continue to decrease, due to the reduced operational status of and severe fleet reductions in the Northern Fleet. Throughout the 1990s, the Russian Navy has experienced significant cutbacks in personnel and material. From 1991 to 1998, the total number of ships in the Northern Fleet was more than halved (Hoenneland and Joergensen 1999, 41 and 181). Drastically reduced operational schemes and significant HEU savings resulted (Bremer Maerli 2002b, 34).

[139] Clearly, there could be production challenges, e.g. associated with the shaping the material into best geometries for nuclear explosives, removal of impurities and the possible need to covert uranium oxide to metal. These obstacles, however, could be manageable even for non-state actors (see Section 4.1.2.4.1).

naval fuel has been particularly exposed to thefts (see Appendix V). The enrichment levels of the fuel involved make such activities particularly worrisome.[140] Rough estimates indicate that with highly enriched uranium as few as 10 naval fuel assemblies could suffice to supply enough highly enriched uranium for a nuclear explosive (Bukharin and Potter 1995, 47).[141]

Sensitivity concerns and the strategic importance of nuclear submarines cause the nuclear-weapon states to maintain a high degree of secrecy around their nuclear naval operations. Very little is officially known about submarine nuclear-fuel stocks, nor current and future consumption needs of naval HEU (Maerli 2001d, 24).[142] Hence, large quantities of HEU are managed without the transparency needed to build confidence that they are safe and secure or to provide the foundation for deep, transparent, and irreversible nuclear arms reductions ([P8], 14).

The problem could be exaggerated by new naval HEU markets outside international control. The former Russian Ministry of Atomic Energy (MINATOM) has actively promoted extending the uses of the naval reactors for the purposes of providing electricity and heat to remote coastal communities (see e.g. Belyayev and Leontyev 2004, 18).[143] The reactors with HEU fuel will then be placed on floating barges and transported to coastal areas or possibly underground, e.g. in mines, to make energy available locally. For MINATOM the naval reactors could represent a new opportunity for Russian nuclear exports, and hence new revenues. For the international community, it could represent a new danger of nuclear proliferation (Maerli 2001b, 9).

Nor is control of material for naval propulsion likely to be included in a future Fissile Material Cut-Off Treaty (FMCT) (Maerli 2001c, 124, Miller 2003, 1). It is the firm expectation of Washington, for example, that an FMCT would prohibit the production of HEU, plutonium, and uranium-233 for nuclear explosives, but not prevent the use of HEU for non-explosive military uses such as naval reactors ([P8], 16). In consequence, yet another verification loophole may be created in a future FMCT. Mere concerns that opponents may continue to produce HEU for bombs under the cover of a naval fuel programme could limit the strength of and, consequently, political interest in the treaty.

Furthermore, there might be important and positive synergistic effects by looking at non-intrusive verification of naval fuel and on-going warhead dis-

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140 Because the difficulty of gaining access to this material is the major barrier to the spread of nuclear explosives, it has been proposed that material with high enrichment levels should be subjected to the same stringent security standards as nuclear weapons (Bunn 2000; Fetter 2003).

141 Here it is assumed that about 12 kg of weapons-grade uranium would be needed to produce an implosion-type nuclear device and that as much as 300 kg of U-235 is available in the reactor cores. Other sources indicate only half of this amount of U-235 in the cores (see Bremer Maerli et al. 1998, 18).

142 Open-source technical characteristics of fresh Russian naval fuel are presented in Appendix IV

143 As part of a massive government reorganization, Russian President Putin 9 March 2004 broke up the Russian Atomic Energy Ministry and reassigned its activities to other cabinet-level ministries (Nartker 2004, 1w). Under the new governmental structure, civilian nuclear activities will be handled by the Federal Atomic Energy Agency, a part of the newly created Industry and Energy Ministry. Military aspects of the former Atomic Energy Ministry have been transferred to the Defence Ministry.

mantlement verification in parallel.[144] The United States and Russia are engaged in a range of cooperative programmes to reduce the dangers of the excessive stocks of fissile material and to meet their disarmament obligations. Several of these activities call for measurement on material with compositions that are either considered classified or sensitive by at least one party.[145] An overarching problem for many of these activities revolves around identifying the material in a closed container such as either a warhead, a weapon component, or fissile material from a dismantled nuclear weapon (Office of Nonproliferation Research and Engineering 2001, 2). Both the USA and Russia view the information that could be revealed by measurements as extremely sensitive, and are committed to preventing its release to the other and to other parties (Pura 2000b, 4).

Hence, technical communities are now examining a variety of non-intrusive measurements on items with sensitive or classified properties, some of which may be applicable on unirradiated naval fuel. The underlying physics is well understood, but there are technical challenges involved in the need to protect and limit the data output while providing enough information to foster sufficient confidence in the results of the measurements ([P7], 21). Such cooperation is essential for improved nuclear husbandry, but it is progressing at a limited pace.

Finally, of the programmes the US Department of Energy administers in Russia, the joint physical security upgrades at Russian naval facilities have by far been the most successful. This is largely because of the flexible and stepwise working approach chosen and the cooperative working spirit and trust developed ([P6], 49). The progress made suggests that valuable lessons can be learnt from the US–Russian naval security upgrade programme, lessons that could improve and contribute to other nuclear husbandry activities ([P6], 48–49). The naval MP&A Program has, moreover, created a sound basis for an overall Russian HEU accounting exercise. The naval MPC&A may therefore act as a springboard to increased transparency and possibly future non-intrusive verification ([P6], 48).

4.3.2 Naval Fuel Transparency and Non-Intrusive Verification Foundations

The situation of trust and cooperation built through the MPC & A Program has played a crucial role in opening up the Russian nuclear complex (Bukharin et al. 2000, 68). It has allowed relationships to be built, laying the

144 The positive effects of looking at different non-intrusive verification schemes in parallel have been stressed by Pura 2000a, among others. Experience from naval fuel transparency and non-intrusive verification may provide important feedback for improved HEU weapons-dismantling activities and third-party control of weapons-useable fissile material as well. The attribute approach, one of the methods for proposed for non-intrusive verification of naval fuel (Section 4.3.3.2.1), is an important part of the trilateral initiative between the USA, Russia and the International Atomic Energy Agency for control of fissile material declared excess to national security needs.

145 Bilateral (US–Russian) initiatives include the Highly Enriched Uranium (HEU) Purchase Agreement, the Plutonium Production Reactor Agreement (PPRA), and verification activities at the plutonium storage at Mayak. Fissile materials declared in excess to US and Russian security needs are controlled by the International Atomic Energy Agency (IAEA), under the so-called "Trilateral Initiative".

foundations for a wide range of other cooperative activities to promote nuclear security. With the Latour model from Chapter 3 and the cooperative naval MPC&A activities on fresh Russian naval fuel as starting points, this section explores the practical foundation needed for increased transparency and non-intrusive verification on stocks of naval fuel.[146]

4.3.2.1 Establishing Common Ground

Whereas a culture crash between American and Russian actors has slowed down other cooperative projects on nuclear safety in Northwest Russia (Hoenneland 2003, 91), the MPC&A Program for the Russian Navy has made remarkable progress in reducing the vulnerability of large amounts of highly enriched uranium to theft and diversion, at relatively modest cost (Bukharin et al. 2000, 60). For the fresh naval fuel security upgrades the Russian and US sides shared interests and incentives from the very beginning.[147] This facilitated cooperation even into new and highly sensitive areas. As reflected by the naval MPC&A upgrades, where there is a desire for cooperation, and a wish to make it habitual and strong, transparency then follows.

Moreover, the MPC&A activities on fresh naval fuel, and later on nuclear warheads, of the Russian Navy offered a flexible approach to work inspections in a cooperative atmosphere with mutual exchange of information. Instead of a strict on-site inspection regime, a cooperative and less adversarial approach was chosen ([P6], 42). US and Russian MPC&A experts would sit down together and jointly assess the situation before and after the security upgrades. What the US team might lose in terms of insight through formal inspections it was likely to gain through a voluntary and informal flow of information ([P6], 43).

Initially, a flat, pragmatic, and highly efficient organizational structure was chosen for the naval upgrades. Work was conducted in stages, with a step-by-step approach and one facility at the time ([P6], 42). Communication was free among all parties involved. US team members could personally contact high-level counterparts in the Russian Navy. This drastically increased interaction and allowed for quick problem-solving when needed ([P6], 42). Both sides, moreover, maintained stable teams with limited personnel changes (Bukharin et al. 2000, 59 and 61).

4.3.2.2 Forming Alliances

The stepwise, flexible working approach chosen for the naval upgrades and the continuity in the working teams soon ensured close working ties between the actors. In the words of Latour (Section 3.4.3), alliances were built. These alliances, which included high-ranking officers of the Northern Fleet, proved instrumental for the success of the programme ([P6], 46). This partnership eased interactions with bureaucrats and military opponents of the collaboration. Russian evaluations tend to be time consuming, and a large number of agencies are involved in decision-making (Maerli 2003f, 155). The alliances

146 A related set of criteria may be found in Shields and Potter 1997, 386–405.

147 Several thefts of naval HEU fuel concerned the Northern Fleet (see Appendix V). Americans, on their behalf, were eager to limit the diversion of any proliferation-attractive material ([P6], 42).

also created an important vehicle for communication with different "Power Ministries" of the Russian Federation ([P6], 46).[148] These ministries had the potential for severe interference in cooperative nuclear security activities. The impact of their policies and priorities in this regard should not be underestimated (Bukharin 2003, 139).

The direct contact established between foreigners and Russian officers was also important in other ways. The group of Russian officers now stands forth more clearly in society as a separate political interest group (Hoenneland and Joergensen 1999, 20). They have to a larger extent become involved in politics in order to ensure the autonomy and decision-making authority of the defence sector. This is new, and could change ways of military behaviour and attitudes, also when it comes to practical nuclear arms control measures.

For instance, it was the officers of the Northern Fleet who in the mid-1990s acknowledged that they had a security problem and no or very limited means to fix it. The then commander-in-chief of the Russian Navy, Admiral Gromov requested assistance and cooperation between the Navy, the Moscow-based Kurchatov Institute, and possibly the United States, on upgrades for naval fuel storage and handling (Shmelev et al. 1998). This created the foundation for successful nuclear security cooperation. And it was initiated amongst a set of actors whom very few would have thought would ever cooperate, just a few years earlier.

This forming of alliances required a profoundly new level of openness, with access to and insight into more or less secret military objects. Other factors working in parallel to erode Russian military norms of secrecy include the increased (local) civilian influence on the Northern Fleet due to economic hardship (Hoenneland and Joergensen 1999, 163),[149] as well as international nuclear clean-up efforts.[150]

4.3.2.3 Mobilizing the Means

Cultural differences between actors on the Russian side also played a role for the success of the naval MPC&A Program ([P6], 46). The Northern Fleet quite early acknowledged an internal security problem and evinced a genuine interest in fixing it. For the naval security upgrades, this was probably paramount for avoiding many of the practical, structural and political impediments that hampered other parts of the cooperative security assistance.

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148 "Power Ministries" is a widely used expression referring to Russian defence and security agencies. Apart from the Ministry of Defence, the following agencies are normally included in this categorization: the Ministry of Internal Affairs (MVD), the Federal Security Service (FSB), the Federal Intelligence Service (SVR), the Federal Government Communication and Information Agency (FAPSI), the Federal Protection Services (FSO), the Ministry of Internal Situations (MChS), the Federal Border Service (Hoenneland and Joergensen 1999, 45).

149 When the impoverished Northern Fleet became heavily indebted both to its supporting industry and to other regional enterprises on whose services it is dependent, efforts were made to convert parts of the nuclear (submarine) industry to embark on the production of civilian consumer goods. However, while it may have created new incentives for openness, the success of such endeavours has been very limited (Hoenneland and Joergensen 1999, 125–132).

150 The magnitude of the environmental crisis in the wash of the nuclear activities of the Northern Fleet makes it unlikely that Russia will ever able to deal with the problems alone. This could forge new openness as deemed necessary by international contributors and donors when they stand ready to render support (see Section A.7.2 in Appendix VII).

MINATOM, in contrast, tended to put less emphasis on the insider threat and regarded MPC&A deficiencies as primarily an economic problem.[151] Accordingly, international expertise and cooperation easily became secondary to obtaining domestic funding for upgrades ([P6], 46). To use Latour, MINATOM's willingness, or ability, to explore opportunities and thus potentials for *mobilization* by assessing new means, methods, and non-traditional cooperative partners, was low compared with that of the Northern Fleet.

When dealing with the Russian Navy, the working approach of the naval MPC&A upgrades has indicated a highly efficient way of solving access problems and achieving important and concrete results at sensitive facilities ([P6], 48). Russian Naval MPC&A can therefore provide a useful source of working methods and approaches that might be fruitful at other sensitive facilities in the Russian nuclear weapon complex.

An integrated approach to international nuclear security cooperation is needed (Hafemeister 2003, 111). Currently, however, such unusual programme approaches are not held up to broad scrutiny, except on a piecemeal or even accidental basis, since there is no regular discussion of policy implementation standards (Gottemoeller 2001, 32).

4.3.2.4 Implementing Change

To achieve long-term nuclear security, ingrained habits, ways of thinking, and priorities need to change – all the way from the presidential level, down to the individual actors handling nuclear material (Bukharin et al. 2000, 27). Changes will have to come from the individuals who conclude that such changes are in their interests and in the interest of their organizations – as well as their countries.

To implement change, each of the loops of mobilization, alliance-building, autonomization and public representations need to be connected, to work together in what Latour denotes the "bloodstreams" of science. Technical, structural and political forces need to pull in the same direction, at the same period of time. Coordination may be challenging. However, once the relevant linkages have been established, the process may be hard to stop and difficult to reverse.

In fact, the diverse elements may be mutually reinforcing, as evidenced by the willingness on both the US and the Russian side to move forward to secure naval nuclear weapons once the unirradiated fresh fuel was protected (see Section 4.1.2.2.1). This advancement required political will, technical solutions, as well as organizational structures on both sides, ready to meet new requirements and implement factual changes.

Equivalent processes may be envisioned for HEU transparency and non-intrusive verification on the sensitive naval fuel cycle.

[151] MINATOM used to be the main agency representing the Russian Federation in bilateral and multilateral discussions on nuclear installations and nuclear waste (Hoenneland 2003, 86), prior to President Putins massive government reorganization March 2004 (see Footnote 143). Streamlining Russian bureaucracy could be a positive move, but concerns have been voiced that the resulting government structure could complicate practical U.S.-Russian nuclear non-proliferation activities (Nartker 2004, 1w). To ease bilateral nuclear safety and security cooperation in the Northern areas, Russia has also established a new organization, SevRao (the Northern Enterprise for Treatment of Nuclear Waste), a locally based agency under the former MINATOM (Bremer Maerli 2003f, 155). SevRao will operate in parallel to Nuklid, another entity with close ties to the former MINATOM.

4.3.3 Naval Fuel Transparency and Non-Intrusive Verification Alternatives

Experience indicates that an incremental approach is the best way to move forward throughout the implementation processes towards bilateral or trilateral verification (Section 4.3.2.1). One approach could be to use small gestures such as creating bilateral declarations as stepping-stones to more elaborate agreements.

Here, the prospects of increased naval transparency through declarations will be explored first. This presentation will be followed by a discussion of various possible schemes for non-intrusive fresh naval fuel verification.

4.3.3.1 Transparency Through Declarations

As seen in Section 4.2.1.1.3, transparency basically takes place as a unilateral act by the state itself, normally after careful considerations of the pros and cons to national security. As such, it may be orchestrated and even pinpointed to cover certain domestic aspects of nuclear activities, addressed to certain international recipient(s), for confidence-building purposes.

Transparency does not involve any technical means per se. Rather, it uses existing channels of information (like interviews, public statements, on-site visits) to present the desired message. The more substantial transparency, the better, as this may have a self-enforcing effect on the credibility of the information provided. At present there are no treaties that oblige nuclear weapon states to declare, directly limit or accept controls on their fissile material. Consequently, if properly introduced and nurtured, transparency in fissile material may create a strong foundation for nuclear security.

Declarations, one form of transparency, can have an important confidence-building aspect, as an indication of a state's good will. Stockpile declarations may be particularly important, as the size of the holdings of fissile material provides a ceiling for the number of nuclear explosives that could be produced, as well as a marker for future reductions. Declarations could make less probable any (state) diversion of fissile material for clandestine production of nuclear explosives ([P7], 21; [P8], 17).

