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E-NOTES

"A nation must think before it acts." - Robert Strausz-Hupé

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Iran, DAESH & the Rising Specter of Radiological Warfare in the Middle East

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The official silence on radiological warfare probably is expressive of classification rather than disinterest.[1]

Louis Ridenour (1949)

Ironically, in the post-cold war world, one of the safest places for plutonium may well be on top of a missile.[2]

Paul Woessner & Phil Williams (1996)

Among the several argued deficiencies of the nuclear agreement between the P5+1 and Iran, the most abject is perhaps also the least discussed—the consummate failure to address radiological weapons.

The use of radiological weapons has been called the "poor man's nuclear warfare."[3] So it may come as a surprise that the international community has never negotiated a treaty prohibiting radiological weapons, this despite their definition as a "weapon of mass destruction" (WMD) by the United Nations and the United States, among others.

This essay takes on the grim subject of radiological weapons, perhaps the most vilified of an already-vilified class of weapons. That term—WMD—is a misnomer when applied to radiological weapons, however, as their effect is more likely localized, ephemeral and disruptive rather than destructive on a mass scale.

Radiological weapons are an inherent part of the nuclear risk[4] but infrequently considered independent of it, save in the context of their improvised embodiment, the terrorist's "dirty bomb." That term excludes the likely more lethal class of military-grade radiological weapons to which nuclear and near-nuclear states such as Iran or Syria (or for that matter, Israel) today have access. To the extent these weapons are ever discussed, it is usually in a defensive context, for example, as an area-denial weapon, the proverbial "Death Sand" (*Todessand*)[5]-- this despite James Ford's observation that while radiological

The translation of all source material is by the author unless otherwise noted.

[1] Louis N. Ridenour (1949). "How Effective Are Radioactive Poisons in Warfare?" Bulletin of the Atomic Scientists. 6:7 (July 1950), 224.

[2] Paul N. Woessner & Phil Williams (1996). "The Real Threat of Nuclear Smuggling." *Scientific American*. 274:1 (1 January 1996), 41. Last accessed 4 July 2015.

[3] From a 1964 *New Scientist* article by the same name on the same subject.

[4] So write Torsten Sohns in his essay, "Protection Against Weapons of Mass Destruction: A German Perspective." See: Sohns (1998) in Oliver Thränert (1999). *Preventing the Proliferation of Weapons of Mass Destruction: What Role for Arms Control?* (Bonn & Berlin: Friedrich-Ebert-Stifung), 145.

[5] The phrase "Death Sand"—*Todessand* in the original German text—is from a 1949 monograph by the Austrian physicist Hans Thirring. See Thirring (1949). "Über Das Mögliche Ausmaß Einer Radioaktiven Verseuchung Durch Die Spaltprodukte Des U235." *Actua physica austriaca*. (Wien: Springer), 379. An American 1950s popular writer of the 1950s, J. Alvin Kugelmass, called it "Our silent mystery weapon:

weapons "may not be well suited as 'military weapons' in the classic sense," their use "could be powerfully coercive."[6]

Gavin Cameron thought radiological weapons the "most likely form of nuclear device as well as the least catastrophic."[7] What he meant is that they possess the least lethal potential of all nuclear devices—Stephen Gowan stops here, sardonically dismissing radiological weapons as "weapons of little destruction"[8]—but are capable of inflicting widespread psychological and economic damage even if their lethal effects are more confined.

> "[B]eing nuclear, it conveys an added prestige and status on the perpetrators. Radiological terrorism would set a group apart and take its terrorism to a new level, so has considerable attractions. Furthermore…the arguments that make a nuclear-yield device an unlikely, if dangerous, threat apply to a much lesser degree for radiological weapons. While a nuclear-yield bomb would be extremely expensive and difficult mass-casualty weapon, a radiological device would only be moderately difficult."[9]

While his image of a people held hostage by radiological weapons—a "large-scale Lod"[10]—is no less vivid today, the language employed c.1975 by the RAND Corporation's Brian Jenkins (whom Cameron quotes) to diminish their threat seems almost quaint:

> "Terrorist actions have tended to be aimed at producing immediate dramatic effects, a handful of violent deaths—not lingering illness, and certainly not a population of vengeance-seeking victims…If terrorists were to employ radioactive contaminants, they could not halt the continuing effects of their acts, not even long after they may have achieved their ultimate political objective. It has not been the style of terrorists to kill hundreds or thousands."[11]

Modern day violent actors indubitably seek both immediate dramatic events ***and*** the deaths of thousands, and are not fearful of an imagined "population of vengeance-seeking victims."[12]

It is easily conceived if not often openly acknowledged that radiological weapons could be used in an offensive capacity, much like their improvised cousin, the dirty bomb, wrought large(r). As conceptualized by the United States in World War II, offensive radiological weapons could be used variably to contaminate terrain or "as a gas warfare instrument" (i.e., "radioactive poison gas").[13]

It is reasonable to postulate that a state menaced by a radiological weapon-capable adversary—state or non-state—would try to rate that risk and to erect a workable defense, possibly extending to "a radioactive maginot line."[14] Israel has indeed been

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death sand."

[6] James L. Ford (1998). "Radiological Dispersal Devices: Assessing the Transnational Threat." *Strategic Forum*. 136 (March 1998). http://www.au.af.mil/au/awc/awcgate/ndu/forum136.htm. Last accessed 9 July 2015.

[7] Gavin Camaeron (2001). "Nuclear Terrorism: Reactors & Radiological Attacks After September 11." Paper presented to the IAEA Meeting 2/11/01. .\ http://www.gazettenucleaire.org/~resosol/InfoNuc/documents-importants/IAEA%20Nuclear%20Terrorism%20After%20September%2011.pdf. Last accessed 8 July 2015.

[8] Stephen Gowans (2015). "The Concept of WMD, and its Use against Syria, in the Propaganda Systems of Western States." https://gowans.wordpress.com/2015/05/20/the-concept-of-wmd-and-its-use-against-syria-in-the-propaganda-systems-of-western-states/. Last accessed 9 July 2015.

[9] *Ibid.,* 15-16.

[10] Jenkins is referring to the Roman siege of Lod (then called *Lydda*) during the Kitos War (CE 115-117).

[11] Brian M. Jenkins (1975). "Will Terrorists Go Nuclear?" RAND Corporation report no. P-5541 (November 1975), 6. http://www.rand.org/content/dam/rand/pubs/papers/2006/P5541.pdf. Last accessed 9 July 2015.

[12] Others reached a similar conclusion: "Above all else, the concept that a 'new' form of terrorism has emerged resonates through the recent literature. In particular, a number of authors have begun to question the long-held notion that 'terrorists' want more people watching than dead.' Many now claim that this view, espoused by Brian Jenkins several years ago, may have been true insofar as secularly motivated terrorist organizations were concerned, but that such an idea might not characterize well some contemporary groups." National Defense University Center for Counterproliferation Research (2002). "Chemical, Biological, Radiological, and Nuclear Terrorism: The Threat According to the Current Unclassified Literature" (30 May 2002), 4-5.

[13] Subcommittee of the S-1 Executive Committee (1943). Document E. Memorandum from Drs. Conant, Compton & Urey to Brigadier General L. R. Groves on "Use of Radioactive Material as a Military Weapon."

[14] The author asked whether radioactive waste "could be spread in front of a defense position, thereby creating a radioactive 'maginot line'. Any enemy troops that crossed it would face certain death." R. De Rose (1955). "What are we doing about our deadly atomic garbage?" *Collier's* (20 August 1955), 34. Quoted in Adri De La Bruheze (1992). "Radiological Weapons and Radioactive Waste in the United States:

engaged in a defensive effort, apparently for at least the past decade. It is also reasonable that a state might assess whether radiological weapons (even if it is ambiguous about possessing them) can serve some deterrent role, even if its sole mission is a narrowly defined preemptive one. Such a mission might well involve rendering a clandestine facility—where, say, a rogue state was pursuing weapons-grade enrichment activities at scale—unusable for an extended period of time, even if physical destruction of the facility was unachievable.

It is the author's contention that radiological weapons in the Middle East have a significant albeit under-acknowledged provenance—and a significant if almost never acknowledged place in regional arsenals. Together with the sustained presence in the region of hostile, radiological weapon-aspirant non-state groups such as ISIL/DAESH[15] and Al-Qa`ida, it is worth asking: is there a rising specter of radiological warfare in the Middle East? Answering that question requires, in good FPRI fashion, that one understand historical and technical factors that influence the place of radiological weapons in order to put those factors in proper contemporary context.

