NUCLEAR REACTOR REALITIES

(An Australian viewpoint)

PREFACE

Now that steam ships are no longer common, people tend to forget that nuclear power is just a replacement of coal, oil or gas for heating water to form steam to drive turbines, or of water (hydro) to do so directly. As will be shown in this tract, it is by far the safest way of doing so to generate electricity economically in large quantities – as a marine engineer of my acquaintance is fond of saying.

Recently Quantum Market Research released its latest Australian Scan (The Advertiser, Saturday April 17, 2012, p 17). It has been tracking social change by interviewing 2000 Australians annually since 1992. In the concerns in the environment category, *"[a]t the top of the list is nuclear accidents and waste disposal"* (44.4 per cent), while "global warming" was well down the list of priorities at No 15, with only 27.7 per cent of people surveyed rating the issue as "extremely serious."

Part of the cause of such information must be that people are slowly realising that they have been deluded by publicity about unverified computer models which indicate that man's emissions of CO_2 play a major part in global warming. They have not yet realised that the history of the dangers of civilian nuclear power generation shows the reverse of their images. The topic of nuclear waste disposal is also shrouded in reactor physics mysteries, leading to a mis-placed general fear of the unknown.

In this article only nuclear reactors are considered. Both carbon dioxide and nuclear waste are left for other discussions.

Most people's understanding of the dangers of civilian nuclear power reactors comes from the very wide publicity throughout the world given by the media of three events: the Three Mile Island miscue in the USA in 1979, the Chernobyl disaster in 1986 in the Ukraine and the Fukushima accident in Japan in 2011.

Each was handled extremely badly by scaremongering parts of the media, aided and abetted by the significant anti-nuclear groups which had developed good access to the media. There were neither lives lost nor any radiation injuries at Three Mile Island. On site at Chernobyl 31 men died and some 45 people died later from radiation, although there have been many injuries – some long lasting. Some official Fukushima figures put the death toll at five, three, some at two, others at one. There are official reports that not one of them was truly caused by radiation.

Brief consideration of verifiable facts of all three may help to put that xenophobia (fear of the unknown) into context. For this reason the following tract has been written as a part of a discussion of some relevant nuclear realities from an Australian viewpoint.

ABSTRACT

This is an attempt to breach the gap, or should it be the void, between the understanding(s) of nuclear reactor physics by those in the field and by intelligent lay people. As such it can be seen as an oversimplification which should not be quoted as a stand alone document portraying the science of nuclear reactor physics.

A brief history is given of some relevant yet little known facts about nuclear reactors, natural, military and civilian. Appendix 8 gives brief details of some relevant parts and actions of the Australian Atomic Energy Commission (AAEC) and associated matters.

Four different types of nuclear reactors are recognised. The first in history are the natural ones, the second are man's research reactors, the third are those designed to produce just one kind of core material for nuclear weapons and the fourth meet military and commercial requirements for the generation of electricity and/or mechanical power (using steam). Of the almost one thousand man-made nuclear reactors, operating over some sixty plus years, only three civilian ones are regarded as disasters. Only one of these is shown to have killed men (some 76 people with high radiation doses at Chernobyl), despite the fear engendered by the world's media about the technology. That is an incredible safety record.

Appendices contain most of the material supporting the main text, including a snap shot history of nuclear warships. There are so many different types of civilian reactors that no attempt has been made to reference them all, much less to put them into context.

Appendix 5, on Chernobyl, gives very simple details as to why nuclear fuel that has spent more than two operating months in a civilian power reactor cannot be extracted and then used as a source of plutonium 239 for weapons. There would be too much of other plutoniums, particularly 240, 241, 242, for that to work.

Appendix 7 gives the US Regulatory Commission's draft conclusion of their "State-of-the-Art Reactor Consequence Analyses" research project, which was initiated in 2007, promulgated for comment in 2012.

See Appendix 8 re Australia's Atomic Energy Commission – abolished in 1987 – together with comments on the associated inculcation of fear of nuclear unknowns.

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INTRODUCTION

Here is a story of nuclear reactor physics which extends from about one thousand eight hundred million years ago into the twenty-first century AD.

Its application by humans has only been from December 1942 to the present, although the foundation for this was laid almost half a century earlier in the international field of nuclear and thence to reactor physics in the 1940s.