Such declarations could be part of bilateral or multilateral agreements on data exchanges on the aggregate stockpiles of fissile material, based on existing commitments of transparency, or they could be arranged under special agreements on naval information exchange ([P8], 17).[152] One option is a phased approach, where there is a movement towards more comprehensive exchange of information as mutual confidence increases (Fetter 2003, 136). As a minimum, voluntary state transparency on fresh naval fuel could include regular declarations of the following:[153]

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[152] Formalized agreements already exist for some fissile material stockpile declarations. One example is the guidelines agreed to by the five declared nuclear-weapon states under the NPT, together with Belgium, Germany, Japan and Switzerland, to increase transparency in the management of civilian plutonium by publishing annual statements of each country's holdings of civilian plutonium. In 1998, the IAEA published its Guidelines for the Management of Plutonium (INFCIR/549).

[153] For a somewhat related set of recommendations for nuclear warhead declarations, see Fetter 1999, 4–7.

- current domestic quantities of fresh HEU dedicated to naval propulsion;.
- national estimates of future naval HEU needs;
- fresh naval fuel, if any, withdrawn from military stockpiles and put under international control. ([P7], 21).

This approach would allow for the provision of information on the total quantities of HEU dedicated to naval propulsion, while protecting any detailed and possibly sensitive information regarding the fuel and reactor operations.

Due to the large uncertainties in the current quantities of stocks of fissile material, comprehensive initial declarations are particularly important. States may also be willing to declare quantities of spent naval fuel generated through naval propulsion, or possibly their naval HEU production history. If so, this could allow for comparisons of stocks of fresh and spent fuel, to substantiate declarations.

Early declarations, even those of a very general nature, could build confidence as well as encouraging governments to improve internal accounting systems (Fetter 2003, 150). Confidence in the declarations given could be further strengthened through non-intrusive verification throughout the naval fuel cycle ([P7], 20).[154] This aspect is further explored in the following.

4.3.3.2 Non-Intrusive Naval Fuel Verification

From the state perspective, acceptability, in the sense of what is tolerable to relevant domestic security environments, becomes the key issue. To the extent that any activities at all are to be performed on sensitive fissile material, this is therefore likely to be done in a non-adversarial, non-intrusive manner, using appropriate equipment and measurement procedures. As seen in Section 4.3.2, all interested parties also need to have a certain level of "ownership" in the (new) practical arms control process and activities.[155]

Once verification is deemed acceptable, the level of monitoring may rise with increased experiences and trust (Hafemeister 2003, 110). Experience has shown that the likelihood that an arms control technology will be accepted increases if the following criteria are taken into consideration (Gosnell 2000, 1–2):

- measurements cannot reveal classified information;
- simple technology is preferable to complex technology;
- familiar technology is preferable to unknown technology;

154 If states wish to establish agreed limits on stocks of fissile material, it would also be highly desirable to verify the accuracy and completeness of declarations (Fetter 2003, 146).

155 Reciprocity and increased openness with regard to the fuel practices of the US Navy may not only be desirable but also a prerequisite for genuine Russian openness on their naval fuel cycles.

- passive measurements are generally preferable to active interrogation measurements.

All measures should be as transparent as possible, hence the call for simplicity and familiarity ([P7], 22). In the simplest cases, radiation emitted from the object of interest can be measured directly, through passive measures. Active measurements collect and analyse the resultant radiation after, for example, neutron bombardment. However, such measures may be overly intrusive, and that would violate the chief principle of arms control verification: Not to reveal any classified information. Current efforts to protect classified information include carrying out the radiation measurements behind information barriers, normally in combination with a set of acceptable attributes; and describing, to the extent possible and desirable, the objects in question.

4.3.3.2.1 Naval Attributes, Templates, Tagging, Seals and Tags

Limited gamma emissions, a low neutron background and ubiquitous uranium presence in all background radiation, masking weak signals, and the preference for passive measurement techniques – all these challenge the identification of appropriate HEU verification techniques ([P7], 21).[156] Self-shielding of fuel assemblies could further complicate the detection and measurements of gamma rays.[157]

However, operational schemes for international non-intrusive HEU verification have already been put in place (see e.g. Bieniawski et al. 2000; Ucan 2000).[158] A set of similar non-intrusive verification measures may be introduced on the sensitive naval fuel. Possible measures include naval fuel attributes, naval fuel templates, naval fuel tagging, and tags and seals on containers for fresh naval fuel transports.

To protect classified information and to meet the criteria for acceptability for practical arms control measures, all measurements should be performed externally, on the fresh-fuel transportation containers, not directly on the fuel. For gamma detection, the signature radiation must therefore be sufficiently penetrating to escape through both the fuel cladding and the container wall. Table 4.7 summarizes the pros and cons of the possible measures.

Various naval attributes (like isotopic ratio, threshold mass, possibly uranium metal, and contaminants) may be identified with a set of passive gamma-spectroscopy techniques. This, however, will depend on stringent uses of information barriers, as the measurements may be overly intrusive ([P7], 23).[159] Moreover, if the attribute approach is chosen for non-intrusive

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[156] Generally, HEU measurements are likely to be more challenging than measurements on weapons-grade plutonium. Naval fuel with lower enrichment levels is, however, likely to be more detectable than HEU emanating from weapons, due to the higher presence of the isotope U-238, with more penetrating gamma rays.

[157] Similarly, calculations of organ doses from external gamma radiation must take into account the shielding effect of the body (Stranden 1979, 926).

[158] Of particular interest is the US–Russian HEU deal. According to the 1995 HEU "Megatons to Megawatt" deal, 500 tons of Russian highly enriched uranium will be downblended and used in commercial US power-reactors. Transparency and non-intrusive verification are a prerequisite for successful implementation.

[159] To protect sensitive information, an automated system could here be used to measure the attributes and produce a simple "yes" or "no" to the question "Does the object display the agreed set of attributes?" (Fetter 2003, 147). An attribute measurement system with the successful use of information barriers was used on classified nuclear material and shown to a Russian audience by US scientists in August 2000. See Avens 2001, 15.

verification, all parties involved should devise the naval fuel attributes jointly, together with proper measurement and inspection procedures, which will have to be negotiated and formalized.

Table 4.7: Different non-intrusive verification techniques for naval fuel

	Pros	Cons	Possibly in combination with	Remarks
Attributes	Passive measurements; fairly well-known concept	May be too intrusive. A set of measurable attributes is needed to gain confidence. Hard to measure HEU directly	Tagging: presence of high-energy isotopes a distinct attribute	Relies on information barriers and high-resolution gamma-ray spectroscopy
Templates	Passive measurements No agreed values for measured characteristics Fairly robust and easily operated system, once installed	A wide variation of fuel enrichment levels and fuel shapes may require multiple sets of templates The need for authentication requires additional schemes for protection of equipment during storage	Tagging: presence of high-energy isotopes eases the identification and comparisons	Relies on information barriers and high-resolution gamma-ray spectroscopy
U-232 Tagging	Unique U-235 identifier	Needs to be introduced in HEU sample Resulting and highly penetrating gamma ray not unique to U-232	Templates and attributes	Isotope does not occur naturally. Traces will be found in all reprocessed uranium fuel.
Tags and Seals	Fairly easy to implement, no need for information barriers	May provide a false sense of security; heavily dependent on procedural solutions and surrounding hostility	All the above	More a supplement than a stand-alone element.

(*From [P7], 24*)

Another approach could be to perform and compare measurements on naval fuel with known data for reference items. Here output data from the gamma spectroscopy is measured up to that of a set of naval fuel templates. The wide range of enrichment levels and different fuel designs may, however, require a disproportionately huge number of fuel templates. This is likely to complicate measurements, and, as with the attribute approach, a trusted information barrier is required for the comparisons ([P7], 24).

Tracking the fresh fuel by means of chemical tags – e.g. fuel contaminants with strong radiation signatures – is another option, either by adding isotopes or by using contaminants already present. A prime candidate in this regard is the isotope U-232. The 2614-keV gamma rays associated with decay of this isotope are very penetrating because its attenuation is near minimum at this energy (Lemley et al. 1999, 2). The isotope is a reliable U-235 indicator.[160] However, the fact that the most penetrating gamma radiation is not unique to the isotope U-232 complicates measurement set-ups. Its presence alone may not mean that the uranium is highly enriched. More elaborate, yet practically feasible, measurement schemes with parallel detection of different isotopes with different gamma ray energies are hence needed for confirmatory verification of shielded HEU (Gosnell 2000, 5).

Tamper-indicating devices like seals and tags on naval fuel transport containers may also support verification and control of fresh naval fuel. These may ensure a literally closed fresh naval fuel cycle, from the point when the transport container leaves the naval fuel production facilities, and to its destination in a naval reactor.[161] The effectiveness of a tags-and-seal regime, however, will depend upon the appurtenant inspectoral procedures and the degree of surrounding hostility (Johnston 2001).[162]

To optimize non-intrusive verification of naval fuel, more R&D and increased information-sharing are needed in several areas ([P7], 25).[163] Problems in the practical implementation of the proposed non-intrusive verification schemes should also be anticipated ([P7], 25). There are several "real-world constraints" to overcome. These include, apart from the obvious issues of classification and sensitivity, the possible impact on operational activities at the naval bases and the need for new working procedures.

4.3.4 Summary Answer to Principal Research Question [Q3]

> **[Q3]:** *"Within legitimate security constraints, what kinds of measures could be put in place to enhance the transparency and non-intrusive verification of stocks of sensitive fissile material?"*

For practical arms control measures, a cooperative approach, where all parties involved share common goals and intentions, in a non-adversarial set-

160 During the enrichment process, the U-232 is preferentially swept into the light isotope fraction that becomes HEU, and minuscule amounts get into the depleted uranium. Therefore, the presence of U-232 in a uranium sample is consistent with that uranium being U-235. But unfortunately, the most distinctive gamma emission associated with its decay series is not unique. U-232 and Th-232 have a common daughter (Th-228), and their decay schemes are identical from that point on. Consequently, thorium could be placed in the container in sufficient quantities to spoof verification measurements.

161 This would require validation of the integrity of the tags and seals at designated checkpoints throughout the fuel transport cycle. Once the fuel is introduced into the naval reactors, tracking could end as the radiation levels will make the fuel self-protective after the first chain reactions have been initiated in the submarine or icebreaker reactor cores. Any attempt then to divert the material for nuclear explosive purposes would then not only be very difficult, but highly dangerous as well.

162 A tamper-indicating system on fresh naval fuel transportation containers is fairly easy to piece together, at least in theory. In practice, however, the limitations and fallibility of tamper detection tags and seals should be taken into account when designing the systems. See Johnston 2001.

163 To avoid spoofing, or suspicion of spoofing, measurement procedures and techniques should be developed carefully and jointly by all interested parties. This is likely to require more information on fresh Russian naval fuel is required in order to determine the best attributes and tags for fuel identification and control. More information is, moreover, needed on the transportation containers used for fresh naval fuel, to permit best possible external gamma-ray attenuation estimates and optimum uses of passive detectors in combination with information barriers.

ting, has given the best results by far. What different actors might lose in terms of insight through formal inspections they are likely to gain through a voluntary and informal flow of information. This, however, would require an appreciation of the benefits associated with transparency, and an understanding of the disadvantages associated with continued secrecy.

After a decade of cooperation, less than half of the proliferation-attractive material in Russia has been secured with international assistance. This lack of progress maintains the risk of diversion and, accordingly, raises the threat of nuclear terrorism. The HEU stocks are managed with very little of the transparency needed to build confidence that they are safe and secure, or to provide the foundation for deep, transparent, and irreversible reductions in nuclear arms. To improve nuclear security, options for increased transparency and non-intrusive verification of proliferation-attractive material should be further explored.

Declarations of quantities of HEU destined for naval propulsion could be a starting point for increased transparency and hence more credible and accurate estimates of naval HEU stocks, consumption, and future needs. Confidence in such declarations could later be substantiated through non-intrusive verification. A set of fairly simple and technically available non-intrusive verification measures for naval fuel cycles is available without compromising national security needs and legislation. Most promising appears to be the attribute approach, possibly coupled with naval fuel tagging (U-232).

If implemented, such measures could raise confidence that naval fuel is not being diverted for the purpose of producing nuclear explosives. It could, moreover, help establish an international transparency norm for naval fuel cycles and other stocks of sensitive fissile material, and hence to reduce the threat of nuclear terrorism.

Chapter 5: Conclusion and Implications

In three sections, this concluding chapter discusses implications of the research findings for nuclear terrorism prevention, nuclear husbandry, and nuclear terrorism risk assessments. The direct repercussions for countermeasures against nuclear terrorism are presented, and a set of consequential recommendations for practical nuclear arms control are offered. The chapter ends with some considerations on nuclear terrorism risk analysis and model development.

5.1 Nuclear Terrorism Prevention

If, as Falkenrath argues (Section 3.1), nuclear terrorism is to be put in the category of first-order national security challenges, this raises serious questions about what can and should be done about the threat of nuclear terrorism. Reducing vulnerability by protecting particular or possible targets is neither prudent nor desirable.

Yet, as Dhanapala stresses (Section 3.1) a purely reactive posture is equally unsatisfactory. In the fight against nuclear terrorism, governments could hence chose measures to make the threat less prominent; they could create operational capabilities that might give them a better chance of detecting and defeating plots in the making; or they could put in place structures to minimize the consequences of a nuclear terrorist attack.

Terrorism countermeasures have traditionally included political governance, socio-economic measures, communications and educational efforts, military interventions, judicial and legal measures, and law-enforcement and intelligence activity (Schmid 2003a, 22–27).[164]

In the USA, measures against terrorism have been put together under the rubric of "Homeland Security", whose strategic objectives (in order of priority) are to: Prevent terrorist attacks within the United States; reduce US vulnerability to terrorism; and minimize the damage and recover from attacks that do occur (United States Office of Homeland Security 2002, vii). Such measures are all likely to play a role, small or large, in fighting future acts of terrorism. However, their use, efficiency and costs will differ significantly. The respective countermeasures must be scrutinized and prioritised accordingly.

Different countermeasures against nuclear terrorism can be viewed as different lines of defence. The first line of defence will then be security meas-

[164] To identify and classify preventive and counter-terrorist measures, the Terrorism Prevention Branch of the United Nations Office on Drugs and Crime has developed a set of eight categories from a "Toolbox of Measures to Prevent and Suppress Terrorism". A detailed summary description of these may be found in Schmid 2003a, 22–27.

ures installed at facilities containing fissile material, in order to prevent unlawful diversion. In March 2002, the IAEA Board of Governors endorsed an action plan designed to upgrade worldwide protection against acts of terrorism involving nuclear and other radioactive material. In approving the plan, the Board recognized that the first line of defence against nuclear terrorism was the strong physical protection of nuclear facilities and material (the International Atomic Energy Agency 2002a).[165]

The second line of defence could be border controls, detection systems at busy traffic junctures, and intelligence and public surveillance. Nuclear terrorism emergency preparedness measures and response (see Appendix VII, Section A.7.7) to mitigate effects of any attacks may be viewed as the third line of defence.

Now, the risk of nuclear terrorism would be drastically reduced if the perpetrators were unable to smuggle the nuclear explosive into the target country due to a rigorous second line of defence. The probability of a successful interception would depend on the level and sophistication of the (technical) border control and terrorists' own skills.[166] However, once the fissile material leaves the facility of origin, all subsequent control and countermeasures become secondary.

Not only will the number of locations, means of transportation and persons to control increase dramatically: Finding the infamous needle in the haystack, in this case unirradiated fissile material, may be extremely hard, as the radiation signatures of such material are weak and the quantities needed for a workable nuclear device are limited. In reality, efforts to detect and interdict nuclear smugglers are extremely unlikely to reduce the likelihood anywhere close to zero (Allison 1995, 69). The probability of an undetected transfer could be high.

Even heightened vigilance and high-tech forensics are not enough to deter all would-be nuclear smugglers (Vogel 2002, 952). Current domestic capabilities to quickly determine who exploded a nuclear device and where the fissile material originated from are modest (Board 2004, 1w). Due to its potentially dissuading effects, as perpetrators may face swift identification and retaliation, calls have been made for launching new US programs of so-called nuclear attribution or post-event forensics (Committee on Science and Technology for Countering Terrorism, 2002, 60). Officials hope that if terrorists know that a bomb can be traced, they will be less likely to use one. However, as seen in Section 2.1, terrorists are not easily deterred.

[165] The plan covers eight areas: physical protection of nuclear material and nuclear facilities; detection of malicious activities (such as illicit trafficking) involving nuclear and other radioactive material; strengthening of state systems for nuclear material accountancy and control; security of radioactive sources; the assessment of safety- and security-related vulnerabilities at nuclear facilities; response to malicious acts or threats thereof; the adherence to international agreements and guidelines; and enhancement of programme coordination and information management for matters relating to nuclear security (International Atomic Energy Agency 2002a).

[166] Potential terrorists may try to conceal their explosive devices. In October 2003, recipes for an "invincible" bomb, i.e. a bomb that could pass through airport security and x-raying undetected, were revealed (NTB 2003, 6). The use of conducting fluids instead of electrical cords for electric transfers was one of the features of such a device.