Radiological Weapons: A Primer

Like a particularly vicious form of poison gas.
-Henry DeWolf Smyth

Radiological weapons were added to the legal definition of weapons of mass destruction in 1994, joining the triad nuclear-biological-chemical when the term was first codified in 1992. WMD is too oblique a term, however, for radiological weapons. Those designed to kill or main large numbers of human beings are more properly described as *weapons of mass victimization*.[16] Likewise, radiological weapons designed deliberately to render structures and land useless for long periods of time are best characterized as *weapons of mass contamination*.[17]

The formal definition of a radiological weapon is a device—other than a nuclear explosive one—designed to employ radioactive material by disseminating it to cause damage, destruction or injury by means of the radiation produced by the material's decay. An explosive radiological weapon (RW) or radiological dispersion device (RDD) combines an explosive device and radioactive material, detonating the former to disperse and scatter the latter.[18] A fragment[19] RW/RDD uses a high explosive (e.g., dynamite) to disperse radioisotopes[20] (either alone or in combinations of two or more) that are in the physical

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Insiders' and Outsiders' Views, 1941-55." *The British Journal for the History of Science*. 25:2, 224.

[15] The author has elected to use DAESH, an adapted acronym of the group's transliterated Arabic name, *ad-Dawlah al-Islamiyah f'il-Iraq wa'sh-Sham* or "Islamic State of Iraq and the Levant".

[16] James D. Ballard (2000). "Weapons of mass victimization: Considerations for the 21st century." Paper presented at the United Nations Congress on terrorist victimization: Prevention, control and recover, Vienna, Austria.

[17] Using radiological weapons "to contaminate small critical areas" was proposed as far back as the United States War Department's 1943 paper "Use of Radiological Material as a Military Weapon" [http://nsarchive.gwu.edu/radiation/dir/mstreet/commeet/meet3/brief3.gfr/tab_f/br3f1e.txt]

[18] Other devices are designed to disperse radioactive aerosols by active means other than an explosive detonation, e.g., sprayers, or by passive exposure to radioactive material. These types of devices while they can produce serious effects are not of particular interest in the context of this essay.

[19] A high explosive (HE) weapon can be tailored so that one or another of its damage-agents dominates its effects, the result being predominantly either a blast weapon or a fragmentation weapon. In a fragmentation weapon, a HE charge is surrounded by material designed to split into fragments upon detonation and disperse (sometimes directionally).

[20] A chemical element has unique chemical properties that derive from the number of *protons* or positively charged particles inside the nucleus, which also contains uncharged particles called *neutrons* that determine its nuclear properties. Each element has a family of different nuclear forms called *isotopes* that have the same number of protons but different numbers of neutrons. Most isotopes are unstable and undergo radioactive decay during which ionizing radiation is emitted. Called *radioisotopes,* they can emit different types of ionizing radiation are alpha, beta, and gamma radiation. Alpha emitters decay by releasing a helium nucleus (two protons and two neutrons, called an alpha particle) and are relatively harmless as external hazards because their range is short. They can, however, cause significant cellular damage if inhaled and deposited in lung tissue; ingested through contaminated food; or if they enter an open wound. Beta emitters decay by releasing a high-energy electron (a beta particle). While they can cause skin lesions (a "beta burn"), beta emitters are relatively harmless unless internalized. Gamma emitters decay by releasing highly energetic gamma rays that, unlike alpha and beta particles, easily penetrate the skin. In high doses, gamma emitters can cause Acute Radiation Syndrome (ARS) *aka* radiation toxicity or radiation sickness. ARS is a set of symptoms resulting from injuries to the bone marrow, gastrointestinal system, cardiovascular system, central nervous system, gonads, and skin by internal exposure to ionizing radiation. The onset latency and magnitude of ARS are determined primarily by the total radiation dose received, the rate of delivery of the radiation, and the distribution of radiation in the body. An isotope's half-life is a measure of the amount of time it takes for half the radioactive substance to decay. A short half-life means a rapid decay, and a long half-life means a more lengthy decay.

form of a metal or a ceramic. The radionuclides of choice are cobalt-60, strontium-90, and plutonium-238, any of which is sufficiently long-lived to cause long-term radioactive contamination of structures and soil.[21] Cobalt-60 is normally produced in metallic pellets that that an explosive detonation disperses in small metallic fragments. Cleaning a contaminated area involves searching for and collecting these particles, which though time-consuming is relatively straightforward. Strontium-90 and caesium-137 in the form of a powdery salt are highly dispersible, making decontamination difficult and time-consuming.

Military-grade RW/RDD will be referred to as radiological weapons to distinguish them from non-military improvised weapons. Although the principal intended effect of detonating a fragment radiological weapon is to distribute radioactive material and cause radioactive contamination, the detonation's blast effect can also cause physical trauma, thermal burns, and in some cases, radiation injury depending of the magnitude of the explosion. The immediate lethality is almost always due to the blast effect. The use of pulverized or powdered radioactive material is a meaningful advantage of military-grade versus improvised weapons. Powdered metals pose a risk of spontaneous ignition—along with metal dust, powdered metals are prone to explode when in contact with oxygen—that usually precludes the use of these forms in improvised weapons since the danger increases drastically when radioactive metals are used.[22]

The radioactive material released in a detonation causes two different effects, *radiation exposure* and *radioactive contamination*. Radiation exposure—also called irradiation—occurs when external ionizing radiation penetrates tissue; it does not require any physical contact with radioactive material. Humans are susceptible to external and internal radioactive contamination. External contamination occurs when radioactive material settles on clothing, hair, or skin. Internal contamination occurs when where radioactive material is inhaled, ingested, or absorbed through the skin or wounds. While radiation exposure does not perforce imply radioactive contamination, radioactive contamination always involves radiation exposure. The radiation dose[23] can accumulate over time; thus, the extent of any injury depends on the duration and the amount of radiation exposure and radiation contamination.

From the security viewpoint, radioisotopes with medium half-lives (on the order of months to decades) present far greater security risks than very short (minutes or seconds) or very long half-life radioisotopes.

Medium Half-Life Commercial Radioactive Sources

Radioisotope	Half-Life	High Energy Alpha Emissions	High Energy Beta Emissions	High Energy Gamma Emissions
Cobalt-60	5.3 years	N/A	Low-energy	Yes
Cesium-137	30 years	N/A	Low-energy	N/A
Iridium-192	74 days	N/A	Yes	Yes
Strontium-90	29 years	N/A	Yes	Low-energy
Californium-252	2.7 years	Yes	No	Low-energy
Plutonium-238	88 years	Yes	No	Low-energy

The impact of prompt radiation is extremely difficult to estimate, and lethal and serious doses can vary sharply according to exposure even in the same areas. There are deterministic injuries—when an individual receives a known exposure to radiation and became ill as a result—and stochastic ones—likely future illnesses resulting from radiation exposure—as well as non-quantifiable psychosocial damage. Moreover, the characterization of radiological weapons presents a significantly greater

[21] Co-60 is a beta and multiple gamma emitter with half-life of 5.27 years. Sr-90 is beta emitter with a half-life of 29 years. Pu-238 is an alpha emitter with a half-life of 87.5 years.
[22] Julian Palmore (2003). "'Dirty Bombs': An analysis of radiological weapons." *Defense & Security Analysis*. 19:1, 70. http://www.tandfonline.com/doi/pdf/10.1080/1475179032000058035. Last accessed 4 July 2015. Palmore illustrates this point with the historical example of Nazi Germany's use of aluminum powder in high explosives (Amatol) to increase the yield of V-2 rocket warheads by as much as 30 percent.
[23] Two different materials, if subjected to the same gamma-ray exposure, will in general absorb different amounts of energy. The energy absorbed by any type of material is defined as the *absorbed dose*, the historical unit for which is the *radiation absorbed dose* or "rad". It refers only to energy absorbed by a type of material. It is energy absorption that causes biological damage along with ionization, which creates radicals and causes chemical reactions to occur.

problem than does the detection of these weapons. Estimating the type and effects of a specific radiological weapon — particularly true of contamination—is difficult.[24]

That being said, external decontamination of humans can be as simple as removing contaminated clothing and shoes (where about 95 percent of external agents settle) and washing the skin and hair with soap and water. Normal body-cleansing mechanisms (e.g., digestion and excretion) will achieve partial internal decontamination, and can be supplemented through the use of dilution (e.g., water, phosphorus) and decorporation agents (e.g., laxatives, chelating compounds). The use of blocking agents can inhibit uptake of some radioactive materials (e.g., Sr-89, Sr-85).

The physical effects of a radiological weapon detonation are dependent on several factors, among which the type and the amount of radioactive material are especially critical.[25] The effects in open-air detonations are highly dependent on local weather conditions and terrain:

> "Early experiments showed that cities, or build-up areas, would require 'something approaching 100 times greater concentration' because structures would absorb a large fraction of the radiation. As a result of these early studies, the U.S. government concluded that RDDs were not a 'militarily useful weapon'."[26]

The decontamination of buildings and other structures can be complicated by the fact that certain radioactive substances are water-soluble (e.g., cesium-137), and penetration of the solution into materials like concrete may be followed by the virtually irreversible fixation of the dissolved elements.[27] Likewise, some radioactive substances including cesium-134 and strontium-85 react and bond with concrete and other substances (e.g., tile, asphalt), making decontamination expensive and time consuming.