Like most stories, it is one of triumphs and disasters, of intrigues and politically motivated pluses and minuses; of making and destroying nations, armies, reputations, governments and corporations, but primarily it is one of fear of the unknown and of commercial and political wills to trade on that by those who do not understand the physics of nuclear power reactors, but do understand how to manipulate the xenophobia (a fear of the unknown that we all have to some degree) of the general public. This was neatly confirmed in a statement on p.4 of The Economist's March 2012 Special Report on Nuclear Energy:

> *"To the public at large, the history of nuclear power is mostly a history of accidents: Three Mile Island, the 1979 partial meltdown of a nuclear reactor in Pennsylvania caused by a faulty valve, which led to a small release of radioactivity and the temporary evacuation of the area; Chernobyl, the 1986 disaster in the Ukraine in which a chain reaction got out of control and a reactor blew up, spreading radioactive material far and wide; and now Fukushima. But the field has been shaped more by broad economic and strategic trends than sudden shocks."*

One trusts that the reader will see these misapprehensions debunked in the article here.

Man's history with nuclear power can be said to have commenced in the early nineteen thirties when three top-line nuclear physicists argued for two years with one of the founders of that field, Albert Einstein, because his General Relativity Theory, they thought, was flawed as it did not include sub-atomic particles. Einstein finally gave in to Niels Bohr from Denmark, Werner Heisenberg from Germany and Richard Feynmann from USA.

This present tract has been written knowing that economic, national, educational and political factors usually override any decision-making in the nuclear power generation field, but those factors have not been considered here in their contexts of finance, location, scientific philosophy etc..

Any discussion for lay people of nuclear reactor physics must be based on a simple model of atoms that does not need high level maths, physics or chemistry. Therefore a nineteen thirty model, (taught in many secondary schools over the past seventy years), is Appendix 1, which the non-technical reader should study before going further. While it leaves out those complications, it is close enough to not be misleading. For those with no physics, we can regard atoms as minute planets composed of positively charged and neutral masses, orbited by negatively charged satellites that weigh virtually nothing. Many television logos portray them.

Relevant higher mathematics and physics deemed essential for understanding have been either very much simplified or ignored to keep the body of the main text readable.

In science attempts are always made to try to disprove theories. If they succeed, it is back to the drawing board. If they fail, the theory or theories are strengthened, but, in real, hard-core science, they cannot ever be truly proved. If they are believed, one must remember that belief is a religious concept which, when spoken or written by honest people, can and often does live side by side, but should never be in conflict with or rebuttal of scientific theories.

Of course, we are also suffering from those accepted as experts in this field by politicians, economists, accountants and their advisers who understand very few of the nuances enumerated. They do not understand that consensus has no place here.

(Australia's part has been chequered by the fear of the unknown so prevalent in human societies over the centuries. Its three nuclear reactors and its Atomic Energy Commission, with its follow-on, Australian Nuclear Science and Technology Organisation (ANSTO), are discussed in Appendix 8.)

The writer does not claim to be an expert in any field but has relevant formal technical education, including post-graduate level nuclear reactor physics, and has practical experience over the past 55 years in uranium mines, uranium deposits, uranium exploration and at an executive level as Director of Planning, Exploration Division, Uranium Branch of Australia's now defunct Atomic Energy Commission.

NATURAL REACTORS

Almost two thousand million years ago, at a place called Oklo in the West African country of Gabon, a natural fission reactor initiated its action. This had been predicted in 1956 and was found in 1972. To date 16 reactor sites have been identified there, which ran for a few hundred thousand years, averaging about 100 kW of power output during that time. See references (1) & (2).

The easiest general explanations available for those interested in these occurrences and their discoveries are in three Scientific American references (2), (3) & (4), the first of which was written in 1976, the second and third were written in 2005 and 2009.They give the geologic setting and the nature of the announcement to the world, in some detail, with some overview of the physics and how and why they were identified as natural fission reactor sites. None mention any effects of these reactors starting and stopping caused by an effect outlined here in Appendix 3.

An important part of the explanation of this phenomenon is that at that time, so long ago, uranium was naturally as rich in the particular isotope we have to enrich it in now for most of our light water moderated reactors. This apparent paradox is explained in some detail in Cowan (1976), an article well worth reading.

Many attempts have been made to unseat the hypothesis that the Oklo reactors (and the relatively nearby Okelobondo ones) actually initiated their actions some 1.7 to 1.9 (American) billion years ago. Despite many serious attempts to deny these very old ages, to date no-one has been able to disprove them.

MAN-MADE REACTORS

A brief history of some relevant facts of man-made nuclear reactors is given here. This requires much reference to the glossary for the meaning of technical terms. A warning – misapprehensions on the part of the media about these have caused wide-spread, continuing fear of the unknown, beyond reasonable levels, among educated people.
The records that give rise to such a contention have been patched together from verified, formally published, relevant pieces of information covering the period from 1944 (yes, 1944) until 2012. Data are quoted in the somewhat technical appendices as this history has been blurred by many publications based on only partial understanding. Now it is time to try to set the record a little straighter.