Furthermore, public surveillance, intelligence, and sting operations have other inherent limitations and uncertainties, making detection less likely.[167] With an emphasis on the second layer of defence, tighter societal control may result, and fundamental civil liberties could be at risk. US citizens can now be locked up for merely asserting that they are part of a terrorist plot.[168] The term "enemy combatants" has been introduced into the civilian sphere to detain perceived suspects without charges, keep them in secret and hold them incommunicado, denying them counsel *(New York Times* 2003). In the aftermath of a nuclear terrorist attack, basic human rights may be further compromised to manage the chaos and to track down the perpetrators.

From a medical point of view, interventions after a nuclear terrorist blast could provide of very limited remedy. The remedial effects of even a sturdy third layer of nuclear terrorism preparedness and emergency response is likely to be correspondingly low. While chemical and biological agents at least offer some opportunities for protection and medical remedy, there is very little defence against the pressure, heat and radiation from a nuclear detonation (Maerli 2003a).

Still, some analysts, most notably from the USA, maintain that civilian defences against nuclear terrorist attacks are feasible, and that the population should prepare on a daily basis (see e.g. Couch 2003). Structural chaos and breakdown in logistics and medical capacities will further limit the effects of any post-event prophylaxis. The possibilities for meaningful mitigation would be very minor. Accordingly, efforts to thwart nuclear terrorism should be aimed entirely at prevention (Levi 2003, 4).

Furthermore, a key factor for decisions about nuclear terrorism risk reduction is that the nature of the terrorist threat and the targets, weapons, and means of delivery will change over time, often in response to successful countermeasures. This dynamic relationship makes countermeasures focusing on the later steps in the nuclear terrorist chain, i.e. the second and third defensive lines, a particularly daring endeavour. Terrorists will adapt to the defences in place and seek the weakest spots known (Committee on Science and Technology for Countering Terrorism 2002, 36).

The closer that nuclear terrorists are to succeeding, the more arbitrary and uncertain any countermeasures put in place seem to become. Law-enforcement officers and others may therefore fight in vain, and against the clock, the further up potential terrorists are on the ladder of nuclear terrorism havoc.

From the assessment of the various steps on the nuclear terrorism pathway (see Section 4.1.2), it is clear that that the most effective countermeasures are those that focus on the early steps. Denying terrorists access to fissile material would disrupt any further nuclear terrorism plans. It would ef-

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167 In the words of Stephen Lander, former director of M15, the British Secret Service, "Intelligence is about secret information others want to keep secret. 100% success is never achieved" (quoted in Hutchinson 2003, 196).

168 The case of Jose Padilla is indicative. Padilla is a US citizen who was taken into custody in Chicago in May 2002, after returning from Pakistan. He is suspected of being part of a "dirty bomb" plot by al-Qaeda, but as of early 2004, the US government had not pressed any charges against him (Koch 2004, 59). The US government insists that military-style rules like the enemy combatant doctrine now apply to US citizens, even on US soil, because al-Qaeda has "made the battlefield the United States" (*New York Times* 2003). A principal decision on the issue by the US Supreme Court is expected spring 2004.

fectively reduce to zero the probability of nuclear terrorism, independently of other technical capabilities and competence (associated with subsequent steps) that the terrorists might have. As such, preventing diversion of nuclear weapons material (step 3) represents *the* nuclear terrorism chokepoint: This is the step in the pathway to nuclear terrorist capabilities that can most directly and reliably be stopped (Bunn et al. 2003a, 32; Nunn 2003, 2).

Consequently, the prevention of nuclear terrorism must start abroad, through optimum nuclear husbandry.

5.2 Nuclear Husbandry

For a long time, there were two impediments to would-be nuclear proliferators; the acquisition of fissile material, and the technical know-how for building a nuclear device. Today, none of these should be regarded sufficient. Nuclear explosive technology is no longer a secret shared by a few and the construction of a crude nuclear explosive does not represent insurmountable difficulties for non-state actors.

The by far the most efficient way of reducing the risk of nuclear terrorism is to reduce the risk of theft of nuclear material by controlling the material at its sources. This can best be done by establishing stringent domestic and international norms of protection, control and accounting.

Within the legitimate security constraints of states, the following countermeasures could be considered against the threat of nuclear terrorism.

- *Accelerate, unblock, and upgrade fissile material security programmes*. A decade after the instigation of international security upgrades, most proliferation attractive and sensitive fissile material in Russia has not been dealt with. While unprecedented work has been carried out, much remains to be done to accelerate, unblock, and upgrade the fissile material security programmes to reduce the nuclear threat legacy of the Cold War.[169]

- *Expand funding for fissile material security*. As the nuclear security activities are accelerated and expanded, the burden should be shared by more than one donor (i.e. the USA). Specifically, Europe should engage more vigorously in the work, possibly using as a platform the

169 In January 2001, a bipartisan panel mandated by the US Secretary of Energy to assess the security of Russia's nuclear material concluded that "the most urgent unmet national security threat to the United States today is the danger that weapons of mass destruction or weapons useable material in Russia could be stolen and sold to terrorists or hostile nation states and used against American troops abroad or citizens at home" (Baker and Cutler 2000, 25). Among the key recommendations of the panel were a tripling of current funding and establishing of a strategic plan to secure and /or neutralize in the next eight to ten years all nuclear-weapons-useable material located in Russia. Top-level agreements, moreover, should be reached with the Russian Federation on acceptable measures for transparency and access. For the 2002 fiscal year, however, the US Congress approved only a small fraction of the funds the panel deemed necessary to secure the material. The Bush Administration initially rebuffed attempts to provide more funding (*International Herald Tribune* 2001, 8).

G–8 Global Partnership Against the Spread of Weapons and Materials of Mass Destruction.[170]

- *Improve nuclear transparency and accountability*. Nuclear programmes and stockpiles remain shrouded in secrecy. This is hardly the best way to ensure responsible nuclear husbandry and international recognition of the security challenges. Nuclear weapon-state declarations and data exchanges on national nuclear material stockpiles should be stimulated, as should non-intrusive verification of fissile material.

- *Establish nuclear stockpile inventories.* Proper accountability is crucial to for nuclear security. Current uncertainties in fissile material holdings can only exacerbate the nuclear terrorist threat. An overall Russian stockpile inventory exercise should be launched, sponsored if necessary by international donors.[171]

- *Improve and implement non-intrusive HEU verification***.** To meet international and domestic non-proliferation and disarmament demands, technical communities are now examining a variety of non-intrusive verification measurements on nuclear items with sensitive or classified properties. Important progress has been made on joint plutonium verification. Similar efforts should be made for verification schemes for highly enriched uranium.

- *Assess ongoing nuclear security programmes and approaches.* More than a decade of cooperation in international nuclear security offers a cornucopia of experiences. These should be assessed and best practices identified. Particularly successful programmes, like the joint naval security upgrades, could provide important inputs for fruitful working approaches and strategies in other ongoing and future cooperative nuclear security programmes.

- *Clarify nuclear security concepts.* Optimum cooperation in international nuclear security will rest upon a clear, concise, and joint understanding of the means applied, the obstacles to overcome and the adversaries to defeat. Today, confusion prevails when it comes to the applicability of the range of practical nuclear husbandry activities. Consequently, commonly applied concepts in nuclear security should be regularly reviewed and clarified, possibly through joint international exercises and workshops.

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170 In June 2002, the G–8 countries committed themselves to raising up to $20 billion over the next ten years for specific cooperation projects, initially in Russia, to address issues of non-proliferation, disarmament, counter-terrorism and nuclear safety. Among the priority concerns are the destruction of chemical weapons, the dismantlement of decommissioned nuclear submarines, the disposition of fissile materials and the employment of former weapons scientists. For more on this, consult www. sgpproject.org (last accessed Dec. 14, 2003).

171 Again, the G–8 Global Partnership may serve as a platform.

- *Establish and implement mandatory standards of physical protection of fissile material and nuclear installations*. While safeguards aims at deterring state nuclear proliferation, physical protection is the primary barrier against potential nuclear terrorists. Yet, despite recent updating, the international standards for physical protection are non-mandatory and probably too weak to meet contemporary nuclear terrorist threats.[172]

- *Expand physical protection information-sharing and international peer-reviews.* Domestic standards and practices for physical protection differ widely. While sensitive information is protected, physical security experiences and best practices should be shared in international fora, to raise the general level and norms of nuclear security.[173]

- *Expedite international efforts to put material declared excess to national needs under international (IAEA) control*. Both the USA and Russia participate in the Trilateral Initiative, whereby stocks of fissile material in excess to national needs are put under international control. So far, however, only very small quantities have been put under IAEA control. Nuclear-weapon states should review current stockpile inventories, with a view to increasing excess declarations.

- *Make all nuclear arms reductions truly irreversible*. The principle of irreversibility, i.e. that material and weapons taken out from the arsenals of nuclear-weapon states should be irrevocably rendered unuseable for the purposes of nuclear explosives, is essential for reducing the threat of nuclear terrorism. If destruction of the fissile material is not an option, deals should be struck for international control and/or irrevocable disposal of fissile material.[174]

- *Commence negotiations on a Fissile Material Cut-Off Treaty*. Ending the production of weapons-useable material would create an upper boundary to the number of nuclear explosives possibly produced by states or terrorists. A fissile material cut-off treaty – covering all fissile material, including naval HEU – is a prerequisite for genuine stockpile reductions and, hence, reduced threat of nuclear terrorism.

The challenges posed by nuclear terrorism are substantial and require both immediate and sustained efforts by national governments and international organizations (Potter 2003, 5). Each of the suggested measures may not alone prevent future acts of nuclear terrorism. However, they are likely to be mutually self-reinforcing and eventually sufficient to establish the norms and

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172 See Section A.7.5, Appendix VII, for more on this.

173 For instance, the IAEA initiative to organize country-wise physical protection peer reviews, International Physical Protection Advisory Service (IPPAS), should be expanded.

174 The latest strategic nuclear arms reduction treaty, the Strategic Offensive Reductions Treaty (SORT), does not include provisions for destruction or protection of nuclear warheads or fissile material. As such, it offers very little toward reducing the nuclear terrorist threat.

standards needed to avoid further proliferation of fissile material, to states and to non-state actors, and thus to prevent nuclear terrorism.

5.3 Nuclear Terrorism Risk Analysis

Bunn et al. present a useful model for the steps towards nuclear terrorist violence. It allows for a stepwise assessment of terrorist intentions and terrorist capabilities, and covers both the ideological and operational aspects of terrorism. Accordingly, the model has merits as a useful means for understanding the dynamics and the different elements of the terrorist threat. Moreover, it represents a valuable tool for evaluating and prioritizing various countermeasures for the steps throughout the nuclear terrorist chain. There may, however, be room for improvements.

The model is strictly linear and one-dimensional. Each of the steps relies (solely) on the preceding one. It does not take into consideration that terrorists' possible nuclear ambitions could develop as a combination of intentions and technical opportunities. For instance, it seems likely that the quest of the Japanese cult Aum Shinrikyo for nuclear explosives was driven by opportunities rather than a carefully crafted plan (see Section 4.1.1.2). Ability may govern, and perhaps enhance, motivations. For some groups, possession of chemical, biological, radiological or nuclear means will likely lead to the attempted use of these (Center for Counterproliferation Research 2002, 6). This dynamic is not reflected in the current linearity of the model.[175]

Nor can one rule out situations where (sudden) technical capabilities to perform acts of nuclear terrorism may in fact *reduce* the motivational aspects of a group. Members of a terrorist group could have second thoughts after realizing the real ramifications of their planned act(s); group psychology rather than individual psychology appears to be the primary determinant of terrorist behaviour (Post 2000, 273). Terrorists may follow their own rationalities based on extremist ideologies or particular terrorist logics, but they are not irrational (Bjørgo 2003, 234).[176] The group majority may hence override any individual nuclear ambitions.

Distinguishing sharply between motivational and technical aspects may be a useful analytical move, as it would separate and clarify the various facets of nuclear terrorism. However, such a strict intentional/capability-based dichotomy may also provide a too narrow scope for evaluation. Motivations, as well as technical nuclear terrorist capabilities, may change along the way. An admittedly more complex but more accurate model would be two-dimensional, as presented in Figure 5.1.[177]

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175 This dynamic relationship, moreover, provides an extra incentive for limiting technical nuclear capabilities of terrorists.

176 There is no common personality profile that characterizes most terrorists, who appear to be relatively normal individuals otherwise (Bjørgo 2003, 234).

177 The author of this thesis owes this point to Dr. Jon B. Reitan and Dr. Steinar Høibraaten.

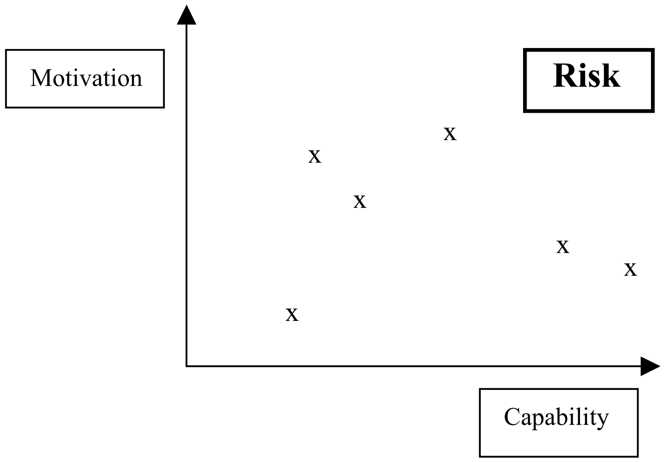

Figure 5.1: Nuclear terrorist threat as a continuous function of motivations and capability

Here, rather than a linear model, the nuclear terrorist threat is (continuously) viewed as a product of both intentions and capability, to provide the best and most comprehensive threat picture possible at all times. Again, however, it should be observed that, in the absence of motivations or perpetrators with nil technical capability, the risk threat of nuclear terrorism would be zero.

The Bunn model has other potentials for improvements as well. For instance, the second step of the model ("Decide to escalate to the nuclear level of violence"), seems to assume with some certainty that the group intends to *use* the nuclear explosive device(s) they are pursuing. Thus, possible nuclear blackmailing is effectively excluded from the considerations of the model. This is unfortunate and inaccurate, as even credible nuclear threats should be regarded as nuclear terrorism (see Section 1.4.1). Plausible hoaxes may warrant proper governmental responses, and the psychological and societal reactions may be strong.

Furthermore, possible perpetrators may circumvent some of the technical steps in the nuclear terrorist path. For instance, terrorists may acquire the fissile material directly themselves, without any middlemen or sellers. Or they could construct the nuclear explosive inside the target country, or even at location, to limit transportation and the number of border-crossings. In either case, one or more steps may be bypassed. Countermeasures focusing (solely) on the(se) step(s) could be in vain.

In sum, the developments and dynamics possibly leading up to nuclear terrorism could be more complex and interrelated than described by the initial linear model. Accordingly, the model should be expanded to reflect this complexity and allow for more holistic and comprehensive studies of a (generic) threat.

Chapter 6: Some Reflections on Research Findings

To further the overall scientific and political discourse on reducing the risk of nuclear terrorism, this chapter aims at putting the research findings and the implications of these findings into the current political context. As such, a critique of the ongoing "War on Terrorism" forms an integral part of the chapter. No effort will, however, be made at systematically and methodically assessing current political indifferences and preferences in the international fight against terrorism.

6.1 Strong Perceptions and Responses

Terrorism is like sand in the machinery of states (Lodgaard 2003b), prompting them to respond, sometimes jointly and irrespectively of their political or religious inclinations.[178] In the eyes of an institutional authority, conventional terrorism primarily poses a threat to societal order, but the general public may perceive any terror as a real and (life) threatening danger. In the face of nuclear terrorism, however, the state and citizens are in a sense suddenly put on a par: Catastrophic events may unfold, threatening both the state and its population. This is a subtler aspect of nuclear explosive devices as the great "equalizer".[179]

Synergetic, and thus strong, societal responses are likely. By this, an extended terrorist threat may also be used to justify acts in support of political agendas, such as the consolidation of political power (UN General Assembly Security Council 2002, 6). Effectively, through rhetoric and heavy politicization of security issues, the control institutions and instruments of civilian society and the powerful states become mobilized and strengthened, thereby giving governments new and unprecedented room for manoeuvre (Beck 2003).[180] Large-scale terrorism, or a potential thereof, may generate new political leverage, domestically as well as internationally.

Following the terrorist attacks, the UN Secretary General singled out terrorists' use of nuclear, biological and chemical as the gravest threat facing the world (Hoyos 2001). Former US Senator Sam Nunn echoed this assertion, claiming that "the most significant, clear and present danger we face is the threat posed by nuclear, biological and chemical weapons. The question

178 The attacks of 9/11created a wave of sympathy and a broad international coalition against terrorism. States like China, Russia and Iran, among many others, expressed their support to the United States.