Victor L. Issraelyan wrote in 1982 when he was Soviet ambassador to the United Nations Disarmament Conference:

> "Since radiological weapons are not yet developed and have never been used on the battlefield, it is difficult to speak of their effectiveness in military terms. However, it is quite easy to conceive of several hypothetical possibilities for their use, for example, as a means for an offensive military operation on the battlefield, for deliberate long-lasting radioactive contamination, or for establishing radioactive barriers."
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> "It is quite obvious that military requirements in each particular case can vary considerably. While in one situation it might be preferable to employ radioactive materials of high intensity with a short half life, in others only radioactive materials of medium intensity with a long half life would be used."[28]

Issraelyan's suggested "radioactive barrier" might involve, for example, establishing an obstacle (particularly in an area where terrain features cannot be exploited) that is seeded with sodium carbonate (soda ash), which becomes highly radioactive when exposed to neutrons produced in a nuclear explosion.[29] It evokes Eliot's imagery:

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[24] Anthony H. Cordesman (2001). "Radiological Weapons as a Means of Attack." Center for Strategic & International Studies, 8 November 2001. http://csis.org/files/media/csis/pubs/radiological[1].pdf. Last accessed 11 July 2015.
[25] James L. Ford (1998). *Radiological Dispersal Devices: Assessing the Transnational Threat.* Institute for National Strategic Studies. 136 (March 1998), 3.
[26] *Ibid.,* 3-4.
[27] J. Real, et al. (2002). "Mechanisms of Desorption of 134Cs [cesium-134] and 85Sr [strontium-85] Aerosols Deposited on Urban Surfaces." *Journal of Environmental Radioactivity*. 62:1, 7.
[28] Victor L. Issraelyan & Charles C. Flowerree (1982). "Radiological Weapons: A Soviet and US Perspective." The Stanley Foundation Occasional Paper 29 (February 1982), 21. https://www.nonproliferation.org/wp-content/uploads/2014/02/radiological_weapons_control_op.pdf. Last accessed 7 July 2015.
[29] The suggested application is from Roger D. Speed (1979). *Strategic deterrence in the 1980s*. (Standord: Hoover Institute Press), 118-119. The idea, however, is neither novel nor new. In March 1944 the Manhattan Project's commanding officer, General Leslie R. Groves, warned General Marshall, "Radioactive materials are extremely effective contaminating agents; are known to the Germans; can be produced by them and could be employed as a military weapon. These materials could be used without prior warning in combatting an Allied invasion of the Western European Coast." [Groves (19632; 1983). *Now It Can Be Told: The Story of the Manhattan Project.* (New York: DeCapo Press)] General MacArthur advocated something similar to President-elect Eisenhower during the Korean War, similar to the radioactive barrier across North Korea he proposed in 1950.

"What are the roots that clutch, what branches grow
Out of this stony rubbish?"[30]

However horrific a radioactive barrier may seem, it was given serious consideration by the United States in the 1940s and 1950s.

A Wartime America Assesses Radiological Weapons.

A magnificent example of military madness being encouraged by learned professors.[31]

A May 1941 National Academy of Sciences report contemplated the "production of violently radioactive materials...carried by airplanes to be scattered as bombs over enemy territory" as the first of three "possible military aspects of atomic fission."[32] The "violently radioactive" material of choice was strontium-89, which is produced more abundantly by nuclear weapons than strontium-90 and is far more radioactive,[33] also yielding a very high radiation dose when internalized.

Two years hence, no less a figure than Robert Oppenheimer suggested the United States investigate possible "military uses of radioactive materials"—again strontium—during World War II.[34] Oppenheimer was prompted by doubts whether a fission weapon could be produced—and if so, how soon—raising the question of radiological weapons as a possible fallback.[35]

In July 1945, the Smyth Report—named for Henry DeWolf Smyth, its author and a consultant to the Manhattan Project—hypothesized it would be "possible to extract [radioactive fission products] and use them as a particularly vicious form of poison gas."[36] The 1946 CROSSROADS tests at Bikini Atoll in the Marshall Islands yielded dramatic evidence of the destructive potential of radiological warfare. Oppenheimer once again raised the question of military uses, writing in July 1947:

> "As everyone knows, the third[37] is that fission products can be used as poisons. I do not know whether this is a particularly effective form of warfare."[38]

The absence of international control over military uses of radioactive material prompted him to suggest again that the United States investigate and, if found practicable, produce radiological weapons. In February 1948 a group he chaired—the United

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[30]*The Waste Land*, lines 19-20.

[31]Barton J. Bernstein (1985). "Oppenheimer and the Radioactive-Poison Plan." *MIT Technology Review*. 88:4 (May/June 1985), 17. Bernstein quotes an unnamed "distinguished physicist" concluding about Oppenheimer ("who [he] first knew…in the postwar years at Princeton"), "it is a magnificent example of military madness being encouraged by learned professors."

[32] Quoted in Richard Rhodes (1986). *Making of the Atomic Bomb.* (New York: Simon & Schuster), 365. Later that same year, Princeton physicists Henry DeWolf Smyth and Eugene Wigner reported that the fission products produced in one day's operation of a 100-megawatt reactor could render a large area uninhabitable. While the NAS did not recommend the use of "radioactive poisons," but serious consideration was given to the possibility that Nazi Germany might do so, and recommended defensive measures. See: Eugene Wigner & Henry D. Smyth (1941). "Radioactive Poisons." National Academy Project, 10 December 1941. (ACHRE No. NARA-033195-A).

[33] 1 gram of Sr-89 has a radioactivity of 27,800 curies which the same 1 gram of Sr-90 has a radioactivity of 143 curies.

[34] He wrote, "I think we should not attempt a plan [to investigate the use of strontium] unless we can poison food sufficient to kill a half a million men, so there is no doubt the actual number affected will, because of non-uniform distribution, be much smaller than this." See: "Letter from Robert Oppenheimer to Enrico Fermi dated 25 May 1943." Quoted in Bernstein (1985), *op cit.,* 14-17.

[35] Advisory Committee on Human Radiation Experiments (1996). *Final Report of the Advisory Committee on Human Radiation Experiments.* (New York: Oxford university Press), 325.

[36] Smyth, Henry De Wolf (1945). Radioactive Poisons, Section 4.27. *A General Account of the Development of Methods of Using Atomic Energy for Military Purposes under the Auspices of the United States Government, 1940-45*. (Washington, DC: Government Printing Office). This document is commonly referred to as "The Smyth Report". http://www.atomicarchive.com/Docs/SmythReport/smyth_iv.shtml. Last accessed 8 July 2015. The authors were quick to qualify in the following paragraph (Section 4.28) that they "did not recommend the use of radioactive poisons nor has such use been seriously proposed since by the responsible authorities, but serious consideration was given to the possibility that the Germans might make surprise use of radioactive poisons, and accordingly defensive measures were planned."

[37] The "third" refers to the last of three "monopoly" fields of use that Oppenheimer suggested should be reserved to the international agency contemplated by the 1946 Acheson-Lilienthal Report (formally, the "Report on the International Control of Atomic Energy"). Oppenheimer was a member of the committee that prepared the Acheson-Lilienthal Report.

[38] J. Robert Oppenheimer (1947). "Functions of the International Agency in Research and Development." *Bulletin of the Atomic Scientists*. 3:7, 176. Bernstein (1985), *op cit.,* 17, quotes an unnamed "distinguished physicist" concluding about Oppenheimer ("who [he] first knew…in the postwar years at Princeton"), "it is a magnificent example of military madness being encouraged by learned professors."

States Atomic Energy Commission's General Advisory Committee[39]—recommended forming an ad hoc panel under the Atomic Energy Commission. It was chartered

> "for the purpose of examining the present status of possibilities of employing radioactive materials in warfare and of suggesting useful field tests of proposals and weapons relating to the problem of dispersal," including possible defenses against radiological weapons."[40]

The ad hoc panel began work in April 1948 by exploring the large-scale production of radioisotopes for use as radiological warfare "agents." Oppenheimer's committee suggested the ad hoc panel take the approach of an offensive-defensive competition "between those who wish to disperse the material in order to contaminate an area and those who would attempt to decontaminate it."[41]

The parallel Military Liaison Committee expert panel did just that, i.e., study the offensive and defensive aspects of what it termed "Rad War". While early experiments concluded radiological weapons were ineffective battlefield weapons—denying territory during a military campaign, the Defense Department concluded, required an operational radiological weapon capable of producing a sustained high radiation dose rate over an area of at least $10km^3$—the weapons could have a significant psychological effect. While Oppenheimer's GEC panel remained focused primarily on the production question, it disbanded in November 1950 without recommending specific radiological warfare agents or a preferred production method.[42]

Around the same time, another noted physicist, Louis N. Ridenour,[43] wrote an article asking "How Effective Are Radioactive Poisons in Warfare?"[44] Regarding what he called *radioactive poisoning*—"the delivery to a target of radioactive materials"—Ridenour wrote:

> "This is a novel type of warfare, in that it produces no destruction, except to life. Even the hazard to life and health is short-lived, its duration being governed by the lifetime of the radioactive materials used."
>
> "Radioactive poisoning of this sort is a novel thing. It can be regarded as a horrid and insidious weapon, since the person in a poisoned area has no way of knowing that he is in danger…He may receive a lethal dose of radiation two weeks before he knows he is endangered, and yet a few days later he may be dead."
>
> "On the other hand, this weapon can be regarded as a remarkably humane one. In a sense, it gives each member of the target population a choice of whether he will live or die. For, as we shall see, the concentrations of radioactivity that it is practicable to use will surely kill a person who remains in the affected area a month, while giving an excellent chance of survival to a person who flees at once, with a folded, dampened handkerchief over his nose and mouth. The high explosive and incendiary bombs of the last war gave the target population no such choice. They killed you or they didn't, and the issue was decided in a flash, without your participation in the judgment."[45]

After an extended discussion of various technical questions, Ridenour sums up by asking, "What shall we conclude from all of this?"