Most research reactors have the commonality of uranium cores and graphite moderators, although many had (have) cores of moderately to highly enriched U 235.

An American financial and political disaster in 1979, Three Mile Island, caused no deaths nor injuries, but was so badly covered in the media by biased, ignorant people, (journalists and politicians included), that it caused massive fearful ('precautionary') evacuations and helped to set USA civilian nuclear power generation back by decades, while, quite appropriately, costing the people involved very high financial losses. See Appendix 4 for a brief history and explanation.

Chernobyl was not inherently very highly dangerous. Its reactor physics basics were well established many years before, but the executive/managerial structure was irresponsibly irrelevant. That was clearly the cause of the tragedy. The appreciable dangers inherent in this form of thermally unstable reactor (never adopted at commercial levels in the West) were well publicised in text books some twenty years before the accident (or the 'Caused,' call it what you will). Importantly, this reactor had no containment dome to constrain escaping radioactivity. Steam/ hydrogen explosions, caused by gross mismanagement, did huge environmental damage, but that which allowed radioactivity to kill most of the 76 people who died in the disaster, and its securing of the plant, was the prior steam explosion within the core of the reactor which blasted core material – radioactive fuel pins, their damaged zircalloy cladding, burning graphite and red hot metallic objects – into the surrounding countryside (see Appendix 5).

The Japanese Fukushima disaster in 2011 was caused by an unplanned tsunami that disabled the cooling systems, causing a series of hydrogen explosions,(not steam ones) in the buildings of the reactors, forcing a major evacuation of the zone due to radioactive contamination. The cores remained intact as proven by intact instrumentation recording pressures as more or less normal. To date most technical assessment reports indicate that although clean-up crews were exposed to unacceptable levels of radiation, all associated deaths were caused by the tsunami, not by the reactors. Radioactive emissions from three meltdowns are estimated in total to be at about one tenth of just the one Chernobyl core steam/ hydrogen explosion event.

For the general public to get these into perspective it is necessary to look at man's nuclear reactor activities over the last seventy years.

By far the most experience in operation of reactors has been gained in the military fields, primarily of the former USSR, USA, France and UK. Some thirty years ago USSR had 169 nuclear powered vessels in the navy, (that is they had reactors producing steam to drive turbines to turn propellers). USA had over 140, while other nations had relatively few. Some of the early ships had up to eight reactors each, while now even the largest generally have only two. None-the-less, since 1950 there had been over 500 military propulsion reactors afloat showing more than 15,000 reactor operating years. Now the total operating time is more than double that number. Say 40,000 years of operating experience and any error would be small enough not to affect the argument that there is a large amount of experience but very few accidents.

In the civilian fields there are about 440 operating power reactors and a significant number of research reactors still operating, with a combined total of only about 500 reactors giving an additional, say, 20,000 operating years.

While there have been few military disasters in the western world, the death toll from those has been recorded as very low, but the experience has permeated the civilian control and operating spheres. These have rendered the civilian side safer. Only Chernobyl has caused significant loss of life in the civilian nuclear power scene. This is covered in Appendix 5. There is no comparison between this one disaster, with less than 80 lives lost, and those of the coal mining and oil drilling operations over the last sixty years.

From a dispassionate viewpoint, nuclear power generation has proved to be much safer that any alternative major source of on-line electric power. But it is not understood.

Research reactors are used extensively for medical research and to produce isotopes for treatment, mineral analysis etc as well as for nuclear research in many countries.

Nuclear Weapons – Cores Production Reactors

The first critical reactor problem in history, was revealed in some detail in "*Dark Sun*," 1995, by Richard Rhodes (5).The first mention of the problem that I hold is in "The secret history of the atomic bomb," 1977, by Anthony Cave Brown and Charles B. MacDonald.

The plutonium production complex at Hanford, Washington State, U.S.A. faced a near disaster on September 27, 1944, when its first big production reactor, the B pile, started up successfully, ran for about twelve hours, mysteriously died, started up again spontaneously after a delay and about twelve hours later began another decline.

Princeton theoretician John Archibald Wheeler worked out the reason in an all-night marathon review of fission physics. As there were surplus holes drilled in the graphite blocks the problem was overcome simply by adding many more fuel pins into those.