179 Traditionally, this notion has been used to explain how conventionally inferior states may compensate any military weaknesses with nuclear weapons.

180 Actors standing ready to wipe out the heart of New York City with crude nuclear weapons is a scary, and hence mobilizing, scenario. However, without causing significant distress in the public, both the USA and Russia keep some 2000 nuclear warheads on high alert, ready to be launched within minutes at each other (Nuclear Age Peace Foundation 2002).

is not whether we must prepare for terrorism or for attacks with weapons of mass destruction. These two threats are not separate but interrelated and reinforcing, and if joined together, become our worst nightmare" (Nunn 2001, 2).

The political response to possible acts of super-terrorism has been profound, particularly in the USA. This is reflected in multi-billion dollar budgets to prepare for and respond to threats or incidents of terrorism, the establishment of entities like the US Department of Homeland Security,[181] the US "Patriot Act", and a strong push for missile defences.[182] Around the globe, states are scrambling to counter the terrorist threat, through a range of means including increased public surveillance and intelligence cooperation, efforts to boost transparency in financial transactions, as well as the Proliferation Security Initiative, to enhance interception of international shipments.[183] NATO has established its own response force. In academic circles, articles on terrorism are proliferating and terrorism journals are flourishing (Silke 2003, 20). Most conferences and talks on international security relations now seem duty-bound to include some reference to terrorism.

This situation opens extraordinary opportunities for shaping international politics and order. Ideally, the global terror threat and a globalized risk society could pave the way for a new era of supranational and multinational cooperation to counter a trans-national threat (Beck 2003, 145). However, these opportunities could also be ruined by domestic misapprehensions of interests. In the name of the "War on Terrorism", unilateralism could take precedence over multilateralism. The consensus-based multilateral diplomacy, as reflected in international treaties, may be perceived to be too puny to deal with contemporary threats. According to some US analysts, such "least-common-denominator solutions" would "not only undermine effective diplomacy, but also and jeopardize the security of America" (Spring 2004, 4).

Hence, the US takes responsibility and acts where others, most notably Europeans, are too weak (Kagan 2003). Ambassador Linton F. Brooks, head of the US National Nuclear Security Administration (NNSA), explains the foundations of the US perspective (2003, 2w):

> *The events of that day [September 11, 2001] were galvanizing for the American people and the world. I think the significance of that day is that it brought a collective recognition that a long-emerging threat had come to fruition, and was now starkly visible and at the forefront of our national collective consciousness".*

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181 The US federal spending on homeland security programmes for 2003 was 28.2 billion US dollars. From www.whitehouse.gov/omb/budget/fy2004/ homeland.html (last accessed 21 March 2004).

182 Opponents of the system maintain that it will have no effect against future acts of terrorism. Terrorists will not deploy intercontinental missiles (with a distinct return address), but rather non-conventional delivery systems like trucks or cargo containers (see e.g. Allison 1995, 69). Both the USA and NATO are now gearing up to put in place operational systems – the USA in time for the 2004 presidential elections, and NATO through the launch of a feasibility study (NATO 2003).

183 The Proliferation Security Initiative is a (US-led) coalition of states that are preparing, inter alia, to search planes and ships, trains and trucks carrying suspect cargo, and to seize weapons or missile shipments that raise proliferation concerns (Weiner 2003, 1w).

The terrorist attacks legitimized a redefining of the strategic culture of the United States (Vedby Rasmussen 2003, 15) and resulted, first, in a responsive war on the Taliban regime in Afghanistan. In March 2003, a preventive[184] war against Iraq was initiated, primarily to ensure that nuclear, biological, or chemical Iraqi weapons could never be deployed and used against the USA or its allies, by the Iraqi regime or terrorists.[185] The US President sidestepped the UN Security Council after it became clear that international consensus for military intervention could not be achieved.[186] The war was deemed necessary by the USA, but it also ignored European preferences for strengthening international order through effective multilateralism (Solana 2003, 6 and 9). The effects on international security relations, international law and international (nuclear) non-proliferation activities may be profound (Cirincione 2003).

6.2 Dramatic Proclamations

The United States has, by all means available, assumed a global burden of fighting terrorism. The efforts are accompanied by a forceful, warlike rhetoric. The phrase "War on Terrorism" is more than coincidental colloquial speech. Nearly a slogan, it has become a strong political mobilizer, despite the limitations of the term. It is questionable whether we really are engaged in a "war" in the traditional sense.

The trans-national character of contemporary terrorism renders doubtful any effective reprisal of non-state actors, as traditional military responses require geographically defined and confined targets (ElBaradei 2003, 1w). Modern terrorism is not easily deterred (Cordesman 2001, 35; Carter 2004, 6w), and perhaps is even stimulated by absolute military superiority and actions (Urquhart 2003, 12). Hence, optimal solutions for dealing with the non-traditional, non-state threat of nuclear terrorism are probably not to be found in the traditional military "tool-boxes" of states.

If, however, we are to believe President Bush, we are at war, as terrorists could "threaten civilization itself with their mad, global ambitions"(Knowlton 2003, 2w). For this reason, we "should fight back" and not "wait for the authors of mass murder to gain the weapons of mass destruction" (Bush 2001, 1w). Moreover, we all have to act now "because we must lift this dark threat from our age and save generations to come." Such heated

184 The Bush Administration, and others, prefers to talk about "preemptive" rather than "preventive". There is indeed a difference between the two concepts. "Preemptive" war refers to a direct, immediate, specific threat that must be eliminated at once; in the words of the US Department of Defense manual, "an attack initiated on the basis of incontrovertible evidence that an enemy attack is imminent". By contrast, "preventive" war refers to looming, potential, future, and therefore speculative, threats (Schlesinger Jr. 2003, 24).

185 On 16 March 2003, US Vice-President Dick Cheney appeared on the TV programme *Meet the Press*, claiming that Saddam Hussein "has been absolutely devoted to trying to acquire nuclear weapons. And we believe he has, in fact, reconstituted nuclear weapons"; then he added "I think Mr. ElBaradei frankly is wrong" (NBC News 2003, 3w). ElBaradei is the Director of the International Atomic Energy Agency, IAEA, an agency that (rightfully and authoritatively) has stated that the Iraqi nuclear weapon programme has been neutralized (Bremer Maerli, 2003b). Three days after Cheney's TV appearance, the latest Iraq war was initiated.

186 In the USA, only Congress can make the final legal decision to engage in war. However, Congress has never blocked military action if the president so desired (Nyhamar 2003).

rhetoric by may stand a risk of effectively gagging open discourse, and ethically founded and justified counterarguments (Njålsson 2003, 7).

It is, moreover, striking to observe how much Bush in his speeches emphasizes own victimization. The acts of terrorists are performed by “the shock troops of a hateful ideology” (Bush 2003, 2w). In other words, the “civilized” world (i.e. the world of Bush) has, involuntarily and unwittingly, become the subject of catastrophic dangers posed by irrational and mad actors. Such outcries could be heartfelt and genuine, showing a US president who is concerned about possible emerging threats. Moreover, people expect their president to take action and show the way. On the other hand, such dramatic proclamations may be detrimental.

Firstly, they seem to indicate an inexorable certainty of catastrophic events that we all will be facing. Referring again to Beck (2003, 31), this phenomenon could be a “fabricated insecurity”, upon which a state may legitimize its powers and actions. In this process, it is essential to develop stereotypical images of the enemy that can be used to integrate and further enhance culturally founded prejudices. Deliberately used to further state military and power structures, they can become self-fulfilling prophecies. As such, they are meta-weapons that states may use to legitimize their actions in a circular manner (Beck 2003, 69).

Secondly, endlessly referring to the collective jargon of “weapons of mass destruction” can only blur the respective, and highly differing, threats posed by biological, chemical and nuclear weapons (Maerli 2003a, 11; Morrison and Tsipis 2003, 77). Mixing the disparate weapons in an “appropriate” cocktail of political rhetoric may prevent us from identifying the best measures to meet these different threats.

Thirdly, publicity and a strong focus on terrorism work both ways. For instance, the debate on bioterrorism has been characterized by too much hyping of the problem, possibly resulting in misperceptions and an increase in biological weapon hoaxes (Chyba 2001). With the strong focus Bush has chosen to give the issue, he may stand a risk of inspiring opponents. Terrorists monitor developments in society closely, and they learn from each other. In part due to the natural conservatism of terrorists (Section 4.1.1), once a successful approach is developed, it is likely to be replicated in some kind of form (Center for Counterproliferation Research 2002, 7).

Copycat effects hence prevail. A vivid illustration: Prior to the Aum Shinrikyo cult releasing the nerve-gas sarin in the Tokyo metro in 1995, the US Federal Bureau of Investigation (FBI) would encounter about a dozen cases a year involving threats or actual attempts to acquire or use chemical, biological, radiological or nuclear material. After the Tokyo terror attack, this figure increased sharply. In 1997, the FBI opened 71 investigations of this type; in 1998, it launched a full 146 (Tucker 2000, 2).

Fourthly, in this setting of coarse-grained vocal moral dichotomy of “us” and “them” and religion-charged enemy images, there is no room for considerations on the causes of terrorism. The fact that the nuclear terrorist threats may well be a product of past (nuclear weapon) policies by “civilized” states, could, moreover, be suppressed. The result might be misguided fixes to multifaceted security challenges.

6.3 Flawed Postures

To stem further nuclear proliferation, President G. W. Bush in a speech at the US National Defense University on 11 February 2004 called for strengthening multilateral arms control (Bush 2004). Firstly, he proposed steps for augmenting the existing treaty-based regime in some areas where it faces systemic shortcomings, most notably on export controls. Secondly, he declared that efforts should be pursued for strengthening the regime where it faces problems that can be addressed by internal reforms.

In addition to urging other states to expand their internal control of nuclear proliferation activities, Bush specifically proposed broadening the scope of the Proliferation Security Initiative; expanding the Nunn–Lugar Cooperative Threat Reduction Program; curtailing the sale of enrichment and reprocessing equipment; refusing to sell equipment for civilian nuclear programmes to countries that fail to observe the IAEA's Additional Protocol on safeguards; establishing a new special committee under the IAEA Board of Governors for safeguards and verification; and finally, denying positions on the IAEA Board of Governors to states that are under investigation for illicit nuclear activities (Spring 2004, 3).

These proposals are encouraging, not least as they recognize the importance of international cooperation and multinational mechanisms to stem nuclear proliferation. However, the steps may provide too limited remedies in the long-term fight against nuclear terrorism; by failing to deal with the underlying nuclear postures of leading nuclear weapon states, they do not address the inherent dangers of nuclear proliferation to states and non-state actors.

A more comprehensive and consistent approach to prevent nuclear proliferation is needed (Arms Control Association 2004; Carter 2004). As some countries possess nuclear explosives (or are protected by them in alliances) and others do not, this asymmetry breeds chronic global insecurity and further incentives to proliferation (ElBaradei 2003, 1).

According to the US National Security Strategy, issued in September 2002, the United States now must "deter and defend against the threat before it is unleashed" (United States of America 2002a, 14). US military and civilian agencies must therefore "possess the full range of operational capabilities to counter the threat and use of WMD by states and terrorists" (United States of America 2002b, 2). Building upon the December 2001, Nuclear Posture Review,[187] some of the weapon capabilities advocated herein are nuclear (Butcher 2003, 66).[188]

By expanding the nuclear target list, the new posture explicitly increases the nuclear threat to possible US adversaries (May 2003, 2w).[189] Rather than

187 The Nuclear Posture Review is classified. Excerpts made available reveal the establishing of a New Triad composed of offensive strike systems (both nuclear and non-nuclear), defences (both active and passive), and a revitalized defence infrastructure (hereunder a strengthening of US nuclear testing capabilities) that will provide new capabilities in a timely fashion to meet emerging threats. From GlobalSecurity.org 2001.

188 May 2003, the US Senate lifted the ban on "mini-nuke" research and development. The time required to resume nuclear testing has been shortened to 18 months or less. On the possible US development of new nuclear weapons, see Ferguson and Zimmerman 2003.

189 Pentagon has apparently produced contingency plans for preemptive use of nuclear weapons against several new states (Barnaby 2003b, 3). In March 2002, the British Minister of Defence announced, for the first time, that also British nuclear weapons could be used

reflecting an updated strategy for minimizing the demand for nuclear explosives and material, the current US nuclear posture adds an unknown amount to inducements for nuclear proliferation (du Preez 2002, 67).[190]

Moreover, very limited consideration is given by the US to following up the practical steps on nuclear disarmament and non-proliferation from the 2000 Review Conference of the Nuclear Non-Proliferation Treaty (2000 Review Conference). Nothing less than the viability of the NPT could rest upon the successful implementation of these steps (Maerli 2004a, 6).

Rather than fulfilling its own commitments under the NPT, the US focus has shifted from eliminating nuclear explosives and material, to eliminating certain regimes that may have them, today or in the future. In this selective and coercive counter-proliferation strategy some nuclear weapons are tolerated, even encouraged, and others are not. Universal norms and treaties then become a hindrance to US freedom of action, instead of serving as strategic levers in the battle against non-proliferation (Cirincione 2003, 2w).

A sound and forward-looking nuclear posture should lay the groundwork for multilateral actions to minimize the problem of nuclear terrorism, including adequate measures to safeguard and, as needed, dispose of the hundreds of tons of excess nuclear weapon material (May 2003, 4w). But President Bush' 2005 budget request includes a cut in the Nunn-Lugar Program and the administration has not acted quickly in the past to remove bureaucratic barriers to this critical program (Baynard 2004, 2w; Boston Globe 2004, 1w).

So far, the core of the US national strategy to nuclear issues has seemed destined to reduce international cooperation in enforcing non-proliferation commitments, rather than enhance it (Perkovich 2003). The implications for the threat of nuclear terrorism could be harsh: Without the international non-proliferation regime, terrorists are likely to have an easier time gaining access to nuclear explosives (Holdum 2002).

6.4 A Non-Victorious "War" on Nuclear Terrorism

As citizens, state leaders, and analysts struggle to grasp the magnitude, range and implications of the threat of nuclear terrorism, the path of prevention that we, this far, have embarked upon seems less than optimal. In the "War on Terrorism" there has been a conspicuous unwillingness – or possibly an inability – to deal with the post-Cold War nuclear challenges.

The vast stocks of fissile material not properly secured create a tangible nuclear terrorist threat. But rather than focusing on the persistent proliferation problems associated with the possible *supply* of existing nuclear material, the international community, driven forward by the USA, tends empha-

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first during a military crisis, to respond to or deter biological or chemical attacks (Bremer Maerli 2003b, 24).

190 The US unilateralist emphasis on flexibility has, moreover, brought the strategic arms control process to a halt, Bremer Maerli 2004a, 5). The Strategic Offensive Reductions Treaty (SORT) has no milestones or intermediate goals, no provisions for destroying fissile material or delivery systems, and verification has no role in assuring compliance. Apart from the obligation not to have more than 2,200 strategic nuclear warheads by 31 December 2012, it is actually hard to see how SORT can be violated.

size the nuclear *demand* side of the proliferation problem, often with an appurtenant preference for (military) coercion.

One can hope that terrorist groups having both nuclear intentions and capabilities would see reasons not to resort to nuclear mass destruction to achieve their objectives. But only an effective worldwide system of controls over fissile material can give assurance that such scenarios will not turn into reality (Narath 2002, 15).

To non-state actors, the technical barriers to the production of crude nuclear explosives are not likely to be insurmountable. In the "war" on nuclear terrorism the security of all stocks of fissile material should, without delay, be considerably improved as a crucial anti-nuclear terrorist measure. Comprehensive fissile material inventories and stringent norms should be developed to ensure that all stocks of fissile material are completely secure and rendered unuseable as nuclear explosives.

Approaches to security and accounting for nuclear material must adapt to changing conditions (Bunn 1999, 2). As opposed to other security threats, like the plethora of small arms, controlling stocks of fissile material represents a definite and thus manageable problem, once the political will is established. Many of the measures in need for implementation, however, call for reconsiderations of current postures, practices and priorities of the nuclear weapon states.

The attacks of 9/11 have given a new urgency to discussions on nuclear transparency (Walker 2003, 15). When the US "War on Terrorism", with all its ramifications, was instigated on that dreadful day, the era of the nuclear stockpile opacity and nuclear *Alleingang* of the nuclear-weapon states should also have ended.[191] It did not. The prospects of winning a "war" on nuclear terrorism are correspondingly low.

191 *Alleingang* is German. It means going solo or alone, here in the context of pursuing (narrow) domestic goals and ideals regardless of the interests and preferences of the international community.

Appendixes

Appendix I: Radiological Terrorism vs. Nuclear Terrorism[192]

Too often, *nuclear* terrorism is confused with *radiological* terrorism, and vice versa. Despite some shared features, the means, mechanisms, and not least the consequences of the two types of terrorism are quite different.