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[39] The General Advisory Committee or "GEC" was one of two bodies established under the 1946 Atomic energy Act (the other being the Military Liaison Committee or "MIC") to provide consultative support to the United States Atomic Energy Commission.
[40] Adri De La Bruheze (1992). "Radiological weapons and radioactive waste in the United States: insiders' and outsiders' views, 1941–55." *The British Journal for the History of Science*. 25, 214. https://journals.cambridge.org/download.php?file=%2F8063_100DD6124837D5E6CD26D99B7D3F7410_journals__BJH_BJH25_02_S0007087400028776a.pdf&cover=Y&code=542fd2d6fe250d07ae713db408d36660. Last accessed 8 July 2015.
[41] De La Bruheze (1992), *op cit.,* 217.
[42] *Ibid.,* 219.
[43] Ridenour at the time was a physics professor and Dean of the Graduate School of the University of Illinois.
[44] Louis N. Ridenour (1949). "How Effective Are Radioactive Poisons in Warfare?" Bulletin of the Atomic Scientists. 6:7 (July 1950), 199-202, 224. https://books.google.ca/books?id=4g0AAAAAMBAJ&pg=PA193&dq=Bulletin+of+the+Atomic+Scientists+%22How+effective+are+radioactive+poisons+in+warfare%22&hl=en&sa=X&ei=C2udVfKpLYvw-QHxnYGYBQ&ved=0CCAQ6AEwAQ#v=onepage&q=Bulletin%20of%20the%20Atomic%20Scientists%20%22How%20effective%20are%20radioactive%20poisons%20in%20warfare%22&f=false. Last accessed 8 July 2015.
[45] *Ibid.,* 200.

> "The area that can be poisoned with the fission products available to us today is disappointingly small; it amounts to not more than two or three major cities per month. The problems presented by the proper use of fission products in war are very difficult. Despite these drawbacks, the novel and unique properties of the weapon may well make it useful in special situations."[46]

It is understandable that looking back, the *Bulletin of the Atomic Scientists* described Ridenour's as "one of the most bizarre articles in the history of the Bulletin."[47]

The Army Chemical Corps continued to carry out radiological weapons-related tests at Oak Ridge and the Proving Ground into at least the mid-1950s. The CIA in 1957 determined that the agency "will consider the possibilities for clandestine use of radiological weapons in general war, and will seek policy approval of plans for their use as feasibility may be indicated,"[48] but there was little documented interest in developing radiological weapons for the next four decades.[49] The United States radiological weapons testing program remained classified until 1974, and largely unknown thereafter until a 1993 General Accounting Office report.[50]

Forewarned Is Forearmed: Israel Assesses its Radiological Defense

It was made clear during the war that [chemical, bacteriological & radiological] weapons are very decisive. It was also made very clear that the moral teachings of the world are not very effective when war reaches a serious stage…We should fully equip ourselves in the defensive and offensive use of [these] weapons."[51]

Israel is a fake temporary state. It's a foreign object in the body of a nation and it will be erased soon.[52]
-Ayatollah Akbar Hashemi Rafsanjani

The reality of an Israel menaced by radiological weapons is not new: its lineage extends back some five decades. If General Nasser was the face of the existential threat to Israel in the 1950s and 1960s, and Saddam Hussein was during the 1970s and 1980s, the modern face of this threat is Iran's Supreme Leader, Ayatollah Ali Khamenei.[53] As discussed in the next section, he was joined recently by Abu Bakr al-Baghdadi of ISIL/DAESH.[54]

Nasser Pursues Radiological Weapons

Egypt in the aftermath of the 1956 Sinai campaign actively pursued a surface-to-surface missile capability that extended to the development of radiological weapons. It sought commercial radioactive materials in Europe and Canada—reputedly containing cobalt-60 and strontium-90 industrial capsules—intending to weaponize the material in conventional warheads. Israel conducted counterintelligence operations against the Egyptian project in the 1950s and early 1960s under the cryptonym DAMOCLES. By May 1964, the *Manchester Guardian* exposed a team of German scientists engaged in assisting Egypt with two

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[46] *Ibid.,* 224.
[47] "45 years ago in the Bulletin." *Bulletin of the Atomic Scientists*. 51:4 (July/August 1995), 9. https://books.google.com/books?id=VQwAAAAAMBAJ&pg=PA9&lpg=PA9&dq="How+Effective+Are+Radioactive+Poisons+in+Warfare?"&source=bl&ots=pj1Ntx6b4P&sig=qB0WT8ueUKTi0TWOgMDk9ZHocw0&hl=en&sa=X&ei=gHudVYCLFYLp-QHG_aOgBQ&ved=0CCAQ6AEwAQ#v=onepage&q="How%20Effective%20Are%20Radioactive%20Poisons%20in%20Warfare%3F"&f=false. Last accessed 8 July 2015.
[48] United States Central Intelligence Agency (1957). CIA Global War Plan for Clandestine Operations. Annex G. Technical Services. Document No. 5197c260993294098d50d6fa http://www.foia.cia.gov/sites/default/files/document_conversions/1705143/AEDEPOT%20%20%20VOL.%204_0027.pdf. Last accessed 2 July 2015.
[49] James L. Ford (1998). *Radiological Dispersal Devices: Assessing the Transnational Threat.* Institute for National Strategic Studies. 136 (March 1998), 2.
[50] Advisory Committee on Human Radiation Experiments (1996), *op cit.,* 327.
[51] Akbar Hashemi Rafsanjani, speaking in October 1988. Quoted in Anthony Cordesman (1998). *Weapons of Mass Destruction in the Middle East.* (London: Brassey's, 1991), 93.
[52] Former Iranian president Rafsanjani speaking on 6 July 2015. Quoted by the Iranian state news agency *IRNA*: http://www.irna.ir/en/News/81673652/. Last accessed 7 July 2015.
[53] Dieter Bednarz & Ronen Bergman (2011). "Israel's Shadowy War on Iran: Mossad Zeros in on Tehran's Nuclear Program." *Der Spiegel* [published online in English 17 January 2011]. http://www.spiegel.de/international/world/israel-s-shadowy-war-on-iran-mossad-zeros-in-on-tehran-s-nuclear-program-a-739883-3.html. Last accessed 8 July 2015.
[54] Abu Bakr al-Baghdadi is the nom de guerre of the Islamic State caliph, Ibrahim Awwad Ali al-Badri al-Samarrai.

covert projects—under the reported cryptonyms IBIS and STRONTIUM—to load radioactive material into small missiles and artillery projectiles, which General Nasser intended to direct toward Israel.[55]

Saddam Hussein's Prototype Weapon

Iraq disclosed in the late 1980s that it had fabricated a prototype radiological weapon. Its intended use was area-denial against Iranian troop formations by means of contaminating contested buildings complexes and territory.[56] The weapon utilized powdered zirconium oxide irradiated in its Tuwaitha[57] research reactor, and combined it high explosives that would disperse the material in an airburst. The irradiated zirconium oxide (0.5-1kg) was packed into three-foot long lead-lined capsules. Each capsule was loaded into a prototype iron aerial bomb casing based on Iraq's Nasser-28 aerial bomb. The intent was to take advantage of the compound's relatively short half-life[58]—75.5 days—to allow Iraqi forces to secure contaminated areas in a matter of a few weeks. The weapons were unwieldy, however, at twelve feet long and weighing more than three thousand pounds.

Iraq's Al Muthana State Establishment[59] conducted field tests of three prototypes—one ground-level static test and two airdrops—in which the weapons worked as planned by contaminating a wide area with low-level radiation in large radioactive clouds. These clouds tended to disperse quickly, however, and the preponderant ground contamination was concentrated within the bomb crater and declined sharply within a short distance. The relatively short half-life of the irradiate zirconium oxide also meant the material had to be recharged in the Tuwaitha research reactor every several days. A redesigned prototype bomb casing (derived from the Muhanna-3 chemical bomb casing and designated the "Muhanna-4") succeeded in reducing its weight by over two-thirds (from 1400kg to 400kg), which allowed more than one bomb could be delivered by a single military aircraft. Based on the ambiguous test results, however, Iraq's Military Industrialization Corporation reportedly terminated the program in mid-1988.