The cause was Xenon Poisoning which is explained in Appendix 3. That reactor, known as the B pile, was a graphite-moderated, enriched uranium cored reactor – cylinders of graphite bored with 2,004 horizontal channels into which aluminum tubes were inserted. Into these canned uranium slugs (fuel elements having much higher U 235 proportions that natural uranium i.e. 'enriched uranium') could be loaded. When the fuel elements had been irradiated for 28-35 days they were extracted. This was long enough for less than 1% of plutonium to be formed which was dominantly Pu 239 (that could be chemically separated from other fission products, but not from any of the 14 other plutonium isotopes if the reaction were allowed to proceed any further), to yield bomb core material. Each fuel slug was pushed out of the pile, dissolved in acid and almost pure Pu 239 separated chemically from the uranium and other daughter products.

Due to fundamental ignorance, many people think that the fuel pins from a commercial reactor can be used after a year or three for the same purpose. In theory this is possible, but extensive research has shown it to be an extremely expensive way to go to produce a very highly sensitive product with an unacceptably short effective usable life. Briefly, this track has never been followed to acceptable utilisation.

Much later Xenon Poisoning was an unwitting outcome of the mishandling of the Chernobyl reactor in the Ukraine in 1986, (See Appendix 5).

Since that time there have been many reactors built in many countries to achieve the same aim of producing the same product by the same method of extracting "fuel" pins after very short burn-ups. The Russian reactors were for many years two-function ones designed to produce commercial electricity and weapons grade plutonium 239. Most Western ones were originally of B pile type but, with its naval experience, USA drifted rapidly into light water, uranium fuelled reactors for power production. Others followed.

Research Reactors

The first of these became famous in December 1942, when, after years of intensive study by physicists throughout much of the world, a Chicago group under Enrico Fermi succeeded in bringing about the world's first man-made sustained nuclear chain reaction. This was in a graphite pile containing lumps of natural uranium. Thus was created the beginning of a race for nuclear weapons as well as for research reactors, nuclear reactors to power warships and to generate on-line electricity in the civilian field.

The first in Australia was HIFAR, (High Flux Australian Reactor) which began routine operation in 1960. Its maximum heat production was listed as 11,000 kW. Ten tons of heavy water (deuterium oxide) were used to moderate 6.6 lb of U 235 in 25 fuel elements, which were replaced at a rate of one third every 28 days. The heavy water tank was encircled by a tank containing graphite to scatter escaping neutrons back into the tank. Source of information :– brochure, undated, from Australian Atomic Energy Commission (defunct for many years). HIFAR was shut down about five years ago. AAEC had a very much smaller reactor – MOATA – also at Lucas Heights, near Sydney, NSW, until about 20 years ago. A graphite-moderated, highly enriched U 235 core with an output of about 100 kW, it was used primarily for instrumental neutron activation analysis (INAA) of a wide range of elements, but particularly for naturally occurring uranium in soils as well as for other research.

Many countries including Russia, France, Israel, UK, Canada, USA, Chile, Argentina, and Brazil have research reactors. Australia's latest is a tiny one, designed in Argentina called "Opal" which is not suited to commercial INAA. This is used for research as well as for production of medical isotopes.

Commercial Reactors

Initially,in the 1950s, almost all commercial reactors used enriched uranium cores with graphite moderation . they were water cooled.

As the US Navy developed their pressurised, water-moderated and cooled units (PWRs) the commercial field in the Western World swung to this technology. For technical reasons this is unsuited to 239 plutonium production, so for this purpose graphite moderation was used. In the USSR the RBMK dual purpose producers of that plutonium and of civil electricity became the standard (see Appendix 5.)

Meanwhile a myriad of light water and gas cooled reactor types flourished in the West.

A few details are given in Appendix 8, where the Jervis Bay NSW fiasco is mentioned. This may serve as a lead into further enquiries into types known by the acronyms such as SGHW, BWR, Magnox, Candu etc.

More recently pebble bed reactors and fast nuclear reactors have received a lot of attention. See Appendix 2.3.

SUMMARY

After some 60,000, or more, atomic reactor years of experience, the world has only suffered the loss less than 100 people at Chernobyl, and elsewhere, from civilian nuclear reactor accidents – a safety record unmatched in modern technology that is not acknowledged in the eyes of either Western or Japanese media. For comparison, March 2011 figures from the World Nuclear Association quoted over 20,000 deaths from coal, 2,000 from natural gas, 30,000 from hydro in the energy chain for electricity 1969-2,000 AD.

Three Mile Island (TMI) exposed the fear of the unknown engendered by secrecy about applied reactor physics as it links to the military field of atomic weapons development, which fear was exacerbated by the so-called cold war and associated military posturing.