A.1.1 Radiological terrorism

The primary means of radiological terrorism is to cause contamination and health risks (and thus fear) by deliberately dispersing radioactive substances. For this, so-called "radiological dispersal devices" (RDDs) may be applied. As opposed to nuclear weapons, RDDs do not involve any nuclear chain reaction, but rather rely on the innate radioactivity released. The most spectacular form of RDDs could be the use of so-called "dirty bombs". Radioactive material would then be wrapped around conventional explosives and detonated, contaminating the surroundings. In 1995, Chechnyan rebels threatened to blow up several assembled dirty bombs in Moscow,[193] but the threats were never carried out.

In the most rudimentary way, the spreading of the radioactive sources could be done by simply pouring out or dispersing the material, e.g. in highly trafficked (and (confined) areas. Decontamination would be difficult, time-consuming and expensive. Food and drinking sources could also be contaminated, again with huge societal and economic losses – as evidenced by experiences from past radiological accidents, as in Goiania in Brazil, 1987. Other scenarios involve dispersal of radioactive substances into the environment or the ventilation system of a building or metro system (Steinhausler 2003, 784).

Radioactive sources are widely available today through their wide range of uses in industry, medicine and research. However, substantial contamination would require large to very large radioactivity levels – levels difficult to procure and to handle. Moreover, of the millions of commercial radioactive sources used globally, only a small fraction pose inherently high security risks because of their portability, dispersibility and high level of radioactivity (Ferguson et al. 2003, 62). Most types of radioactive waste potentially available to terrorists have low specific activity (Committee on Science and Technology for Countering Terrorism 2002, 46) and thus generally represent a small risk.[194]

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192 The following text builds on Bremer Maerli 2004b.
193 In the form of armed containers with caesium.
194 However, a "dirty bomb" could also be constructed with a nuclear explosive device containing material that becomes activated by the weapon's radiation (such as cobalt), thereby magnifying the radiological impact of the device (Narath 2002, 11).

The thousands of containers of radioactive material used in medicine, industry and research that have been lost or stolen worldwide could be used to make crude “dirty bombs” (United States General Accounting Office 2003b). Such scenarios, however, would not include the immense blast, heat, or radiation from the triggering of a nuclear explosion. The effect could be more like that of chemical weapons, and contamination could probably be dealt with (Cordesman 2001, 20).

Depending on the amounts of radioactivity used, dispersal effectiveness, and exposure time and exposure patterns, the risk of immediate fatalities from acts of radiological terrorism would appear generally low (Barnaby 2003a, 5). Fatalities, if any, would probably emanate from blast effects from the chemical explosives rather than from radiation exposure as such (Committee on Science and Technology for Countering Terrorism 2002, 46). The main danger to health and life would lie in the long-term (stochastic) effects (like increased cancer risks), although the use of RDDs could create strong emotional effects and widespread panic (Ford 1998).

In sum, radiological terrorism could have strong psychological and societal impacts. However, it would most probably not be catastrophic, as a successful nuclear terrorist attack could be.

A.1.2 Nuclear Terrorism

Improvised, or crude, nuclear devices are most likely to be either on a gun-type design or an implosion design. These are the two fundamental designs for nuclear fission weapons as first used in 1945 in Hiroshima and in Nagasaki, respectively. Vast amounts of energy are released when fissile material, either highly enriched uranium or plutonium, fissions. The possible effects of a crude nuclear explosive are discussed in Appendix II.

Later generations of nuclear weapons have more complicated designs, using a combination of nuclear fissions and fusions to boost the nuclear explosive yield. While both the implosion type and the gun-type design may produce yields in the kiloton-range, modern high-yield nuclear weapons can create explosions equivalent to megatons TNT explosions (i.e. 1,000 times greater than the earlier devices).

Essential for the design of any fissile explosive is swift compression of the nuclear material: This is necessary to create a super-critical mass and to avoid pre-ignitions that would cause the device to fizzle (see Appendix III). A super-critical mass is a mass capable of sustaining a nuclear chain reaction. The fissioning of either uranium or plutonium atoms then results in subsequent fissions of new uranium or plutonium atoms. The critical mass depends upon the type of fissile material used, its density and purity, and the sophistication of the nuclear explosive device.[195]

[195] To create a critical mass for implosion-design weapons, a sub-critical spherical mass is symmetrically compressed by an array of triggers packed around conventional explosives with fissile material in the centre. In a gun-type design, one sub-critical mass is fired onto another sub-critical mass of fissile material with the use of conventional explosives. The higher probability of spontaneous fissions and hence a higher neutron background renders it impossible to use plutonium in the relatively slow gun-type design. Generally, it is easier to produce improvized nuclear devices by highly enriched uranium and the gun-type

Terrorists with nuclear ambitions would probably go for a first-generation nuclear explosive of the types described above. The general designs are well known from open sources and declassified information. Terrorists may have lower requirements with regard to safety, security and reliability of their possible nuclear devices than states (see Section 4.1.2.4.2). They may, moreover, not be overly concerned with optimizing the yield or with making their nuclear devices slender enough to fit into missile warheads. Terrorist might deliver the weapons in densely populated areas by the use of other means, like trucks.

The most formidable obstacle facing terrorists and states in trying to acquire nuclear weapons is to gain access to large enough quantities of high-quality fissile material. Stringent protection and control of highly enriched uranium and plutonium are thus essential.

design than using implosion-based plutonium weapons, but the critical mass is higher. For more on crude HEU devices, see Appendix III.

Appendix II: Possible Effects of a Crude Nuclear Explosive Device

Nuclear weapons are quantitatively and qualitatively different from conventional weapons. In addition to extensive mechanical blasts and heat from the fireball, nuclear explosives offer a third killer – radiation. A nuclear detonation is followed by several physical processes. Direct effects in conjunction with the nuclear explosion will be the initial ionizing radiation, an electromagnetic pulse (EMP), heat radiation, blast waves, and structural collapses. Subsequently, there will be secondary fires and firestorms, as well as residual radiation and radioactive fallout.

This appendix gives a basic overview of possible effects of the detonation of a crude nuclear explosive in a densely populated area. It is assumed that the device would provide a (modest) yield of one kiloton, detonated at ground level.[196] The assessment is by no means exhaustive. It is challenging to determine the consequences of nuclear explosions, as a range of factors will govern the effects. Damage and lethality estimates will vary according to local conditions and are therefore attended by with fairly large uncertainties. In-depth studies and refined model assessments should be initiated to understand the real impacts, dose levels and fallout patterns that would be associated with nuclear terrorist explosions in densely populated areas.

A.2.1 Direct Effects

No other destructive device can cause greater societal disruption or exact a larger human toll than nuclear explosives (International Physicians for the Prevention of Nuclear War 1996, vi). The number of casualties from a nuclear terrorist attack could be catastrophic, albeit far less severe than in the case of an all-out state nuclear exchange. The consequences would depend on the size, the sophistication and hence the efficiency of the nuclear explosive device, on the location of the target, the density of the surrounding population, the extent of debris dispersal, and any pre-warnings that might provide a possibility of escape or evacuation.

As opposed to a nuclear airburst, the preferred military method, a terrorist nuclear explosion on the ground would produce heavy cratering and hence significant radioactive dirt and debris. Because their fireballs suck up huge amounts of dust and debris, ground bursts create a larger "footprint" of fallout downwind of the impact zone (Hutchinson 2003, 113).[197]

Radiation levels are likely to be correspondingly high. The resulting base surge of radioactive fallout could extend over an area of several square

196 This seems the most likely scenario for nuclear terrorists. An airburst is likely to require military means of delivery, e.g. bomber plane or missiles. The yield of such a device would, however, be much less devastating than those of high-yield (megaton-class) strategic nuclear weapons.

197 This effect may depend on the surrounding building structures. If the fireball is confined between the buildings, it will be blown up to a higher altitude than otherwise expected, leading to reduced local fallout, but causing broadly distributed long-term fallout (United States Office of Technology Assessment 1979, 46).

kilometres, possibly with fatal dose levels of radiation.[198] Shorter exposure could cause significant injury (International Physicians for the Prevention of Nuclear War 1996; United States Office of Technology Assessment 1979).

At the instant a typical nuclear explosive is detonated, the temperature shoots up to tens of millions of degrees and pressure to millions of atmospheres. With a nuclear fission device, roughly half the energy goes in the blast, about a third in heat and the rest in radiation (Barnaby 2003b, 27). Table A.2.1 shows the effects of a 10-kiloton nuclear device (i.e. in the range of the bomb dropped on Hiroshima), as a function of distance.

Table A.2.1: Direct effects from a 10-kiloton nuclear explosive as a function of distance from ground zero. [199]

Yield	Metal vaporize	Metals melt	Wood burns	3rd degree burns	5psi/ 258 km/h winds	3 psi/192 km/h winds
10 kt	0.38 km	0.66 km	1.3 km	1.9 km	1.3 km	1.6 km

(From Cordesman 2001, 53)

In the near vicinity of the detonation, metal would simply vaporize in the intense heat. A bit further away (approx. 650 m.), metal could melt. At 1.3 km. from ground zero, wood could instantly catch fire and create firestorms (see Section A.2.2). This would contribute significantly to the physical destruction of structures also outside the initial blast zone (International Physicians for the Prevention of Nuclear War 1996, 52). Consequently, with a bomb of the size of the Hiroshima bomb, heat would kill people over a larger area than the case with either blast or radiation (Barnaby 2003b, 27). At high yields, blast and thermal effects reach out to greater distances than does the initial radiation. At one kiloton, however, the reverse is true (United States Office of Technology Assessment 1979, 45).

The British Cabinet Office has calculated the lethal effects of a primitive one-kiloton nuclear explosive detonated at ground level in a "typical" city. According to these estimates, people outdoors or near windows inside would be killed by thermal radiation up to 200 meters from the point of detonation (Barnaby 2001, 50). The initial radiation could kill people one kilometre away; the blast could kill people up to a distance 800 m. from the point of detonation. These effects would, however, be reduced by urban structures. Because of absorption of the radiation passing through the multiple walls of several buildings, the initial lethal dose of 6 Sv would extend only some 250 m., covering an area only one-tenth that of the case of unimpeded radiation (United States Office of Technology Assessment 1979, 45). These estimates correspond fairly well with other calculations.

198 From a one-kiloton device and a 24-km/hour wind, radiation levels within an area of about 15 square km^2 would be high enough to cause radiation sickness in the short term to those outdoors (Barnaby 2001, 50). In an area of some 400 km^2, countermeasures would have to be put in place to avoid long-term radiation effects.

199 psi = pounds per square inch, a measure of maximum over pressure in the blast wave. 1 atm. = 101.325 kPa = 14.7 psi.

The findings of Cordesman (2001, 53, Table 4.10) indicate that the direct nuclear radiation from a one-kiloton device would be lethal some 700 m. from ground zero (see Table A.2.2).

Table A.2.2: Direct effects from a one-kiloton nuclear explosive as a function of distance

Nuclear radiation: Lethal dose in open	0.71 km		
Blast: 50% incidence of translation with subsequent impact on a non-yielding surface	0.28 km		
Thermal: 50% incidence of 2nd degree burns to bare skin	0.77 km		
Probability of serious injury from flying debris	1%:0.28 km	50%: 0.22 km	99%: 0.1 km
Probability of fatal blast injuries	1%: 0.27 km	50%: 0.19 km	
Probability of blunt blast injuries	1%: 0.38 km	50%: 0.27 km	99%:0.19 km

(From Cordesman 2001, 53)

Calculations show that approximately half of the structures within 300 m. of ground zero would collapse. Almost everybody (99%) less than 100 m. away from the impact can be expected to suffer serious injuries from flying debris. Twice that distance, half the population would receive fatal blast injuries. About half of those 800 m. from the impact zone would get 2nd degree burns to bare skin.

A.2.2 Secondary Effects

In the case of burns and radiation, it is important to distinguish between immediate and subsequent, secondary injuries (International Physicians for the Prevention of Nuclear War 1996, 51). Initial burn injuries result from the direct thermal radiation of the nuclear explosion. Secondary burns result when an individual is exposed to the fires that are ignited as a result of the explosion. Similarly, initial radiation doses result from direct exposure to the gamma rays and neutrons released in the fission process. Subsequent doses result from exposure to induced radioactivity, as well as from radioactive fallout.

Diseases may easily break out in the aftermath of an attack. The structural damage could destroy sanitary installations and sewerage systems, thereby contaminating the water supply not only with radiation, but also with incitant bacteria and viruses. Corpses and animal cadavers could further add to the risk of epidemics (Statens Strålevern 1995, 8). The collapse of local health services is likely. In Hiroshima, 90% of all doctors and nurses were killed and injured, and only three of the city's 55 hospitals were useable after the attack (Hutchinson 2003, 106). A simulated 12.5-kiloton detonation (ground-based) in the port area of New York City indicates that some 1,000 hospital beds would be destroyed in the nuclear blast, and that 8,700 more would be in areas with radiation exposures high enough to cause radiation sickness (Helfand et al. 2002, 357). The remaining medical facilities would quickly be overwhelmed, even if there were a high level of preparedness.

In consequence, secondary effects would significantly add on to the damages. However, these effects would depend on an even wider variety of factors than would the direct effects from a nuclear terrorist attack, and uncertainties in assessments would loom higher. Most assessments therefore only take prompt (direct) effects into consideration.[200] While casualty estimates from Hiroshima and Nagasaki remain controversial (International Physicians for the Prevention of Nuclear War 1996, 52), the Hiroshima mortality rates as a function of distance from the explosion may give an indication of both direct and secondary effect and hence the total potential lethality of a crude nuclear explosive (see Table A.2.3).[201]

Table A.2.3: Hiroshima mortality rates as a function of distance from explosion

Distance from explosion (km)	< 0.5	0.5– 1.0	1.0– 1.5	1.5– 2.0	2.0– 5.0
First day mortality rate	90%	59%	20%	11%	< 4%
Final mortality rate	98%	90%	46%	23%	< 4%

(From International Physicians for the Prevention of Nuclear War 1996, 52)

As seen from Table A.2.3, nine out of ten people closer than 500 m. from ground zero were killed immediately or the first day. During the subsequent days, the mortality rate increased to 98%. People more than 500 m. but less than one kilometre away from the impact zone had a 10% probability of surviving; nearly 60% of the fatalities occurred during the day of the bombing. For distances between 1 and 1.5 km., more than 50% of the population survived. Further distant, 2 to 5 km. away, 5% died, primarily during the first day.

In other words, the combined effects of a crude nuclear explosive device in a densely populated area are likely to be catastrophic and particularly devastating within a radius of one to two kilometres from the immediate impact zone.

200 Similarly, during the Cold War, nuclear weapon communities may have failed to predict the magnitude of nuclear fire damages when plans for strategic warfare were drawn up (Eden 2004). Policy-makers may thus have been misinformed about the ferocious consequences of mass fires on nuclear targets, in effect underrating the totality of the destructive impacts of nuclear uses.

201 The Hiroshima bomb was exploded in an airburst, not on the ground. Hence, the comparisons are not directly applicable to a ground-based nuclear terrorist explosive. In the case of airburst nuclear explosions, as at Hiroshima, radiation is distributed in the upper atmosphere and falls out around the globe over many years. In ground-burst explosions, the effects would tend to be more localized, though with higher levels of radiation due to the cratering effects.

Appendix III: Crude Gun-Type Nuclear Explosive Devices

Manufacturing crude nuclear explosive devices poses several technical challenges to potential perpetrators. Here, the range of obstacles will not be assessed in any detail.[202] Rather, this appendix will look briefly into two related key aspects in connection with constructing a gun-type device; the risk of pre-ignition, and system expansion once the assembly goes critical.

The point of departure is a simple, modified South African nuclear explosive device, as presented by Barnaby (1996, 7; 2003, 111). While under an international embargo, the apartheid regime produced six first-generation HEU (gun-type) devices from indigenous resources.[203] The devices had a length of approximately 1.8 m. and a weight of slightly less than one ton (Horton 2000, 6; Hutchinson 2003, 129).

In his simplified version of the South African device, Barnaby uses a gun-type device with one hollowed-out HEU cylinder at the bottom, and a smaller cylindrical HEU mass at the top that will fit into the underlying cylinder. The total HEU mass is 55 (40 + 15) kg., in two pieces located 34 cm. apart. The HEU parts are propelled together by means of conventional explosives. The length of the complete device is 0.5 m. The South African weapons were constructed without any neutron initiators (Stumpf 1995, 3w), Barnaby's model device likewise

A.3.1 Risk of Pre-Ignition

The background neutron radiation can cause fissioning in the fissile material of the device and make the chain reaction start prematurely. If this happens the very moment the fissile material is sufficiently compressed to sustain a chain reaction, a "fizzle" yield, i.e. a yield significantly below the explosive power of the design, will result. Due to the lower neutron background, this represents less of a problem for HEU devices than for plutonium-based nuclear explosives.