Netanyahu Confronts the Radiological Threat

But where there is danger, there grows also what saves.[60]
- Friedrich Hölderlin

Consider a widely quoted *Haaretz* "exclusive" published in June 2015:

> "In 2010, staff from the Dimona nuclear reactor began a series of tests, dubbed the 'Green Field' project, designed to measure the consequences of the detonation of a dirty bomb in Israel. The project was concluded

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[55] "Nasser's nuclear breakthrough: Middle East is drawn into atomic arms race." *The Manchester Guardian* (4 May 1964). http://search.proquest.com/hnpguardianobserver/docview/184945458/fulltextPDF/89E9A5C084A84818PQ/1?accountid=11862#. Last accessed 7 July 2015. Under the direction of Egypt's former chief of Air Intelligence, General Mohammed Khalil, Egypt's surface-to-surface missile development program enlisted some 100 German scientists and technicians in the late 1950s and early 1960s, many of whom were veterans of the Wehrmacht's V-2 project. The program operated under cover of a recently built Messerschmitt airframe and engine factory located near Heliopolis and known as "Factory 333". MOSSAD reportedly terminated DAMOCLES in March 1963 following the arrest of two agents in Basel.

[56] Richard Rhodes (2010). *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons.* (New York: Vintage Books), 21. The Iraqi RDW was condemned by the director of the Wisconsin Project on Arms Control, Gary Milhollin, as "nasty stuff meant to kill people over a long period of time" and "cross[ing] the line into moral barbarism." See: William J. Broad (2001). "Document Reveals 1987 Bomb Test by Iraq." *The New York Times*, 29 April 2001.

[57] The Tuwaitha Nuclear Research Center was located some 18 km southeast of Baghdad. Its Al Asil General Establishment was the headquarters of the Iraqi Nuclear Commission and the main site for Iraq's nuclear program. It included several research reactors, and facilities for plutonium separation and waste processing, uranium metallurgy, neutron initiator development, and uranium enrichment. The Pure Lead Project developed shielding for Iraq's nuclear weapons program. The Osiraq reactor bombed by Israel in 1981 was located at Tuwaitha. See: http://fas.org/nuke/guide/iraq/facility/tuwaitha.htm. Last accessed 4 July 2015.

[58] Half-life describes the rate at which a specific radioactive material decays or changes from one nuclide to another nuclide that may in turn be radioactive or stable. Half-life can vary from a fraction of a second to many years, but once a material is stable, there is no longer an associated radiation hazard.

[59] Prior to 1986 the Al Muthana State Establishment was known as Project 922, which directed Iraq's CBW program. The existence of Project 922 was concealed behind a front organization known as the State Establishment for Pesticide Production, which operated a 100km^2 industrial facility near Samarra, Iraq. UNSCOM decommissioned and destroyed the facility over the period 1992-1994. It was common for Iraq to use chemical weapon facilities like the Al Muthana State Establishment to support other WMD programs.

[60] From Friedrich Hölderlin's poem *Patmos* (1808).

in 2014, and its research findings have been presented at scientific gatherings and on nuclear science databases. The researchers explained that the experiments were for defensive purposes and that they were not giving consideration to offensive aspects of the tests."[61]

The article's appearance is curious for the fact that the Green Field and Red House experiments had been discussed in open-source literature since at least 2008.[62] So, coming as it did in the final weeks of the P5+1 negotiations with Iran, the question arises "why now?" although that question may answer itself.

Israel conducted a series of experiments beginning in 2006 and continuing through 2014 to assess the dispersal of radioactive material in an RDD detonation. One group of experiments was conducted in the Negev Desert under the operational name "Green Field". It involved testing the dispersal of radioactive material released in an outdoor detonation of TNT charges at or near ground level. The first set of experiments known as Green Field-I (GF-I) involved multiple[63] detonations conducted over 2006 and 2009. These detonations released a radioactive simulant, and produced data that was used to characterize the height of the explosion cloud formed when explosive detonation aerosolizes and disperses the simulant.

The GF-I experiments altered different inputs—explosive mass (0.25-100kg of TNT and geometry (rectangular, spherical and cylindrical); atmospheric stability; the type of radioactive simulant—to develop data about cloud rise, simulant aerosolization, micro-meteorology, and indoor and outdoor cloud evolution. On this basis a second, and eventually a third set of experiments known as GF-II and GF-III were conducted to assess the results of more detonations—this time dispersing a liquefied form of the radioisotope technetium-99m[64]—during 2010 and 2011.[65] The Green Field experiments produced useful data for

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[61] Chaim Levinson (2015). "Haaretz exclusive: Israel tested 'dirty-bomb cleanup' in the desert. Series of tests in conjunction with four-year project at Dimona nuclear reactor measured damage and other implications of detonation of radiological weapon by hostile forces." Haaretz [published online in English 8 June 2015]. http://www.haaretz.com/news/diplomacy-defense/.premium-1.660067. Last accessed 7 July 2015.

[62] The earliest open-source discussion identified by the author in which Israel's Green Field (GF) experimental program is identified by name is: Ilan Yaar & Avi Sharon (2008). "Calibration of a Cloud rise model for a RDD Scenario." In Samuel Apikyan, et al., eds. *Prevention, Detection and Response to Nuclear and Radiological Threats*. (Dordrecht, Netherlands: Springer Science & Business Media), 193-205. See also: Avi Sharon (2009). "Cloud Model (& some related issues) for RDD & Nuclear Terrorism Scenarios." Negev Nuclear Research Center (November 2009). http://www.nucleonica.net/wiki/images/7/76/ITRAC2_Sharon.pdf. Last accessed 7 July 2015. This material was used at ITRAC^{N} 2 *aka* the "2nd Advanced Training Course on Illicit Trafficking and Radiological Consequences with NUCLEONICA" held at the Institute for Transuranium Elements in Karlsruhe, Germany, on 4-6 November 2009.

[63] The stated number of experimental detonations conducted in GF-I varies widely depending upon the source. According to Yaar, et al. (2014), there were 13 GF-I detonations while Sharon, one of the paper's co-authors, wrote five years earlier that there were "over 100 explosion tests". See: Ilan Yaar, Itzhak Halevy, Zvi Berenstein & Avi Sharon (2014). "Protecting National Critical Infrastructure against Radiological Threat." Paper presented to the 27th Conference of the Israel Nuclear Societies held 11-13 February Daniel Dead Sea Hotel, Israel. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/45/114/45114762.pdf. Last accessed 7 July 2015. Also: Avi Sharon (2009). "Cloud Model (& some related issues) for RDD & Nuclear Terrorism Scenarios." Negev Nuclear Research Center (November 2009). http://www.nucleonica.net/wiki/images/7/76/ITRAC2_Sharon.pdf. Last accessed 7 July 2015. In 2014, Sharon writes that there were 20 Green Field experiments in which liquefied Technitium-99m, a radioisotope, was dispersed. See: Avi Sharon, Itzhak Halevy, Daniel Sattinger, Zvi Berenstein, Rony Neuman, Moriel Pinhas, Pini Banaim, & Ilan Yaar (2014). "Ground deposition pattern of an explosive radiological dispersal device (RDD)." Paper presented to the 27th Conference of the Israel Nuclear Societies held 11-13 February Daniel Dead Sea Hotel, Israel. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/45/114/45114747.pdf. Last accessed 7 July 2015.
It is also noteworthy a 2014 paper of which Sharon is the lead author gives the Green Field project dates as "2010-2014" while a 2013 paper of which he is also the lead author gives them as "2008-2011". Avi Sharon, et al. (2013). "Outdoor Dispersion of Radioactive Materials." Paper presented to the 26th Conference of the Nuclear Societies in Israel, 307-310. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/44/128/44128609.pdf. Last accessed 7 July 2015. But in a 2008 paper co-authored by Yaar and Sharon, they wrote that GF-I commenced in 2006. See: Ilan Yaar & Avi Sharon (2008). "Calibration of a Cloud rise model for a RDD Scenario." In Samuel Apikyan, et al., eds. *Prevention, Detection and Response to Nuclear and Radiological Threats*. (Dordrecht, Netherlands: Springer Science & Business Media), 193-205.

[64] Technitium-99m (^{99m}Tc) is a metastable isotope of the element technetium and a commonly used tracer radioisotope in nuclear medicine. It results from the neutron activation of molybdenum-98 to produce molybdenum-99, which decays into technitium-99m. The experiments coupled an explosive charge and a canister containing 5-7Ci of technitium-99m suspended in 30cm^3 of saline water. A non-experimental RDD would likely use a metallic cobal-60 or iridium-192 source.
As Yaar, et al., write, Technitium-99m is well suited for these experiments: it is easily accessible at a reasonable cost; it has a short half-life (6.02 hours) that allows sufficient time for data collection while short enough to permit access to the experimental field within several days; and its 140.5 keV gamma line is easily detected using simple gamma detectors. [Ilan Yaar, Itzhak Halevy, Zvi Berenstein & Avi Sharon (2016). "Protecting Transportation Infrastructure against Radiological Threats." In Simon Hakim, Gila Albert & Yoram Shiftan (2016). *Securing Transportation Systems*. Hoboken: John Wiley & Sons, Inc.), 32]

modeling a hypothetical outdoor RDD detonation. The principle finding—subject to a charge geometry and choice of radioactive material that create fine aerosol particles[66] upon detonation—was that almost all activity remained concentrated within 200 meters of ground zero.