A result was that, to curb nuclear power and weapons fields, legislation was passed in the USA and elsewhere in the Western World placing time and reporting constraints on civilian development that caused a blowout in the lead time of nuclear power station construction from the time taken from first concrete pour to on-line busbar electric power of civilian reactors. This grew from approximately eight years to fifteen years or more. These escalations of markedly front-end capital-intensive, but technically useless, capital costs effectively shut down all such new development in USA and several Western World countries for many years. Meantime, elsewhere that lead time was slashed to five or even four years, promoting development there as nuclear power costs became competitive with alternatives in many parts of the world.

The USA thus went further ahead of the rest of the world in its development of military nuclear reactor power plants, especially for warships – see Appendix 2.1- but not of civilian nuclear power.

Since TMI, Chernobyl fuelled xenophobia further,which the recent Fukushima meltdowns compounded throughout the Western World. A disastrous tsunami has been portrayed by the media as a nuclear disaster because it seriously damaged nuclear facilities and has destroyed many lives and huge amounts of capital investment. But this was no Chernobyl in terms of release of radioactivity, or cause of radiation deaths, although it did reveal flaws and dishonesty. (See Appendices 4, 5 & 6.)

Work in the civilian field immediately prior to the TMI miscue had reduced the lead time for construction down to four to five years, bringing nuclear power costs down to highly competitive levels in many countries, while reactor operating lives had increased from twenty to thirty years to sixty years or more. This was reflected in the refuelling time quoted for the latest US Navy aircraft carriers as ‘life time’ or once every sixty years.

Education in nuclear reactor physics and associated fields in Australia seems to have been embargoed in Australia by politicians afraid of the unknown (see ref. 10).

The AAEC was pseudo-replaced by ANSTO more than twenty years ago. A Director of ANSTO advised the writer in 2011: “I’ve learned something”, when confirmation was received from staff on site that the new, politically correct, tiny Argentine-designed OPAL reactor at Lucas Heights could not be used on a routine commercial basis to analyse 30 gram samples simultaneously for several elements by neutron activation analysis – which both MOATA and then HIFAR could and did. That Director is a highly qualified geologist and at the time was the Chairperson of the Board of Directors of a significant Australia uranium exploration company (Appendix 8.)

The loss to Australia of its AAEC expertise was graphically revealed in a government publication in 2006 (Abare research report 06.21), the glossary of which (pp xi – xv) contains a hopeless mishmash of poorly defined and misleading definitions while it omits several which should be included. One speculates that this was deliberate obfuscation.

Sic transit gloria.

GLOSSARY

(Note: These definitions are to help; they may not be entirely acceptable in science.)

BARN – 10 to the minus 24 square centimetres – a measure of nuclear capture cross-section. Written as 'b.' Varies with temperature. Assume 3000 K here. A millionth is 10 to the minus 6! So 10^{-24} is a millionth of a millionth of a millionth of a millionth.

CANDU – Pressurised heavy water reactor using natural uranium as fuel. Abbreviation of Canada and Deuterium (q.v.).

CRITICAL MASS – a quantity of fissionable material that will support a self-sustaining chain reaction. Only one neutron from each fission is available to take part in further fissions.

CAPTURE CROSS-SECTION – area of the effective ability of fissile material to interact with neutrons. This varies considerably with the energy of the neutrons. E.g., for thermal neutrons the CCS for U 235 is 590 b and for U 238 is 2.7 b. For Xe 135 it is 2.6 million b.

For fast neutrons the numbers are quite different and very much less.

CRITICAL/ CRITICALITY – A situation when an atomic pile or reactor core is producing as many neutrons as are being lost or consumed. A self-sustaining chain reaction. Subcritical – losing more than are being produced. Super critical- the reaction is producing more than it is losing. C.f. Prompt Critical.

DEUTERIUM – formal name for an isotope of hydrogen containing one neutron and one proton in its nucleus. Paradoxically, the symbol 'D' is used for this.

FAST NEUTRON – a high energy neutron, released at about 15,000 km/second from fission of U-235. Commonly energy level about one thousand electron volts (1 MeV).

FAST NEUTRON REACTOR – often called a fast reactor, is one that sustains its fission chain reaction by fast, as distinct from thermal (or slow) neutrons. Theoretically as the fast neutron capture cross-sections of U 235 and U 238 are about the same, to have as many neutrons interacting with 235 as with 238 (the condition for a chain reaction) there must be at least as much 235 as 238 in the fuel.