A gun-type design apparently makes it possible to eliminate the neutron initiator, however, at the cost at some reduction in yield (Falkenrath et al. 1998, 163). South Africa is the only state known to have done this. The designers of the South African bomb had to rely on stray neutrons in the atmosphere to initiate the chain reaction (Barnaby 1996, 7). The statistical nature of the spontaneous initiation process could result in an initiation delay longer than the transit time through the target (Narath 2002, 6).

Even when the weight and length of the device are kept down, velocities of a few hundred meters per second should be achievable for gun-type designs (Narath 2002, 7).[204] Assuming a (modest) insertion speed of 200 m/sec, the insertion time for the Barnaby device will be:

202 The considerations here are of a general character. No attempts have for instance been made to simulate or calculate the efficiency and probable yields of the crude gun-type designs discussed.

203 These devices consisted of two uranium pieces, one shaped like a sphere with a hole in its middle with a second piece in the shape of a cylinder designed to fit the hole. At detonation, the cylindrical piece of HEU would be propelled down a high-strength gun barrel into the spherical piece of HEU.

204 Field artillery pieces generate muzzle velocities of about 1000 m/sec.

$$t_{ins} = 0.34 \text{ m} / 200 \text{ m/sec} = 1.7 \times 10^{-3} \text{ sec}$$

The number of background neutrons generated during this interval equals:[205]

$$N_{neutron} = 1.4 \text{ (/kg-sec)} \times 55 \text{ kg} \times t_{ins} = 0.13$$

Hence, the number of spontaneous background neutrons from any of the two HEU masses during insertion is quite limited. The risk of pre-ignition, and of a "fizzle" yield, will be correspondingly low.[206]

Nobel laureate Luis Alvarez (1987, 125) has emphasized the ease with which a nuclear explosive device can be constructed with HEU, due to the low neutron background:

> *With modern grade uranium, the background neutron rate is so low that terrorists, if they have such material, would have a good chance of setting off a high-yield explosion simply by dropping one half of the material onto the other half. Most people seem unaware that if separated HEU is at hand it's a trivial job to set off a nuclear explosion… even a high school kid could make a bomb in short order*

Alvarez did not, however, specify what he meant by "high-yield" explosion. The yield will depend upon the effectiveness of the device – more specifically, on the level of system expansion once the chain reaction is initiated.

A.3.2 System Expansion

With regard to efficiency, it is important to keep the bomb assembly intact as long as possible in order, to allow for as many fission generations as possible. The second critical parameter for device is thus its inertia.

Given the very limited neutron background (see above), one can assume that the uranium parts of the device have been fully assembled before the chain reaction is initiated. Once the chain reaction is running, the time between fissions will be:

$$\tau = \lambda / \upsilon \approx 10^{-8} \text{ s}$$

where τ is the neutron generation time, i.e. the mean time it takes for a released neutron to create a new fission; λ is the mean free neutron path equal to 13 cm (Serber 1992, 12); and υ is the average neutron velocity of 1.4×10^9 cm/s (for neutrons with an energy of 1 MeV).

The 55-kg. HEU (90% U-235) of the Barnaby device equals a total of 1.3×10^{28} uranium atoms (U-235 and U-238). Ninety-four fission genera-

[205] The neutron background rate is taken from National Academy of Sciences 1995, 45, assuming 100% U-235.

[206] However, the presence of even quite limited amounts of (light-element) impurities could increase the neutron background and hence increase the risk of a fizzle yield (Serber 1992, 53–54).

tions is more than enough to produce this number of neutrons.[207] The time needed to fission *all* the HEU in the Barnaby device is in theory thus:

$$t_{fis} = \tau \text{ x } 94 \approx 1 \text{ µsec}$$

However, although Barnaby does not say so, neutron reflectors seem to be required for his device as outlined. For uranium enriched to 93%, the critical mass of a *sphere* is 56 kg. (Barnaby 1996, 14). The *cylindrical* geometry of the Barnaby device with 90% HEU would thus require an even higher mass than the 55 kg. of HEU to go critical, unless the core was surrounded by material reflecting escaping neutrons back. This would complicate construction.

What yield might then be expected? Fissioning of *all* the HEU in the Barnaby device would, again theoretically, produce a yield of 935 kilotons. This is because one kilogram (the consumption of a typical fission device) would give a yield equivalent of that of 17 kiloton of high explosives such as dynamite or TNT (Garwin and Charpak 2001, 59).

But the gun-type design is inherently ineffective. In the gun-type bomb that destroyed Hiroshima, only 700 g out of the 60 kg. of HEU enriched to 80% in U-235 actually fissioned. The efficiency of the device was thus as low as about 1.3%. Yet, it produced a yield of 13 kilotons. By comparison, the design yield of the South African devices was 10 to 18 kilotons (Horton 2000, 6). Even a poorly assembled copy of these devices, with an efficiency of say 1%, could thus be able to produce one to two kilotons. This would be a devastating and unprecedented terrorist yield, representing some thousandth part of the true "potential" of the HEU in Barnaby's device.

However, even within the microsecond it would take to fission all the uranium, quite significant system expansions could occur. As the energy release increases exponentially, moreover, much of the energy releases take place very late in the explosion. As much as 99% of the energy released from a crude HEU device will be released during the last five generations of the reaction, mainly as kinetic energy that will expand the fissile material and weapon assembly (Swahn 2001, 48).

A bomb exploding within a period of about 10 nanoseconds could have an explosive power corresponding to the few kilograms of material moving at a speed of 10^9 cm/sec (Garwin and Charpak 2001, 48). Accordingly, within a microsecond the fragments may have travelled 10 cm outwards, in effect drastically reducing the yield, as the assembly will abruptly become sub-critical. Expansion of only a few centimetres will stop the reaction (Serber 1992, 11).

Consequently, not only reflectors, but also a set of tampers seems needed for the Barnaby device to function close to any "design" yield.[208] This is not an insurmountable problem, but it would further complicate construction of the device.

207 $2^{94} = 2.0 \text{ x } 10^{28}$.
208 A tamper is a massive layer of material with inertial properties that slow the expansion of the fissile material. Heavy material, often with good neutron-reflecting abilities, is used (e.g. natural uranium).

Appendix IV: Russian Naval Fuel[209]

Durability, compactness, shock and temperature resistance and power-output flexibility are all important features of naval reactors. This set of demands places major restrictions on the type and construction of naval nuclear fuel.

Due to classification and sensitivity concerns, very little information has officially been made available on Russian naval fuel composition, holdings and handling. However, for any non-intrusive verification, a minimum of basic fuel data is needed. This appendix surveys the information available, as background for the case study on non-intrusive verification (Section 4.3.3.2).

A.4.1 Naval Fuel Holdings

Since 1958, the Soviet Union and Russia have constructed 249 nuclear-powered submarines, representing more than half of the submarines produced worldwide.[210] Two thirds of these vessels were delivered to the Northern Fleet, the rest were destined for the Pacific Fleet. In addition to the combat submarines, five research and development submarines and several full-size land-based submarine-training facilities have been produced. Moreover, the eight ships of the Russian icebreaker fleet are nuclear-propelled, each with one or two reactors, accompanied by four (laid-up) battle cruisers and a communication ship with twin reactors. Most Russian submarines are equipped with two reactors. The overall number of naval reactors produced by the Soviet Union/Russia is therefore at least 480 (Maerli 2001b, 8).

The United States and Russia have the most extensive nuclear propulsion programmes, representing by far the largest fleets globally, using highly enriched uranium (HEU) in the reactor cores.[211] HEU naval requirements for the United States and Russia are an estimated one to two tons a year for each country (Feiveson 1999, 230). An estimated total of 250 to 300 tons of HEU have been used in US and Russian naval programmes since these were initiated, constituting some 10 to 15% of the countries' overall HEU production (Maerli 2002a, 25). Estimates of fresh Russian naval fuel holdings range from 60 tons (Roston and Smigielski 2003) to 80–85 tons (Hibbs 1995, 12).

Naval operations therefore consume a considerable quantity of highly enriched uranium, and naval fuel represents a significant part of the global HEU economy. As enrichment activities have now ceased in both countries, both the US and the Russian navies rely on HEU from weapon stockpiles for their naval propulsion programmes. This will, eventually, reduce the stocks of HEU, but is also likely to limit the quantities of fissile material declared excess to national military needs and put under international safeguards.[212]

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209 The Appendix is largely based on an unpublished article (work in progress) entitled "Nuclear Naval Fuel in Northwest Russia: Knowns and Unknowns", by Morten Bremer Maerli, Nils Boehmer and Ole Reistad.

210 92 ballistic missile submarines (SSBNs), 67 cruise missile submarines (SSGNs), 90 attack submarines (SSNs).

211 All US and British nuclear-powered ships and submarines are fuelled with weapon-grade uranium, and all Russian nuclear submarines today use highly enriched uranium. France and China use LEU in their submarines.

212 In fact, the US Navy proceeds in an extremely cautious manner, keeping *all* its fissile material usable for naval propulsion in military reserve. With the exception of the first ten tons declared excess, all the HEU that the USA has declared as excess and put under in-

A.4.2 Naval Fuel Enrichment

The need for self-sufficiency, strong power-outputs and limited reactor sizes may make it necessary to use highly enriched naval nuclear fuel (Gagarinski et al. 1996, 22). Enrichment of the pressurized water reactors (PWRs) on Russian submarines varies from about 5% to 21% U-235 for the first- and second-generation cores (Bukharin and Handler 1995, 250). Later reactor generations have used higher degrees of enrichment, varying from around 20% to 90%, depending on the specific reactor design (Sukhoruchkin 1997). Some 24 reactors are believed to have been designed to use uranium enriched to 90% U-235 (Bukharin 1996, 63), hereunder liquid-cooled reactors and some of the icebreakers. Current Russian submarines run on fuel enriched to intermediate levels.

Fuel enrichment gradients within each reactor core seem common. Starting with the third-generation submarines, reactor cores may have up to three zones of different enrichments, with the lowest inner ring having about 21% enrichment and the highest outer ring being enriched to 43–45% (Bukharin and Handler 1995, 250). Equivalent enrichment gradients, up to 20% difference, may be found within the different icebreaker reactor cores.[213]

A.4.3 Naval Fuel Composition and Casing

In the early days of nuclear propulsion, as with the construction of the first reactor in the icebreaker *Lenin,* oxide fuel was used. Today, most Russian naval reactors probably use dispersion fuel elements (enriched uranium with a matrix of high heat-conductivity alloy), with thin-walled steel or zirconium (Zr) cladding (Papkovsky undated). According to one source, however, the Russian icebreaker fleet could be powered by both dispersion fuel and fuel rods filled with uranium-zirconium alloy fuel inside zirconium cladding (Handler 1995, 2).

Zr-casings (and Zr alloys) are widely used in light-water thermal reactors because of the small absorption cross-section for thermal neutrons.[214] However, due to the relatively low strength of Zr at temperatures between 360 to 400 ºC, steel claddings are also used. The heat and corrosion resistance of steel is higher and the price lower; however, the material may be exposed to corrosion cracking and has a much higher cross-section for neutron absorption (Kuznetsov 1989, 36). Accordingly, higher enrichment levels of uranium could be needed. Reportedly, the reactor fuel element cladding for the first icebreaker was made of stainless steel, whereas in the second and third

ternational safeguards failed to meet the specifications for use in naval fuel. Yet, the US Navy maintains the right to withdraw any excess material it may need from international safeguards (see Bunn 2000, 54 and Albright et al. 1997, 93).

213 Personal communication with personnel at the Russian Icebreaker Fleet, February 1996.

214 The casing of the fuel elements is designed to prevent any direct contact between the heat carrier and the fuel, in order to prevent radioactive leakage and corrosion. Low neutron absorption, strength, plasticity, creep and vibration resistance, and good thermal conductivity are key casing parameters. The casing must operate under the most severe conditions and needs enduring strength. To reduce the neutron absorption, the casings are made as thin as possible. Typical thickness for casing is from 0.3 to 0.8 mm (Kuznetsov 1989, 32).

it was made of zirconium alloy made by an improved technology (Makharov 2000).

A.4.4 Naval Fuel Shape

The Soviet Union and Russia developed four generations of naval pressurized reactors, each generation with improved reliability, compactness and silence of operation. However, there are no reports to indicate substantially prolonged core lives even in the latest generation of submarines (Maerli 2002a, 35). As for the U.S., various different fuel geometries and shapes have been applied for former Soviet, now Russian, nuclear submarine reactors.

Specifics about the different fuel rod designs remain classified. Generally, an important fuel parameter is the volume-to-surface ratio; this determines the thermal stress per unit surface and, hence, the temperature of the casing and the fuel. Naval reactors are compact and their cores have a high power density.

Most ship reactor cores have a volume of about 1 m^3 and a power density of up to 200 MW/m^3 (Maerli et al. 1998, 14). High power densities require efficient heat removal from the reactor core. This is achieved through the use of a large heat transfer surface, or in some cases by using liquid metal instead of water as coolant.

To increase the surface, plate-type, annular, x-shaped, and perforated fuel elements have been developed (Kuznetsov 1989, 32). A portion of more advanced or modern reactors seemingly makes use of cross-shaped fuel rods, either in clad or in unclad versions (Handler 1995, 2). In addition to the cross-shaped ones, fuel rod-types with finned casings, annular, plate type with longitudinal fins, perforated, and finally, curved plate types have been designed (Kuznetsov 1989, 32).

Appendix V: Thefts of Russian Highly Enriched Naval Uranium[215]

Location	Date	Theft	Enrichment	Perpetrators	Remarks
Andreeva Bay	July 1993	Two fuel elements (each weighing 4.5 kg.)	36%	Two sailors from the Navy's radiation protection department	Two more officers charged, but charges withdrawn due to lack of evidence
Sevmorput storage installation, Murmansk	November 1993	Three fuel elements with 4.3 kg. HEU	approx. 20%	Three officers	Material recovered; perpetrators sentenced
Sevmash shipyard, Severodvinsk	July 1994	Uranium dioxide 3.5 kg.	20–40%	Four businessmen from the area, together with workers at the shipyard	
Sevmash shipyard, Severodvinsk	October 1994	Fuel element(s)	Highly enriched	No information	Arrests in Arkhangelsk, no prosecution
Zvezdochka shipyard, Severodvinsk	July 1994	Fuel element(s)	No information	Employees hired on contracts from the Northern Fleet	Accused seized before the uranium had been removed from the shipyard
Zvezdochka shipyard, Severodvinsk	January 1996	Fuel element(s)	No information	Employees hired on contracts from the Northern Fleet	Uranium removed from the shipyard; arrests in Severodvinsk
Atomflot, Murmansk Shipping Company	August 2003	Fuel assemblies from a nuclear icebreaker	Both U-235 and U-238	Allegedly Alexander Tyulyakov, Deputy Director at Atomflot	Case under investigation

Table A.5.1: Registered thefts of highly enriched naval uranium in the Northern region

215 From [P6], 41.

Appendix VI: Naval MPC&A Upgrades in Northwest Russia[216]

Site	Location	Type	Activity	Timeframe	Remarks
Site 49	Severomorsk	Consolidated Northern Fleet fuel storage	Storagean-nex[217]	May 96–Sept. 99[218]	Main storage for Northern Fleet; possibly at capacity
PM 63	Belomorsk naval base, Severodvinsk	Auxiliary vessel[219]	Shipboard, pierside upgrades	1998–May 2000[220]	First ship upgraded; *PM 12, PM 74* same class
PM 12	Olenya Bay naval base, near Mur-mansk	Auxiliary vessel	Shipboard, pierside upgrades	Aug. 98–Sept. 2000	
2d Northern Fleet storage		Northern Fleet fuel storage			*Planned* before consolidation at Site 49; not started
Sevmash shipyard	Severodvinsk	Fresh fuel storage at sub-marine as-sembly facility	New and integrated up-grades[221]	Started 1998; near completion June 2003	Second phase upgrades 2001
Mur-mansk Shipping Co.	Atomflot, north of Mur-mansk	Auxiliary vessel *Imandra*	Physical barriers, port secu-rity	July 96–Sept. 99[222]	Icebreaker upgraded by Norway, Swe-den
Mur-mansk Shipping Co.	Atomflot, north of Mur-mansk	Civilian nu-clear- pro-pelled icebreakers	Security upgrades onboard ships	Work initiated 1999[223]	Funds pro-vided by Nor-way, Sweden and UK
Navy bases	42 sites[224]	Nuclear weapon stor-age[225]	As for fresh fuel	To be finalized by 2005	Planned; Lo-cations classi-fied

Table A.6.1: Status of US-supported Naval MP&A Upgrades in Northwest Russia.