A second group of experiments known as "Red House" assessed the indoor dispersion of radioactive materials inside larger buildings. The Red House experiments were conducted at an Israel Defense Force Home Front Command facility, and involved four dispersion tests using nonradioactive powders (as a proxy) and six using liquefied technetium-99m.[67] These experiments concluded that the detonation of an RDD inside a building with openings (e.g., windows, doors, ventilation ducts) would result in part of the radioactive materials contaminating the building while some fraction (proportionate to the area of the openings relative to the building's total area) is dispersed outside the building as radioactive material is emitted through the openings. The distribution of radioactive material inside the building is a function of several variables, including it interior geometry (the floor, ceiling and walls reflect the turbulent detonation cloud) and airflow patterns (the building's ventilation system disperses aerosol, net of airborne material that is captured by the system's filters).

The Radiologic Weapon Threat from DAESH

> *Let me throw a hypothetical operation onto the table. The Islamic State has billions of dollars in the bank, so they call on their wilāyah in Pakistan to purchase a nuclear device through weapons dealers with links to corrupt officials in the region. The weapon is then transported…through the porous borders of Central America before arriving in Mexico and up to the border with the United States. From there it's just a quick hop through a smuggling tunnel and hey presto, they're mingling with another 12 million 'illegal' aliens in America with a nuclear bomb in the trunk of their car.* -- "The Perfect Storm," *Dabiq* (DAESH online magazine)

In the case of violent non-state actors like DAESH, possession equals use. "It is a near-universal opinion that deterring the use of CBRN by terrorist who have acquired it will be extremely difficult. Most conclude that acquisition of such weapons generally will lead to attempted use."[68]

In 2001 the Syrian government commenced construction of a gas-cooled, graphite-moderated nuclear reactor—based on a North Korean design, it was similar to (but not an exact copy) of a reactor at the Yongbyon nuclear center—near the town of Al Kibār in the eastern Syrian Deir ez-Zor governate bordering Iraq. In 1985 United States intelligence agencies determined that Syria and North Korea (with which Syria signed a five-year technical cooperation pact in 2001 that was renewed in October 2008) were engaged in a project somewhere in Deir ez-Zor. Subsequent imagery detected the Al Kibār (*aka* Dair Alzour) reactor sometime around August 2007. Within a month, it was struck and heavily damaged in a 6 September 2007 Israeli airstrike—assigned the cryptonym ORCHARD[69]—and later by Syrian efforts to conceal the site.

A 24 May 2011 report by the IAEA Director General concluded "the destroyed building was very likely a nuclear reactor," based this judgment on the features of the destroyed building and the configuration of the infrastructure at the site, among other factors.[70] Environment samples taken at the Al Kibār site by IAEA inspectors in June 2008 "contained particles of anthropogenic[71] natural uranium […] of a type not included in Syria's reported inventory," on which basis the IAEA Inspector

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[65] Avi Sharon, et al. (2013). "Outdoor Dispersion of Radioactive Materials." Paper presented to the 26th Conference of the Nuclear Societies in Israel, 307-310. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/44/128/44128609.pdf. Last accessed 7 July 2015. Sharon, et al. (2013) state that there were seven GF-II detonations while Yaar et al. (2016) state that there were fourteen GF-II and GF-III detonations using liquefied Technitium-99m.

[66] Particles in the air will tend to settle to the ground as a function of several factors including gravity, particle size, and the aerosol's density.

[67] Sharon, et al. (2012) identify the nonradioactive power as titanium oxide while Yaar, et al. (2016) indicate that two nonradioactive powders, caesium chloride (CsCl) and strontium titanate ($SrTiO3$), were used.
Avi Sharon, et al. (2012). "An Experimental Study of Indoor Dispersion of Radioactive Material." Paper presented to the 26th Conference of the Nuclear Societies in Israel, 307-310. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/44/128/44128609.pdf. Last accessed 7 July 2015.

[68] National Defense University (2002), *op cit.,* 6.

[69] Hebrew transl.: *Mivtza Bustan*.

[70] International Atomic Energy Commission (2011). "Implementation of the NPT Safeguards Agreement in the Syrian Arab Republic." GOV/2011/30 (24 May 2011), 2. https://www.iaea.org/sites/default/files/gov2011-30.pdf. Last accessed 9 July 2015. According to this report, "Syria maintains that the particles of anthropogenic natural uranium found at the Dair Alzour site originated from the missiles used to destroy the building."

[71] The origin of uranium in soil can be from geochemical sources or from anthropogenic activity, e.g., disposed nuclear waste.

General concluded:

> "The presence of a significant number of particles of anthropogenic natural uranium at the Dair Alzour site indicates a connection to nuclear related activities at the site and increases concerns about possible undeclared nuclear material at the site. The Agency has not been able to determine the origin of the particles."[72]

According to a January 2015 *Der Spiegel* exposé, Syria moved an unspecified quantity of nuclear material to Marj as Sulţān, a suspected uranium processing facility located in the eastern suburbs of Damascus that has been linked to fuel production for the Al Kibār reactor. Some or all of this material was later reported moved to an underground site 15km west of Al- Qusayr near the Syria-Lebanon border[73] some time before the Syrian government abandoned Marj as Sulţān.[74] Given that United States intelligence officials concluded by mid-2008 that the Al Kibār "reactor was destroyed in early September 2007 before it was loaded with nuclear fuel or operated,"[75] the material moved to Al-Qusayr may include some or all of the 8000 fuel rods intended for the now-destroyed reactor.[76] It is worth noting Al-Qusayr was the scene of intense fighting in June between Syrian government-aligned Hezbollah and DAESH.

DAESH took control of Al Kibār in mid-2014 from the Free Syrian Army (which earlier captured it in February 2013). By June 2015, DAESH was reportedly dismantling the site, including possible excavation of its now-destroyed underground facilities.[77] "The remnants of Syria's undeclared nuclear program pose a proliferation risk," cautioned analysts at the Institute for Science and International Security:

> "Any known or suspected nuclear materials inside Syria are not as readily usable…unless it is further enriched […] Natural uranium is a weak radioactive source and thus a poor choice for a dirty bomb. Nonetheless, the allegedly large stock of natural uranium, other nuclear-related materials, equipment, and other resources associated with the past nuclear program would be attractive to terrorists, certain states, and commodity traffickers. They may wish to sell these goods on the black market or otherwise seek to use them to extract concessions or cause damage. This material may also end up in undeclared nuclear programs of other states."[78]

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72 *Ibid.,* paragraph 21.

73 Erich Follath (2015). "Assad's Secrtet: Evidence Points to Syrian Push for Nuclear Weapons." *Der Spiegel* [published online in English 9 January 2015]. http://www.spiegel.de/international/world/evidence-points-to-syria-still-working-on-a-nuclear-weapon-a-1012209.html. Last accessed 9 July 2015. Regarding the Al-Qasyr site, a *Jane's Defense Weekly* analysis stated, "The site has previously been identified by IHS Jane's as a possible weapons storage complex that could be used by the Lebanese militant group Hizbullah, which controls the adjoining Lebanese territory." However, "The assertion that Syria built an underground reactor to produce plutonium in two years should consequently be treated with skepticism." Jennie Binnie (2015). "Analysis: Syria's alleged secret reactor site." *IHS Jane's Defense Weekly* (15 January 2015). http://www.janes.com/article/47950/analysis-syria-s-alleged-secret-reactor-site. Last accessed 7 July 2015.

74 Marj as Sulţān is located a few kilometers away from the site of a Syrian government chemical weapons attack on 21 August 2013.

75 "Background Briefing with Senior U.S. Officials on Syria's Covert Nuclear Reactor and North Koreai's Involvement" dated 24 April 2008. http://fas.org/irp/news/2008/04/odni042408.pdf. Last accessed 7 July 2015.

76 On this point, spent fuel rods are sometimes mentioned as potential sources of radiological material. However, they are very hot, heavy, and difficult to handle, making them less desirable for use in a radiological weapon than commonly supposed. See: Advisory Panel to Assess Domestic Response Capabilities for Terrorism Involving Weapons of Mass Destruction (1999). "First Annual Report to the President," (15 December 1999). http://www.rand.org/content/dam/rand/www/external/nsrd/terrpanel/terror.pdf. Last accesed 10 July 2015, 33.

77 David Albright, Serena Kelleher-Vergantini & Sarah Burkhard (2015). "Syria's Unresolved Nuclear Issues Reemerge in Wake of ISIL Advance and Ongoing Civil War." Institute for Science and International Security Imagery Brief (30 June 2015). http://isis-online.org/uploads/isis-reports/documents/Syria_June_30_2015_Final.pdf. Last accessed 7 July 2015. The report includes satellite imagery of a building erected on the site of the destroyed reactor in progressive stages of dismantlement and possible signs of excavation work inside the building.