As such, no moderator is needed. Its fuel, however must (for good reasons of physics) have much more fissile material than an equivalent thermal reactor. Other advantages are that it can use almost all of the fissile material in the waste and dramatically reduces the life of the wastes. As long ago as 1984, at a course in South Australia, fast neutron reactors were said to have had two decades of technological development IN UK, France, Japan, Germany and USSR and to be on the verge of commercial application. The Russians have only now confirmed this there – (see Appendix 2.3 comment: SWORDS INTO PLOUGHSHARES.)

FISSILE (here) – able or amenable to splitting by neutrons.

FISSION (or splitting) – in this instance, splitting of atoms by neutrons.

HALF LIFE – the time taken for a radioactive isotope to lose half of its mass. Various isotopes of the same element may have very different half lives. These may range from microseconds to many millions of years.

HEAVY WATER – D_2O as distinct from H_2O. This is a good moderator to slow neutrons down because its ability to capture neutrons is very much smaller than that of H_2O.

ISOTOPES – (This is an amazing word, in an amazing world.) Isotopes of an element - atoms having the same electrical charge as each other, but differing numbers of neutrons and hence differing atomic weights. (See Appendix 1.)

For those of you with high school physics and/or chemistry, you are aware of atoms of various kinds – each with its own particular ways of combining with other atoms to form molecules. Many can survive alone such as gold, silver, platinum, mercury, iron, magnesium etc. without combining while others, known as noble gases, never combine. These are helium, neon, argon, krypton, xenon and radon. What may come as a surprise is that many elements each have a whole range, not just one atomic structure, and hence have a range of atomic weights. The chemical behaviour remains the same, as dictated by the number of the protons and electrons in each element, but the physical behaviour of atoms and compounds of those atoms changes with the atomic weight as the number of neutrons in the nucleus changes, leading to a change of mass, (which can be regarded as weight) of each.

Examples common in today’s media presentations include uranium and plutonium, but let’s start with iodine: We are all aware of iodine, but few people understand that there are 39 known isotopes of iodine, only one of which is not radioactive – i.e. it is stable. Almost all the others have a short to extremely short half-lives, but one, a product of atomic tests in the atmosphere and of nuclear fission accidents, has a half life of 15.7 million years. Four others, used as tracers, have half lives of 4 days, 8 days, 13 days and almost 60 days.

MODERATOR – any material used to slow the speed of neutrons, preferably to so-called thermal energy speed, to permit or to enhance the chance of neutrons being captured to cause nuclear fission. The two most commonly used are graphite and heavy water i.e. deuterium oxide.

NUCLEAR CAPTURE CROSS SECTION – See Capture cross-section.

NUCLEAR POISONING – Refer to Appendix 3 for this and Xenon Poisoning.

PROMPT CRITICAL – A more than doubling of energy output every tenth of a second in an atomic pile or reactor core when more than 1.007 prompt neutrons per fission induce another fission (c.f. e.g. Cohen, 1987, p 1080).

SUBCRITICAL MASS – an amount of fissionable material insufficient in quantity or of improper geometric arrangement to sustain a fission chain reaction. All neutrons produced by fission are lost from such a mass.

SUPERCRITICAL MASS – a quantity of fissionable material whose effective neutron multiplication is greater than one after fission occurs. (a sub-set of this is a prompt critical situation – *OOPS*, normally a run away multiplication.) Extreme examples are nuclear explosions).

THERMAL NEUTRON – a slow neutron. Commonly about 1.5 km/second. Often categorised by the energy level of about 0.025 electron volts (eV).

TRITIUM – a radioactive isotope of hydrogen containing two neutrons in its nucleus, but still only one proton and hence only one electron. Hence the same chemical behaviour.

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TECHNICAL INFORMATION

Appendix 1 – Niels Bohr's Model

Atoms consist of three fundamental particles - positively charged PROTONS, neutrally charged (charge-less) NEUTRONS and negatively charged ELECTRONS.

Protons and Neutrons have significant mass (or weight) and together form the cores of atoms.

Electrons surround the cores as clouds, with their precise locations quite indeterminant but having almost insignificant mass.

A proton carries a single unit of positive charge, equal in magnitude but opposite to the charge of an electron. It is identical with the nucleus of a hydrogen atom. The atomic number of an element, ‘Z,’ is the number of protons in the nucleus of that element. Hydrogen has 1 as its atomic or Z number. All Uraniums have 92, all Plutoniums 94.

The neutron is very slightly heavier than the proton and, as its name implies, is electronically neutral, i.e. it carries no charge.

The total number of protons and neutrons in anyone one atom’s nucleus is called the mass number, denoted by ’A.’ The A for hydrogen is also 1. Most uranium has 238.