216 From Morten Bremer Maerli, "U.S.–Russian Naval Security Upgrades. Lessons learned and the way ahead", *Naval War College Review*, Autumn 2003, vol. 56, no. 4, 26 and 28.
217 Capacity expansion, physical upgrades, computerized control and accounting (Bukharin et al. 2000, 60; Iourassov et al. 1998).
218 US General Accounting Office 2001, 34.
219 Large capacity for fresh and spent fuel, liquid radioactive waste.
220 Wolfsthal et al. 2001, 134.
221 Upgrades for detection, intruder delay, response, and material accounting.
222 US General Accounting Office 2001, 34.
223 Upgrades completed on three (Sovjetsky Soyuz, Vaigach, Yamal) ships as of summer 2003.
224 In Northwestern and Far East Russia, exact locations unknown. The number of warheads is approximately 4,000.
225 US General Accounting Office 2001, 34.

Appendix VII: Possible Study Derivatives

In a nutshell, the primary intent of this study has been to assess the risk of nuclear terrorism and appurtenant countermeasures. In the process several study derivatives have emerged. These are briefly presented in the following.

A.7.1 Improved Nuclear Non-Proliferation Efforts

Strengthening of the Nuclear Non-Proliferation Treaty (NPT) could be vital to peace and stability (Molnár 2003). The regime now finds itself at a critical juncture (Feiveson 1999; Graham 2001), and efforts to boost its long-term integrity should be considered (Cirincione 2003; Gottemoeller 2003).

However, today's sole remaining superpower sees traditional arms control as "largely the agenda of the past" (Brooks 2003, 2).[226] Strong unilateral currents may hence run the risk of undermining the international nuclear non-proliferation regime (Lodgaard 2003a; du Preez 2002; Cirincione 2003; Perkovich 2003).

Ultimately, the effectiveness of the international non-proliferation regime relies not only on its substance and means of verification, but also on the political attitude expressed by the international community (Butler 2003, 135). Proper verification schemes may lessen the politicizing of monitoring issues and opposition to verification as an institutionalized tool for international control.[227]

Innovative transparency and verification schemes for fissile material like the ones presented in this study could provide important and timely lessons for bi- and multilateral efforts and arms control, in effect contributing to a strengthening of the international nuclear non-proliferation regime.

A.7.2 Improved Cooperative Nuclear Threat Reduction

Urgent environmental and proliferation concerns converge on the Kola Peninsula. This northerly region has the world's highest density of nuclear reactors, many of them left inside rusting decommissioned nuclear submarines (Toje and Maerli, 2003). The area contains large quantities of liquid and solid radioactive waste and spent nuclear fuel. These items are partly stored in run-down and unsecured facilities that leak radioactivity into the surroundings.

226 Lacking any real (global) opponents, the USA feels little need to limit its own power through bi- or multilateral arms control (Lodgaard, 2003a). Where for instance the Treaty on the Non-Proliferation of Nuclear Weapons is founded upon formalized, verifiable and mutually committing arms control, the G.W. Bush Administration favours flexibility – as reflected in the May 2002 Strategic Offensive Reductions Treaty between the USA and Russia.

227 The political role of verification remains elusive (Krass 1985, 171; Gallagher 1999). Monitoring problems associated with the Comprehensive Test Ban Treaty and the ever-pending Fissile Material Cut-Off Treaty are obvious examples. Nowhere else, however, has the scepticism towards international inspections and verification been as evident as during the Iraq crisis of spring 2003. The alleged "cat- and-mouse-game" by the Iraqis lead to a US-headed invasion, cutting off further international monitoring. For a discussion of the pre-war Iraqi nuclear programme, see Bremer Maerli 2003b.

In areas until recently closed to foreigners, large amounts of radioactive material have been left unprotected from theft and exposed to the elements. In the past, nuclear waste was routinely dumped into the Barents Sea – home to one of the most important fisheries in the world. Recent Russian plans to import radioactive waste and the envisioned MOX-trading, possibly along the Norwegian coastline, could raise the risk of accidents and mishaps.[228]

For nearly a decade, Norway and other countries have been working co-operatively with Russia to improve the situation. Important progress has been made and hard lessons have been learned along the way. The dialogue and connections that have been established, the cooperative framework that has been institutionalized, and today's more nuanced understanding of the concerns, priorities, and practices of the different actors involved should create a sound basis for new rounds of cooperative, concerted efforts to limit the persistent nuclear security and safety risks in the region (Maerli 2003f, 166).

However, a minimum level of reliable information is essential for the safe and secure handling and protection of the excessive stocks of naval fuel. As such, it is a prerequisite for long-term nuclear security in Northwest Russia.[229] But the facts surrounding Russian nuclear fuel in many instances remain well-kept secrets.

Russian authorities have been reluctant to discuss details concerning their naval fuel handling activities, despite persistent nuclear proliferation and pollution dangers and a need for openness in conjunction with concerted international nuclear clean-up efforts in Northwest Russia (Toje and Maerli 2003; Hoenneland and Joergensen 1999).[230]

Hence, a balance needs to be struck between keeping classified and sensitive information protected and at the same time providing the necessary, less sensitive, information to the parties involved in nuclear fuel handling activities in Russia.

Confidence-building measures and cultural exchange provide ideal avenues for improving this situation (Brende 2003, 10). Ideally, studies like this one could add on to the impetus of increased openness, thus fostering improved cooperative activities aimed at nuclear threat reduction.[231]

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[228] As part of the 2000 US–Russian plutonium disposition agreement, Russia now foresees MOX, based on Russian weapon plutonium, traded or leased to the European nuclear industry.

[229] As the international community now gears up to assist Russia in clean-up activities, as evidenced by the 20-billion pledge by the G–8 Global Partnership Against the Spread of Weapons and Materials of Mass Destruction, there is a need for openness. On 20 May 2003, key states signed the international agreement on Multilateral Nuclear Environmental Programme in the Russian Federation, opening up for several new projects in the northern region.

[230] Two years after the *Kursk* accident, a nuclear submarine slated for dismantling sank during towing on 30 August 2003 outside the Murmansk fjord. Nine crewmembers drowned. Despite high-level promises of improved cooperation and notification practices after the *Kursk* accident, Norwegian authorities were not informed about the latest accident. Given the state of the nearly 200 decommissioned submarines awaiting dismantling in the region, new accidents cannot be ruled out.

[231] Problems remain. In August 2003, representatives of a high-level US–Norwegian delegation were, at the last minute, denied access to a shipyard where dismantling of Russian nuclear submarines are to take place with foreign funding (Diggens 2003a).

A.7.3 Increased Non-Proliferation and Disarmament Awareness and Interest

Ideally, nuclear terrorism risk assessments like this one could also set the stage for renewed nuclear non-proliferation and disarmament awareness and interest. For nuclear disarmament to move forward in any significant way, the process has to be stepwise – and a positive learning experience (Lodgaard 1998). Education itself, however, remains an under-utilized tool for promoting peace, disarmament and non-proliferation (Potter 2001, 5).

A UN Study on Disarmament and Non-Proliferation Education concludes:[232]

> *There has never been a greater need for education in the areas of disarmament and non-proliferation, especially with regard to weapons of mass destruction, but also in the field of small arms and international terrorism. Since the end of the cold war, changing concepts of security and threat have demanded new thinking. Such new thinking will arise from those who are educated and trained today* (United Nations 2002a, 1).

Hence, future arms controllers need to start their training today.[233] Progress in arms control is likely to require skilled personnel with in-depth knowledge of political processes as well as technical know-how. Interdisciplinarity may be key.

A.7.4 Improved Transparency on Emerging Weapon Technologies

A somewhat related, yet quite subtle, study aspect concerns the need to control emerging weapon technologies. For instance, the rapidly developing field of nano-technology could prove capable of producing new types of weaponry. It is still not known whether these new technologies will increase security or potentially add to the arsenal of bio- and techno, or even nano-terrorism (Mnyusiwalla 2003, R11).

The emergence of technology in the hands of secretive or irresponsible states could pose a major threat associated with nano-technology (Knight 2003). Proposals have therefore been made to strengthen bioweapons and conventional arms control agreements in view of possible nano-technology weaponry (*The Ecologist* 2003, 41). However, such efforts are likely to be hampered by the current lack of international control mechanisms for the commercial development and use of nano-technology, and, perhaps more importantly, by strong state traditions of secrecy in weapons programmes.

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232 The study was submitted to the First Committee of the UN General Assembly at its 57th session on 9 October 2002. See http://disarmament.un.org:8080/ education/study.html (last accessed 31 October 2003).

233 The Center for Nonproliferation Studies at the Monterey Institute of International Studies in California is one important example. Attracting students from around the world, it offers inter alia a Masters degree in non-proliferation studies.

While the schemes for increased transparency and non-intrusive verification of sensitive fissile material investigated in this study by no means are applicable, some of the overarching principles and ideals may be pertinent to emerging technologies.

A.7.5 Improved Legislative Framework for Nuclear Security

The first line of defence against nuclear terrorism is the strong physical protection of nuclear facilities and material (International Atomic Energy Agency 2002a). Most countries do provide some form of physical protection for their nuclear material, but because there is no international standard or requirement for physical protection (as there is for safeguards) of civilian nuclear material, protection varies widely from country to country, and is often inadequate (Bunn and Steinhausler 2001, 2-3w).[234]

Studies like this could spur the process of improving requirements and standards for physical protection of nuclear material and facilities. Proper nuclear terrorist assessments could make states more inclined to work together to improve levels of physical protection globally. This seems paramount, not least as initiatives to strengthen international physical protection requirements are moving forward slowly.

For instance, amendment of the Convention on the Physical Protection of Nuclear Material to reach more comprehensively into domestic state practices, law and regulation is underway.[235] However, the extension is likely to be modest, with no real requirement for international reporting or information sharing, and no call for making existing physical protection standards mandatory.

Current IAEA recommendations assume, moreover, that a state's physical protection system should be based on the state's evaluation of the threat, and that this should be reflected in the relevant legislation (International Atomic Energy Agency 1999). The state should continuously review the threat, and evaluate the implications of any changes in that threat for the required levels and the methods of physical protection.[236]

234 For instance, a National Academy of Sciences committee has recommended that, to the extent possible, weapon-useable nuclear material be protected with the same high standards as intact nuclear weapons (National Academy of Sciences 1994, 31). The US government has later formalized this recommendation, but its implementation is still inadequate (Bunn 1998, 138).

235 The current Convention on the Physical Protection of Nuclear Material (INFCIRC/274 Rev.1) obligates parties to make specific arrangements and meet defined standards of physical protection for international shipments of nuclear material; cooperate in the recovery and protection of stolen nuclear material; make as criminal offences specified acts to misuse or threats to misuse nuclear material to harm the public; and prosecute or extradite those accused of committing such acts. After the extension, the convention will also cover more than just nuclear material in transit.

236 Here, however, Norway lags behind, and no national design basis threat has been established (Bremer Maerli et al. 2002).

A.7.6 Improved Nuclear Terrorism Information and Intelligence Gathering

Existing databases on movements of illicit nuclear and radiological material are diverging and need to be improved and coordinated (Schmid 2003a). Open-source reporting of illicit trafficking in nuclear material is often of poor quality, incidental and random (Zaitseva and Steinhausler 2004, 1w),[237] occasionally thickening the air with unfounded rumours about imminent terrorist attacks. The information presented is diluted and disturbed by a fairly high level of both under-reporting and over-reporting (Potter and Sokova 2002, 116–117). Under-reporting may be due to the sensitive nature of the data and reluctance of officials to release data, while the inclination of the media to sensationalize nuclear smuggling incidents and limited journalistic knowledge may result in over-reporting.

Both processes lead to incomprehensive flows of information, and a potential for confusing the public at large, policy-makers, analysts, and even intelligence communities that extract significant quantities of their data from open sources. The result may be skewed analysis and possibly under- or over-appreciated threat assessments.[238]

If the law-enforcement community is to stand a chance of disrupting nuclear deals in the making, it is of paramount importance to have accurate intelligence and underlying threat assessments. Proper threat assessment of nuclear terrorism and risk understanding could help to reduce the "background noise" and thus improve international and domestic nuclear terrorism intelligence gathering.

A.7.7 Improved Nuclear Threat Assessment and Emergency Preparedness

New and innovative consequence management is probably needed to ensure proper response to future acts of catastrophic terrorism (Hills 2003, 245–246). Many states, among them Norway, have established responsive structures for nuclear emergencies. There may, however, be significant differences between a nuclear accident, for instance in a nuclear power reactor abroad, and a planned nuclear terrorist attack (Maerli, 1999, 203; Putnam 2002). These differences should be assessed and understood.

The scale, intensity and dynamics of large-scale terror will be different from traditional acts of terrorism or natural disasters. For nuclear or radiological terrorism, response time, dose rates and dose patterns, as well as the

[237] Errors include failure to differentiate nuclear weapons-usable material from other radioactive material, incorrect use of physical units of activity and dose rate, and misquotation of isotopic characteristics and enrichment levels (Zaitseva and Steinhausler 2004, 1w). For useful overviewes of illicit trafficking incidents, see the NIS Nuclear Trafficking Database produced by the Center for Nonproliferation Studies, Monterey Institute of International Studies www.nti.org/db/nistraff/update.htm (last accessed 30 October 2003), or the Database on Nuclear Smuggling, Theft and Orphan Radiation Sources (DSTO) at the Institute of International Studies, Stanford University.

[238] For instance, do all intelligence officials know the difference between a "dirty radiological bomb" and an improvised nuclear device? How would, and should, they react to reports of seizures of large quantities of caesium at a European border crossing?

psychological responses in the public, are some key parameters that could differ. Checklists, based on specified scenarios, seem desirable.

The evaluations presented in this thesis could provide a useful starting point for such endeavours. The assessment could, moreover, help establish national capability standards for levels of preparedness, as well as creating a basis for proper preparedness preparation, requirements and procurements.[239] A critical question in civilian nuclear defence is always “how much is enough” (Craig and Jungerman 1986, 362). Appropriate responses require risk knowledge, as produced in this study.

Proper assessments of the threat of nuclear terrorism could, moreover, allow medical communities to perform *their* necessary evaluations. What kind of preparedness should, if any, be put in place to deal with low-probability/high-consequence events like nuclear terrorist attacks? To what extent should specific resources be allocated, in what ways and where? Are there possible overlaps between nuclear terrorism preparedness and primary health-care improvements? Important synergies between bio-terrorism preparedness and strengthened primary health-care have been identified (Chyba 2001).

International studies indicate that first-responders are dangerously unprepared (Rudman et al. 2003). In the event of nuclear or radiological terrorism, police and fire-fighters are likely to be among those ordered to the scene of the crime. Today, these forces are largely unprepared for such scenarios (Flood 2003; Rudman et al. 2003, 24).

How first-responders would react is an open question, and refusal to enter contaminated areas cannot be excluded (Maerli 1999). Hence, there may be a need for more exercises and training, as well as suitable equipment. In some countries, most notably the USA, specialized forces have been established to respond to acts of nuclear terrorism (Richelson 2002).

Besides, many of the current models and simulations of nuclear terrorism impact assume relatively simplistic blast, thermal, immediate radiation, and plume/fallout patterns (Cordesman 2001, 44). There has also been very little concern about EMP effects, even when modelling impacts in societies filled with computers and electric communication systems and control devices. Consequently, there could be a risk of providing erroneous estimates, and of misleading responders.

Work should hence be initiated to model the effects of nuclear terrorist effects in urban settings more realistically. Improved models should allow for better prediction of fallout and dose patterns, as well as primary and secondary effects, including the likely collapses in heath services, possible firestorms, and the risk of epidemics (see Section A.2.2 in Appendix II).

239 While the probability of terrorist attacks with nuclear, biological, or chemical material may be low in Norway, it has been recognized that the consequences of such attacks are potentially so serious that the emergency preparedness should be strengthened (Justis og Politidepartementet 2002, 5). Some measures should “immediately be carried out”, in order to increase “the atomic emergency preparedness against acts of terror” (Justis og Politidepartementet 2002, 10).

A.7.8 Improved Communication on Nuclear Terrorism Risk

The victims of acts of terrorism are not the primary targets. They are instrumental, serving mainly as message generators to impress, coerce or terrorize one or several audiences, sometimes simultaneously (Schmid 2003a, 11). The psychological impact of acts of nuclear terrorism is likely to be particularly strong (see Section 4.1.1).

As terrorism should be viewed as a type of violence-induced communication, both the propaganda dimension of the terror and the public relation of countermeasures are essential (Schmid 2003a, 12). At the same time, however, an attitude that issues related to nuclear explosives are "too complicated" and hence should be left with the experts seems to prevail (Craig and Jungerman 1986, 365).

For proper risk communication, there hence is a need for sensitivity to the situations and knowledge of those at risk, or who perceive themselves to be at risk (Irwin and Wynne 1996, 214). Generally, lay understandings of risk may be quite different from the objective risk assessments of "experts" (Reitan et al. 1996, 155; Stern 1999, 33).