78 *Ibid.*

Recent (uncorroborated) press reports claim "Syrian residents from villages near the destroyed Syrian nuclear site…report that members of Islamic State have been excavating the destroyed Syrian secret nuclear facility."[79] Australian intelligence reports reportedly assess that DAESH "has seized enough radioactive material from government facilities to suggest it has the capacity to build a large and devastating 'dirty" bomb'."[80]

The author earlier detailed DAESH's June 2014 seizure of suspected Saddam-era "uranium compounds" from a Mosul University laboratory that originated from Iraq's former al-Jazirah conversion plant:

> "The likely source of the material ISIL seized from Mosul University is al-Jazirah's analytical laboratory, which may have transferred all or part of its inventory of samples from the conversion processes. It is known that some equipment and instrumentation from al-Jazirah was taken to Mosul University after 1991, and that Iraq failed to declare whatever material was transferred as required under its 1979 IAEA safeguards agreement."
>
> "The sample inventory may have been sizeable, and could have included reagents such as uranyl acetate (both radioactive and highly toxic if ingested, inhaled as dust, or by skin contact) as well as uranium oxide "yellowcake"; ammonium diuranate (an intermediate chemical form of uranium produced during yellowcake production); uranium trioxide (UO3) and dioxide (UO2); and possibly, gram-quantity samples of uranium tetrachloride."[81]

The threatened use of radiological weapons by jihadist groups is not new: in 2005, a jihadist operational website published a document that encouraged RDD attacks in western cities:

> "The important thing is to disperse radioactive material in a large commercial area so the government is forced to shut down this area which will cause this country massive economic disruption due to the following reasons:
>
> - The high costs of decontamination of radioactive areas.
> - The high economic losses in this large commercial area due to closure.
> - Subsequent unemployment and loss of jobs.
> - Stoppage of general life in that area.
> - Large compounded problems are to follow due to these losses."[82]

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[79] "Report: Islamic State Excavating Destroyed Syrian Nuclear Site." *The Jewish Press* [published online 1 June 2015]. http://www.jewishpress.com/news/breaking-news/report-islamic-state-excavating-destroyed-syrian-nuclear-site/2015/06/01/. Last accessed 7 July 2015.

[80] "Isis's dirty bomb: Jihadists have seized 'enough radioactive material to build their first WMD'." *The Independent* [published online 10 June 2015]. http://www.independent.co.uk/news/world/middle-east/isiss-dirty-bomb-jihadists-have-seized-enough-radioactive-material-to-build-their-first-wmd-10309220.html. Last accessed 7 July 2015.

[81] John R. Haines (2014). "'Dirty Bombs': Reason to Worry?" *Foreign Policy Research Institute E-Notes* (July 2014). https://www.fpri.org/docs/haines_-_dirty_bombs_0.pdf.

[82] Abu al-Usood al-Faqir (2005). "Instances of Radiation Pollution from 1945-1987." www.al-farouq.com (October 2005). Quoted and translated in Sammy Salama & David Wheeler (2007). "From the Horse's Mouth: Unraveling Al-Qa`ida's Target Selection Calculus." James Martin Center for Nonproliferation Studies of the Monterey Institute of International Studies [published online 17 April 2007]. http://cns.miis.edu/stories/070417.htm. Last accessed 9 July 2015. The online jihadist forum *Muntadayat al-Farouq* [author's note: Farouq is the name of the second caliph Umar bin Khattab (634-644)] was active from August 2005 through early 2006 when its website (www.al-farouq.com) ceased operations.
On 9 October 2005 the Al-Farouq website published a document ("Nuclear Preparation Encyclopedia") which its author under the nom de plume Layth al-Islam ("the Lion of Islam") earlier posted on the al-Firdaws website (www.alfirdaws.org). According to one analysis, "All the information presented by the author is readily available in open sources, but he appears to be the first Al-Qaeda sympathizer to collect this information and translate it into Arabic." ["Al-Qaeda Jihadi Website Publishes 'Nuclear Preparation Encyclopedia'." *WMD Insights*. 1 (December 2005/January 2006), 9. http://cns.miis.edu/wmd_insights/WMDInsights_2006_01.pdf. Last accessed 9 July 2015]
An analysis of the document [links to which were disabled shortly after its publication] concluded, "Unlike previous literature that was largely void of scientific data, this document contains tens of pages on a historical survey of nuclear technology, including an Arabic explanation of nuclear experiments, concepts, and an overview of Enrico Fermi as well as other prominent nuclear pioneers. Most

There is strong evidence as well to suggest Al-Qa`ida attempted to procure radiologic material as well but none (at least in the public domain) to indicate its quest bore fruit. Nor despite the grossly disproportionate attention it garnered, is the scenario sketched in DAESH's online publication, *Dabiq*—purchasing a nuclear weapon from Pakistan—likely or practicable [83]

Magnificent Façade: The Myth of "Peaceful Nuclear Facilities"

The erection of Potemkin villages…never leads to the establishment of the real thing but only to a proliferation and perfection of make-believe.[84]
-Hannah Arendt

It is a lamentable truism of the modern era that marginalizing the threat of confrontations with nuclear weapons has not eliminated the threat of virulent radiation.[85] Radiological weapons are after all, as Torsten Sohns wrote, part of the nuclear risk.[86] When discussed at all, radiological weapons traditionally have been included under the general rubric of nuclear weapons. However, wrote one analyst, "the present reality that terrorist organizations are seeking access to CBRNE weapons has resulted in a renewed concern over radiological weapons in their own right."[87]

Add to "terrorist organizations" rogue states. Most states—and all or nearly all non-state actors—do not have the sophisticated infrastructure required to handle nuclear material safely. For these states and non-states, the difficulty associated with acquiring and handling spent nuclear fuel assemblies without receiving a lethal dose is far greater than the difficulty of producing a radiological weapon using commercially-available industrial and medical radioisotopes.[88] Iran, however, possesses a sophisticated nuclear material infrastructure and so presents a first-tier radiological threat, since it could weaponize, at its option, spent nuclear fuel assemblies as well as industrial and medical radioisotopes. One might reasonably add to that Iran's growing stockpile of uranium dioxide ($LEUO_2$).

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disturbing, it includes information about critical mass and the amount of fissile materials needed in the construction of nuclear weapons. In addition, various sketches and diagrams in English and Arabic are provided of purported gun-type and implosion-type nuclear warheads, which are clearly borrowed from open-source information available on the Internet. […] However, similar to other al-Qaeda WMD production manuals, this nuclear encyclopedia contains numerous basic technical flaws." [Sammy Salama & Lydia Hansell (2005). "Does Intent Equal Capability? Al-Qaeda and Weapons of Mass Destruction." *Nonproliferation Review*. 12:3, 635. http://cns.miis.edu/npr/pdfs/123salama.pdf. Last accessed 9 July 2015].

[83] The relevant paragraph reads, "Let me throw a hypothetical operation onto the table. The Islamic State has billions of dollars in the bank, so they call on their wilāyah in Pakistan to purchase a nuclear device through weapons dealers with links to corrupt officials in the region. The weapon is then transported overland until it makes it to Libya, where the mujāhidīn move it south to Nigeria. Drug shipments from Columbia bound for Europe pass through West Africa, so moving other types of contraband from East to West is just as possible. The nuke and accompanying mujāhidīn arrive on the shorelines of South America and are transported through the porous borders of Central America before arriving in Mexico and up to the border with the United States. From there it's just a quick hop through a smuggling tunnel and hey presto, they're mingling with another 12 million "illegal" aliens in America with a nuclear bomb in the trunk of their car." See: John Cantlie (2015). "The Perfect Storm." *DABIQ* [published online May 2015], 77. http://media.clarionproject.org/files/islamic-state/isis-isil-islamic-state-magazine-issue%2B9-they-plot-and-allah-plots-sex-slavery.pdf. Last accessed 9 July 2015. For an excellent dissection of Cantlie's hypothesized scenario, see Michael Cruickshank (2015). "Don't stress. ISIS can't buy a nuclear weapon." *Conflict News* [published online 23 May 2015]. http://www.conflict-news.com/dont-stress-isis-cant-buy-a-nuclear-weapon/. Last accessed 9 July 2015.

[84] Hannah Arendt (1967) "Truth and Politics." *The New Yorker* (25 February 1967), 78. She wrote, "consistent lying, metaphorically speaking, pulls the ground from underneath our feet and provides no other ground on which to stand," a condition she called *Bodenlosigkeit* (literally, "groundlessness") or to have no foundation.
"Magnificent façade" is from Aleksandr Panchenko's essay, "*Potemkin villages* as a cultural myth," in Panchenko (1999). *Russkaya istoriya i kul'tura: Raboty raznykh let*. (SPb.: Yuna), 462-475.

[85] CAPT David Cohen. USAF (1998). "Ionizing Radiation." In: United States Air Force Scientific Advisory Board (1998). *Report on United States Air Force Expeditionary Forces*, Volume 3: Appendix I, I-125. SAB-TR-97-01 (February 1998).