The number of protons in a nucleus of an element determines the chemical nature (behaviour) of that element. However, as the A changes, by addition or subtraction of neutrons from an element’s core, that element may exhibit marked moderation in its nuclear physics characteristics. Hence we find very different half-lives of different isotopes of the (chemically) same element.

So elements having the same atomic number but different mass numbers are called isotopes of that element. Uranium-235 would be written as ${}^{235}{}_{92}U$ and uranium 238 as ${}^{238}{}_{92}U$, but for ease here, the less technical U-235 & U-238 are employed.

The simplest example of this is to look at what happens when a neutron is added to each hydrogen of water (hydrogen oxide, H_2O). It becomes heavy water i.e. heavy hydrogen water (D_2O). This is a change from H_2O, which is a slow neutron poison, to an excellent neutron moderator! The ‘D’ stands for the second isotope of hydrogen, confusingly named deuterium (as though it were another atom) although it now carries the same Z=1; it’s A is now 2. If a second neutron is added we now are dealing with tritium – same Z=1 but now A=3. Tritium is unstable, i.e. radioactive.

Let us take it from there. Any other technical explanations have been confined to further appendices. This is to allow the main text to be read as a stand-alone article by lay people having no technical background.

Friends and acquaintances having high level expertise in many other aspects of nuclear physics, such as space science of noble gases, analysis by proton induced excitation of gamma and x-rays (PIGME & PIXE), prompt neutron fission (PFN) analysis and of instrumental neutron activation analysis (INAA) have, perhaps unwittingly, convinced me that many of them, unsurprisingly, have no detailed knowledge of the physics of nuclear reactors, but seem unaware of the relevance of this lack, and hence of their propensity to mislead when writing or commenting on nuclear reactors.

For that reason this tract has been written, as much as it has been an attempt to bring some facts to the attention of intelligent educated people who have had no exposure to the field of nuclear reactor physics, as to show the danger of accepting quite technical articles written by nuclear physicists who do not understand the significance of their ignorance of relevant reactor physics, despite their deep and highly relevant understanding of associated areas of nuclear physics.

Appendix 2 – Reactors

2.1 Production Reactors

Initially, in the 1950s, almost all commercial reactors had cores enriched in U 235, moderated by graphite and cooled by water. As the US Navy developed their pressurised water-moderated and cooled (PWR) reactors to drive submarines and eventually some surface ships, the commercial field rapidly swung to these in the western world. For technical reasons explained in Appendix 5, these are unsuitable for plutonium 239 production, so research style, but larger than university sized reactors were continued for this in the west.

In the USSR the RBMK reactors, of which Chernobyl was one, continued to be developed as dual-purpose suppliers of commercial electricity while retaining the capability of producing military grade plutonium 239. (The only one of the fifteen isotopes of plutonium satisfactory for making nuclear explosives.) At the time of the Chernobyl disaster these constituted about 50% of USSR's commercial nuclear field.

Meanwhile a myriad of light water and gas cooled reactor types flourished in the western world. Mention is made of some of these in Appendix 8 in which Australia's chosen Jervis Bay mid-sized commercial reactor is discussed. A later design, the pebble bed reactor, has been trailed and given a lot of publicity, while commercial fast nuclear reactors are now coming to the fore.

2.2 Military Reactors

2.2.1 Nuclear Powered Warships

These include all those designed to generate electricity and/or mechanical power using steam from nuclear reactors. Most nuclear reactor powered warships use light water to moderate neutrons from enriched to highly enriched uranium cores to generate steam to drive turbines. There are almost as many variations on the system as there are navies. An exception was the Lyre Class (NATO designation Alfa Class) Russian submarines which used fast neutron reactors, which have no moderation of their neutrons.

The first warship of which I am aware was the US Navy's submarine SSN 571 'Nautilus.' Laid down on 14 June 1952, launched 21 January 1954, commissioned 30 September 1954 equipped with one pressurised water-cooled S2W Westinghouse reactor. She put to sea first on 17 January 1955. Of interest is the estimate that she predated the first Soviet nuclear-powered submarine by five years. Also of interest is that she was first refuelled in April 1957 with the core upgraded from about 18% U-235 to about 40%. She was again refuelled in 1959 and again in 1964. The world's first nuclear-powered surface warship, cruiser USN CGN 9 'Long Beach,' was completed in 1961.

A series of snapshots, dominantly from a few editions of "Jane's Fighting Ships," gives a vague idea of the number of naval nuclear reactors over the years from about 1974 to the present (2012).