Slovic (1996, 165) has stressed the urgent need to develop plans and material for communicating with the public in the event of a radiological disaster. In the event of a nuclear terrorist attack, the news media are likely to be the single most important channel of communication between the government and the public.

As such, the media may prove the real "first-responders" in a catastrophic terrorist event (Randstorp 2003b). At the same time, however, there is a symbiotic relationship between terrorists and the media (Bjørgo and Heradstveit 1993, 42; Wilkinson 1997, 54).[240] As news sources tend to focus on spectacular and negative aspects (Galtung and Ruge 1965), the media may contribute to the social amplification of risks.

Hence, the level of the threat of nuclear terrorism needs to be communicated in appropriate perspective (Putnam 2002), to journalists and the public at large. By making clearer the multifaceted characteristics of nuclear terrorism, and possible ways to prevent such catastrophic events from happening, assessments like this one could pave the way for a better dialogue between different actors in the communication process.

Again, risk understanding is an essential point of departure.

240 Simplistically put, terrorists need information channels to carry their message and display their violent acts, and the media need to sell their commodity, which is (negative) news.

Glossary[241]

Activation products: **N**on-fissile material that has become radioactive as a result of neutron irradiation.

Atom: The basic component of all matter. The atom is the smallest particle of an element that has all of the chemical properties of that element. Atoms consist of a nucleus of protons and neutrons surrounded by electrons.

Audit: A documented activity performed to determine the adequacy of, and adherence to, established procedures, instructions, specifications, codes and standards.

Becquerel (Bq): The SI unit for measuring the rate of nuclear transformations, or activity. The becquerel is defined as one radioactive disintegration per second. 1 Bq is approximately 27 pCi.

Cold War: A conflict over ideological differences between the United States and the Soviet Union and their allies lasting from the late 1940s until the early 1990s.

Contamination: The unintended or undesirable presence of radioactive substances on surfaces, or within solids, liquids or gases (including the human body).

Cooperative Threat Reduction: A U.S. programme designed to help the countries of the former Soviet Union destroy and protect nuclear, chemical and biological material and weapons, and associated infrastructure. The programme emanates from the Soviet Nuclear Threat Reduction Act of 1991, championed through Congress by Senators Nunn and Lugar.

Critical mass: If the neutrons from the fission of a nucleus cause the fission of at least one other nucleus, a fission chain reaction is produced. The minimum mass that can sustain a nuclear fission chain reaction is called the "critical mass". The fission cross-section and the average number of neutrons per fission are somewhat smaller for U-235 than they are for Pu-239, making the critical mass larger. The critical mass of enriched uranium increases as the relative amount of U-235 decreases. The critical mass of a bare solid sphere of U-235 is approximately 50 kg. However, the inevitable presence of impurities will raise this value.

Criticality: The state of a nuclear chain reaction when it is just self-sustaining (or critical), i.e. when reactivity is zero.

Crude nuclear explosive devices: Technically unsophisticated nuclear explosive devices of the first generation, possibly within the technical reach of non-state actors.

Curie (Ci): A unit of radioactive decay rate defined as 3.7×10^{10} disintegrations per second. It equals the amount of radioactivity in 1 gram of the isotope radium-226.

Decay: The process by which an unstable element is changed to another isotope or another element by the spontaneous emission of radiation from its nucleus. This process can be measured by using radiation detectors.

241 Input entities for the glossary are taken from the main text, as well as from Section I of Central Intelligence Agency 1998; International Atomic Energy Agency 2000; International Atomic Energy Agency 2002b; US Department of Energy, undated.

Decontamination: The process of making people, objects, or areas safe by absorbing, destroying, neutralizing, or removing the hazardous (radioactive) material.

Depleted uranium: Uranium that, through the process of enrichment, has been stripped of most of the uranium-235 it once contained, so that it has more uranium-238 than natural uranium. It is used in some parts of nuclear weapons and as a raw material for plutonium production.

Direct-use material: Nuclear material that can be used to manufacture nuclear explosive devices without transmutation or further enrichment. This category includes plutonium containing less than 80% of Pu-238, highly enriched uranium and U-233. Unirradiated direct-use material (such as fresh highly enriched uranium or separated plutonium) requires the least processing time and least effort to produce a nuclear explosive device.

Domestic Safeguards: See Material Protection, Control and Accounting (MPC&A).

Dose: A general term for the amount of radiation absorbed over a period of time.

Emergency preparedness: The capability to take prompt action that can effectively mitigate the impact of an emergency on human health and safety, property or the environment.

Emergency response: Actions taken to mitigate the impact of an emergency.

Enrichment: Enriching uranium increases the concentration of uranium-235 atoms in a uranium sample. When uranium is mined, it consists of heavy uranium-238 atoms (about 99.3% of the mass), together with medium-weight uranium-235 atoms (0.7%) and light-weight uranium-234 atoms (< 0.01%). See Highly Enriched Uranium (HEU).

Exposure: The act or condition of being subject to irradiation.

Fallout: Radioactive particles resulting from a nuclear explosion that gradually descend to earth.

Fat Man: The second atomic bomb used by the United States. Fat Man was dropped on Nagasaki, Japan, on August 9, 1945. Its design was of an implosion type.

First-generation nuclear explosives: Fission weapons produced for first time in the mid-1940s under the US Manhattan Project. There are two basic designs of this generation: Implosion type and gun type. See Crude nuclear explosives.

Fissile material: Nuclear material capable of undergoing fission by interaction with slow neutrons; uranium-233, uranium-235, plutonium-239, plutonium-241, or any combination of these radionuclides.

Fission: The splitting or breaking apart of the nucleus of a heavy atom usually caused by the absorption of a neutron. Large amounts of energy and one or more neutrons are released when an atom fissions.

Fission products: Radionuclides produced by nuclear fission.

Fuel assembly: A set of fuel elements and associated components which are loaded into and subsequently removed from a reactor core as a single unit.

Fuel element: A rod of nuclear fuel, its cladding and any associated components necessary to form a structural entity.

Fusion: The process whereby the nuclei of lighter elements, especially the isotopes of hydrogen (deuterium and tritium) combine to form the nucleus of a heavier element with the release of substantial amounts of energy.

G–8 Global Partnership: In June 2002, the G–8 countries launched the Global Partnership against the Spread of Weapons and Materials of Mass Destruction. Under this initiative, G–8 countries will support specific cooperation projects, initially in Russia, to address issues of non-proliferation, disarmament, counter-terrorism and nuclear safety. Among the priority concerns are the destruction of chemical weapons, the dismantlement of decommissioned nuclear submarines, the disposition of fissile material and the employment of former weapons scientists. The G–8 countries committed themselves to raise up to $20 billion to support such projects over the next ten years. Some non-G–8 countries, among them Norway, have later joined the partnership.

Gamma rays: High-energy, highly penetrating photons emitted from the nucleus of atoms, similar to x-rays. They can penetrate deeply into body tissue and many other materials. Shielding against gamma radiation requires thick layers of dense materials, such as lead. Gamma rays are potentially lethal to humans.

Gun-type design: One of the two first-generation nuclear explosive designs. In the gun-type design, one sub-critical mass is fired onto another sub-critical mass of fissile material with the use of conventional explosives. The higher probability of spontaneous fissions and, hence, a higher neutron background renders it impossible to use plutonium in the relatively slow gun-type design. Generally, it is easier to produce improvised nuclear devices by highly enriched uranium and the gun-type design than by using implosion based plutonium weapons, but the critical mass is higher.

Half-life: The amount of time needed for half of the atoms of a radioactive material to decay.

Health effects (of radiation): These may be deterministic and/or stochastic. Deterministic effects are radiation effects for which a threshold level of dose generally exists, above which the severity of the effect is greater for a higher dose. Stochastic effects are radiation-induced health effects whose probability of occurrence is greater for a higher radiation dose and whose severity (if it occurs) is independent of dose. Stochastic effects may be somatic effects or hereditary effects, and generally occur without a threshold level of dose.

Highly Enriched Uranium (HEU): Uranium enriched to 20% or more in uranium-235. It is generally considered possible to construct nuclear explosives with enrichment levels as low as 20%. When diluted to an isotopic content less than 15–20% in uranium-235, the material cannot be used in a nuclear device because sufficiently rapid super-critical assembly of the explosive becomes impractical and the critical mass too large. Weapons-grade HEU is enriched to above 90% in U-235.

***Highly Enriched Uranium (HEU) Deal*:** Under the U.S.–Russian Highly Enriched Uranium (HEU) Purchase Agreement, 500 tons of Russian HEU are to be blended to proliferation-resistant low-enriched uranium (LEU) by the year 2013. The material is to be sold to the United States for re-sale as fuel for commercial nuclear power plants. As of end of 2003, 201.5 metric tons of weapons-grade HEU had been recycled into some 5,900 metric tons of LEU power-plant fuel and delivered to the United States. The agreement is also known as the HEU “Megatons to Megawatt” deal. Transparency and non-intrusive HEU verification are prerequisites for its successful implementation.

Illicit trafficking: Receipt, possession, transfer or disposal of nuclear or other radioactive material without proper authorization.

Implosion-type design: One of the two first-generation nuclear explosive designs. To create a critical mass for implosion-design weapons, a sub-critical spherical mass is symmetrically compressed by an array of triggers packed around conventional explosives with fissile material, either weapons-grade plutonium or weapons-grade uranium, in the centre.

Improvised nuclear device: A crude nuclear explosive device possibly within the technical reach of terrorists.

Information barrier: During non-intrusive verification of fissile material in classified or sensitive forms, an information barrier must both prevent the release (accidental or intentional) of any classified information, and at the same time provide confidence that the measured systems are functioning correctly and that the unclassified display (output) reflects the true state of the measured item.

Inspection: An examination, observation, measurement or test undertaken to assess nuclear activities and compliance with formalized agreements.

International Safeguards: see Safeguards.

Isotopes: One or two atoms with the same atomic number, but with different number of neutrons and hence different mass number. There are various isotopes of uranium, which all contain 92 protons in the atom's centre (which makes it uranium). The heaviest atoms contain 146 neutrons, the middle-weight atoms contain 143 neutrons, and the light-weight have just 142 neutrons. In designating these isotopes, it is common to add together the number of protons and neutrons and then attach that total on the back of the name: uranium-234, uranium-235, and uranium-238.

Lethal dose: The dose of radiation expected to cause death without medical treatment.

Little Boy: The first atomic bomb used by the United States. Little Boy was dropped on Hiroshima, Japan, on August 6, 1945. Its design was of a gun-type.

Low Enriched Uranium (LEU): Uranium enriched to below 20% in U-235. Nuclear reactor fuel typically consists of about 3% uranium- 235 and 97% uranium-238.

Manhattan Project: The U.S. Government project, named for the Manhattan Engineer District that produced the first nuclear weapons during World War II. Started in 1942, the Manhattan Project formally ended in 1946. The Hanford Site, the Oak Ridge Reservation, and the Los Alamos National Laboratory were created for this effort.

Material Protection, Control and Accounting (MPC&A): Systems intended to protect material against theft or diversion, and to detect such events if they occur. The systems consist of a combination of physical protection to delay and detect intrusion; control and containment to prevent unauthorized movement of material; and, finally, accounting to ensure all material is accounted for, to enable the measurement of losses, and to provide information for follow-up investigations in case of irregularities.

Monitoring: The measurement of radiation and the interpretation of the results for verification purposes.

MOX: Mixed Oxide Fuel. It usually contains natural or depleted uranium and plutonium oxides.

Mutually assured destruction (MAD): A Cold War concept whereby if one side first launched a nuclear attack, the other side would retaliate in kind.

Naval reactor: A class of nuclear reactors used for propulsion of surface ships and submarines.

Non-intrusive verification: Fissile material verification activities carried out in such a manner that sensitive or classified information is protected. The verification technique normally includes both procedural and technical means, for instance the use of information barriers.

Non-state actors: Sub-national terrorist groups.

Nuclear husbandry: Responsible, careful, and judicious handling, protection and control of fissile material. Seven Nuclear Husbandry Functions span the spectrum of nuclear security activities.

Nuclear installation: A facility that is part of the nuclear fuel cycle or a nuclear research institution.

Nuclear Reactor: A device that sustains a controlled nuclear fission chain reaction.

Nuclear security: Prevention of the loss, theft or unauthorized use of nuclear material or nuclear explosives.

Nuclear terrorism: Acts of violence and destruction performed by non-state actors where the means applied are nuclear explosive devices – or threats of the use of such actions – with the purpose of inflicting destruction, creating fear, getting attention, blackmailing, installing instability, and affecting a wider audience than only the victim(s) directly targeted.

Nuclear weapon complex: The chain of foundries, uranium enrichment plants, nuclear reactors, chemical separation plants, factories, laboratories, assembly plants, and test sites that produces nuclear weapons.

Plutonium-239: A metallic element used for nuclear weapons with a half-life of 24,110 years. For plutonium, more than 90% Pu-239, denoted "weapons-grade plutonium", will normally be preferred in weapon designs, although virtually all combinations of plutonium isotopes may be used to manufacture nuclear explosives. An exception is plutonium containing substantial quantities of Pu-238, which generates so much heat and gamma radiation that it is not practical for use in nuclear explosives. Even reactor-grade plutonium is considered by the International Atomic Energy Agency as direct-use, i.e. weapons-useable material.

Practical nuclear arms control measures: Measures to protect and control nuclear material, i.e. to increase nuclear security, by means of designated tools.

Prophylaxis: The act of preserving from, or of preventing, disease; the observance of the rules necessary for the preservation of health; preservative or preventive treatment.

Public-Interest Science: Qualified scientists and researchers provide independent technical analysis, and present their findings directly to the public, either through the media or at public hearings. Practitioners of public-interest science often denote themselves "citizen-scientists".

Radiation: Alpha or beta particles or gamma rays that are emitted by an atom as the substance undergoes radioactive decay.

Radiation Dispersal Device (RDD): A device other than a nuclear explosive device, designed to disseminate radioactive material in order to cause destruction, damage, or injury by means of the radiation produced by the decay of such material.

Radioactive material: Material exhibiting radioactivity.

Radioactivity: The phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of radiation.

Radiological terrorism: Acts of terror performed by non-state actors where the means applied are radioactive substances.

Reliability: The probability that a system will meet its minimum performance requirements when called upon to do so.

Research reactor: A class of nuclear reactors used to do research into nuclear physics, reactor materials and design, and nuclear medicine. Some research reactors also produce isotopes for industrial and medical use.

Risk: A multi-attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.

Safeguards: Control activities performed by the International Atomic Energy Agency, comprising a set of technical measures by which the IAEA independently verifies the correctness and completeness of declarations made by states about their nuclear material and activities.

Secrecy: Deliberately concealing intents, capabilities, and actions. Secrecy may be viewed as the opposite of transparency. It may be justified from the perspective of national security and international non-proliferation obligations.

Shielding: Dense materials (lead, concrete, etc.) used to block or attenuate radiation for protection of equipment, materials or people.

Significant Quantity (SQ): A measure used in establishing the quantity component of the IAEA inspection goal. The Significant Quantities take into consideration unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses. SQs are defined as 8 kg of plutonium or uranium-233 or 25 kg of uranium-235 contained in a uranium product enriched to 20% or more in uranium-235.

***Special fissionable material*:** This category contains Pu-239, U-233, and uranium enriched in the isotopes U-233 and U-235, or any material containing one or more of the foregoing; and other such fissionable material as the International Atomic Energy Agency Board of Governors shall from time to time determine.

***Spent fuel*:** Nuclear fuel removed from a reactor following irradiation, which is no longer useable in its present form because of depletion of fissile material, poison build-up or radiation damage.

Thermonuclear weapon: A nuclear weapon that uses fission to start a fusion reaction. Commonly called hydrogen bomb or “H-bomb”. Non-state actors are unlikely to have the know-how and competence needed to construct sophisticated nuclear weapons like this.

Threat**:** A (personally) felt or perceived concern about a looming peril, normally non-quantifiable.

Transparency**:** A process in which information about governmental actions, preferences, intentions, and capabilities is made available, or more properly, allowed to flow, to citizens and the international community. Transparency surpasses required activities, such as reporting or verification obligations mandated by treaty. Transparency is "permitted knowledge", and may be viewed as the opposite to secrecy.

Uranium-235**:** U-235 is used as a reactor fuel or for weapons. Naturally occurring uranium U-235 is found at 0.72% enrichment. For fission explosives, nuclear weapon designers prefer a U-235 fraction of more than 90%, normally denoted "weapons-grade uranium". The half-life is 7.04×10^8 years.

Validation**:** The process of determining whether a product or service is adequate to perform its intended function satisfactorily.

Verification**:** The process of determining whether the quality or performance of a nuclear activity is as intended or as required by treaty.

Weapons-grade material**:** See direct-use material.

Weapons-useable material**:** See direct-use material.

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