[86] Torsten Sohns (1998). "Protection Against Weapons of Mass Destruction: A German Perspective." In Oliver Thränert (1999). *Preventing the Proliferation of Weapons of Mass Destruction: What Role for Arms Control?* (Bonn & Berlin: Freidrich-Ebert-Stifung), 145.

[87] LTC John Mark Mattox, USA, SHAPE (2003.). "Deterring Chemical, Biological, Radiological, Nuclear, and High-Energy Weapons Use in the War Against Terrorism:
The Moral Dimension." Paper presented to JSCOPE 2003 Joint Services Conference On Professional Ethics, Anti-Terrorist Operations and Homeland Defense (30-31 January 2003). http://isme.tamu.edu/JSCOPE03/Mattox03.html. Last accessed 7 July 2015.

[88] Charles Ferguson, Tahseen Kazi & Judith Perera (2003). "Commercial Radioactive Sources: Surveying the Security Risks." The Center for Nonproliferation Studies Occasional Paper No. 11. (Monterey: Monterey Institute of International Studies), 3. http://cns.miis.edu/opapers/op11/op11.pdf. Last accessed 13 July 2015.

Some resist characterizing Iran as a prima facie radiological threat. That position is more difficult to sustain when one takes into account that Iran has neither signed nor ratified the International Convention for the Suppression of Acts of Terrorism or the Convention on the Physical Protection of Nuclear Material. Nor has Iran so far expressed support for major International Atomic Energy Agency guidelines like the Code of Conduct on the Safety and Security of Radiological Sources.

The issue of radiological weapons is connected indirectly to the IR-40 heavy water-moderated research reactor at Arak, which Iran has declared will be used for medical and industrial radioisotope production.[89] The July 2015 nuclear agreement provided for Iran to "redesign and rebuild" the Arak reactor to an agreed-to specification (for example, modified with a low-enriched uranium core[90]) under which it would no longer produce weapons-grade plutonium, but instead "support peaceful nuclear research and radioisotope production."[91] Iran should have no objection to following through on that commitment since the converted reactor would result in an enhanced capacity for radioisotope production compared to the original design.

In its original Arak declaration the Iranian government stated that it intended to construct a building for the production of what it called "long-lived" radioisotopes in addition to "short-lived" ones (e.g., molybdenum-99, the parent nuclide of technetium-99m used for diagnostic nuclear medicine). Iran did not clarify what this distinction meant although the IAEA inferred "long-lived" might mean cobalt-60 and iridium-192,[92] which have half-lives of 5.2 years and 74 days, respectively (other analysts interpreted "long-lived radioisotopes" to mean plutonium). Iran revised its Arak declaration in May 2004 and eliminated plans for long-lived radioisotope production citing "difficulties with the procurement of equipment" (i.e., hot cell manipulators and lead glass windows).[93]

Iran earlier declared its intention to substitute radioisotope production at Arak for its existing production facility at the Tehran Research Reactor, which is located within the Tehran Nuclear Research Center (TNRC).[94] A TNRC laboratory that has attracted IAEA attention is the Molybdenum, Iodine and Xenon Radioisotope Production Facility ("MIX Facility" for short) where Iran produces medical and industrial radioisotopes from natural uranium oxide. Iran completed construction of the MIX Facility in 2005 but claims it never became operational due to technical difficulties. It is known, however, that Iran used the uncompleted laboratory between 1987 and 1999 to separate iodine-131 from small quantities of the irradiated natural uranium targets. Iodine-131 is a good illustration of a dual, benignant/malignant use radioisotope. It is utilized in a form of radiotherapy; however, its relative volatility means iodine-131 can contaminate large areas—it is one of three radioisotopes (the others are cesium-137 and strontium-90) that accounted for most of the harmful effects following the 1986 Chernobyl accident. Chernobyl demonstrated the release of iodine-131 is capable of causing the development of malignant thyroid nodules in children within a 300-mile radius.[95]

Iran is not the only state in the region capable of producing some quantity of radioisotopes. The author has identified five other research reactors in the region at which radioisotopes are produced today or have been in the past:[96]*b*

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[89] David Albright & Christina Walrond (2013). "Update on the Arak Reactor." Institute for Science and International Security (15 July 2013). http://www.isis-online.org/uploads/isis-reports/documents/Arak_complex_15July2013.pdf. Last accessed 13 July 2015.
[90] By some estimates, the converted core potentially could produce a greater amount of radioisotopes than the natural uranium core. See: Thomas Mo Willig, Cecilia Futsaether & Halvor Kippe (2012). "Converting the Iranian Heavy Water Reactor IR-40 to a More Proliferation-Resistant Reactor." *Science & Global Security*. 20-2-3 (The Technical Basis for Arms Control, Disarmament, and Nonproliferation Initiatives), 107. http://www.tandfonline.com/doi/pdf/10.1080/08929882.2012.713767. Last accessed 13 July 2015.
[91] United States State Department (2015). "Parameters for a Joint Comprehensive Plan of Action Regarding the Islamic Republic of Iran's Nuclear Program" (2 April 2015). http://www.state.gov/r/pa/prs/ps/2015/04/240170.htm. Last accessed 13 July 2015.
[92] See: Paragraphs 68-70 in International Atomic Energy Agency (2004). "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran." Report by the Director General dated 15 November 2004. http://www.isisnucleariran.org/assets/pdf/iaea-iranreport-111504.pdf. Last accessed 13 July 2015. The author notes that heavy water reactors are optimal for the production of high quality, weapons-grade plutonium, and thus a proliferation concern.
[93] Albright & Walrond (2013), *op cit.* The quoted text is from IAEA (2004), *op cit.,* paragraph 70.
[94] The Tehran Research Reactor is a 5MWt pool-type light water research reactor that was supplied by the United States in 1967 and is housed at the Tehran Nuclear Research Center (TNRC).
[95] Eric R. Braverman, Kenneth Blum, Bernard Loeffke, Robert Baker, Florian Kreuk, Samantha Peiling Yang & James R. Hurley (2014). "Managing Terrorism or Accidental Nuclear Errors, Preparing for Iodine-131 Emergencies: A Comprehensive Review." *International Journal of Environmental Research and Public Health* [published online 15 April 2014]. 15]. 11:4, 4158–4200.
[96] There are additional research reactors in Algeria and Morocco.

- Egypt's Atomic Energy Authority (AEA) operates the Egyptian Second Research Reactor (ETRR-2) also known as the "Multipurpose Nuclear Reactor" at the Nuclear Research Center, the oldest and largest of the four research centers operated by the AEA. Its precise location is uncertain but is reportedly near Inshas, some 60 km northeast of Cairo.

- Israel's Atomic Energy Commission operates the IRR-1 located at the Soreq Nuclear Research Center, Yavne

- Libya's Renewable Energies and Water Desalination Research Center operates the IRT-1 research reactor at the Tajoura Nuclear Research Centre near Tripoli.

- Syria's Dar Al-Hajar Nuclear Research Centre operates the SRR-1 located 140km north of Damascus. In June 2015 the IAEA announced it was studying Syria's request for assistance to convert the SRR-1 to low-enriched uranium (LEU) fuel, and to ship its 1kg of highly enriched uranium (HEU) fuel out of the country.[97]

- Turkey's Çekmece Nuclear Research and Training Center (ÇNAEM[98]) operates the Turkish Second Research Reactor (TR-2), the main purpose of which is the production of radioisotopes (including technitium-99m, iodine-131 & iridium-192) for medical and industrial uses.

Concluding Thoughts

It is unsurprising that the Israeli government would call attention to its multi-year effort to understand the effects of a radiological weapon detonation. *Haaretz* qualified that Green Field and Red House "were for defensive purposes" and did not "give consideration to offensive aspects of the tests."[99] That does not mean they failed to yield information useful to a hypothesized offensive use for a narrowly defined preemptive mission, however.

This essay opened with the observation that among the several argued deficiencies of the P5+1 nuclear agreement with Iran, the most abject deficiency is perhaps the one least discussed—the consummate failure of the P5+1 to address Iran's radiological weapons capability. Earlier consideration of radiological weapons by the United States and others invariably settled on the question of how to defend against their use by an adversary. It is not unreasonable to speculate that some parties in the Middle East today—possibly Iran but most assuredly DAESH—can envision their offensive use, with the nation of Israel and the United States' presence in the region the likeliest targets. The incomprehensible omission of Iran's radioisotope production capacity from the P5+1 process, and the Syrian government's inability to control critical nuclear sites, are a grave regional security and proliferation concern.

[97] "IAEA Studies Syrian Reactor Conversion." *Arms Control. Today* [posted online 8 July 2015]. http://www.armscontrol.org/ACT/2015_0708/News-Briefs/IAEA-Studies-Syrian-Reactor-Conversion. Last accessed 13 July 2015.
[98] ÇNAEM is the acronym of the Center's name in Turkish, *Çekmece Nükleer Araştırma ve Eğitim Merkezi*.
[99] Chaim Levinson (2015), *op cit*.