By 1974 there were 204 nuclear powered warships of which 83 were from USSR and 107 from USA, 11 from UK and 2 from France. By 2012, after several ups and downs, six nations had 159 nuclear warships. These included China and India. Details are given below:

> The first nuclear-powered aircraft carrier, USN CVAN 65 'Enterprise', was laid down in 1958 and commissioned in November 1961, with eight reactors. The next such vessels were ordered in 1967, almost ten years later than "Big E," with only two reactors. These were designed to have at least 13 years of reactor life, while more recently such vessels have been planned and built, with reactors having no in-service refuelling and lifetime service in excess of 60 years. This shows the rapid advances in understanding the application of reactor physics in the U.S. Navy. These latter ships displace over 102,000 tonnes.

As an aside, an April, 2012 visit to Perth, Australia, by an aircraft carrier of the US Navy showed thirty years of operating experience of a ship laid down thirty six years ago! CVN 70, USS Carl Vinson was laid down in 1975, launched in 1980 and commissioned in 1982. Fully loaded she displaces more than 96,000 tonnes.

2.2.2 Warships 1974 – 2012

1974

Nation	Type	Number	Sub sub-total	Subtotal	Total
France	SSBN	2, only one launched			2
UK	SSBN	4			
	SSN	6 + 2 launched, 2 laid down			
	Prototype	1			11
USA	CVN	Aircraft carriers		3	
	SSBN	Ballistic Missile Subs		41	
	SSN	Attack Submarines		58	
		Research Subs		2	
	CGN	Missile Cruiser		1	
	DLGN	Missile Frigate		2	107
USSR		NATO designation			
	SSBN	Delta	4		
		Yankee	32		
		Hotel II	9	45	
	SSN	Golf I & II	22		
		Zulu	2	24	
	SSGN	Charlie	11		
		Echo 1	3	14	83

They also had 3 ice breakers attached to their naval fleet.

World total was effectively 206 nuclear vessels.

1981

France	SSBN			4	
	SSN			6	
	CVN			1	11
UK	SSBN			4	
	SSN			12	16

USA	SSBN	41	
	SSN	86	
	CVN	4	
	CGN	9	140
USSR	SSBN	71	
	SSGN	45	
	SSN	49	
	CGN	1	
	Ice breakers	3	169

The world total was effectively **342** nuclear powered warships.

By 1978 China had laid down 1 SSBN and 5 SSNs, and the overall total of nuclear powered warships was 300 but by 1999 – 2000 that total had fallen to **172** as the USSR had collapsed and several of their very quick submarines had only 7-10 years' life and were time-expired.

These are described in the next section.

The Russian Federation was down to **56**, the USA to **84**, UK was up to **16**, France had **5**.

The new scene in 2012 is:

China	SSBN 3, yet to deploy, plus 3 building with 5 SSNs and another 5 planned.
India	SSBN 1, built in India plus 1 SSN built in Russia
France	Still only 11 nuclear warships, but 3 SSNs laid down, 3 planned, 1 launched, to catch up, as of their 6 SSNs the youngest was commissioned in 1993. Their oldest SSBN is a 1997 boat, the youngest a 2010.
Russian Federation	Their total has fallen from 169 in 1981 to 45 now, but they are building 3 new SSBNs and 2 SSNs
UK	Only 11 boats, but 4 laid down and 2 planned, all Astute class SSNs (updated Trafalgar class).
USA	Down from 140 nuclear warships in 1981 to 82 now, but these include 11 CVNs and they are building 11 new Virginia class SSNs and a new CVN. In summary, the major powers have significantly reduced their fleets while others are slowly building theirs up. (The total is about 150 vessels, depending on what one counts!)

2.3 Swords into plough shares?

Much of the interaction between military reactors and civilian ones is held in secret by each nation operating nuclear warships and/or pursuing the course of nuclear weaponry, but an interesting exception was revealed recently. A submarine reactor design morphing into a civilian power reactor!

On March 22, 2012 World Nuclear Association News (WNN) revealed that Russia is pressing ahead with a small fast reactor, SVBR – 100, along the concept lines of their seven Project 705 Lyre class (3,200 t submerged) submarines. These are quoted in Wikipedia as "the fastest class of military submarines built." Known as Alfa class by NATO, these subs were laid down between 1968 and 1975 and commissioned between 1971 and 1981. They were decommissioned for scrapping between 1974 and 1990. Each had a lead-bismuth cooled fast reactor of 30,000 kW, giving a submerged speed of 41 kt (76 kph) with burst speed in tests to 45 kt. Acceleration to top speed took only one minute and reversing 180 degrees at top speed required about 40 seconds. These reactors had short lives. They had to be kept warm by external heating when in port and when not in use. They were very much smaller and lighter than water-cooled reactors – and safer, too for the coolant would quickly solidify in the event of a leak. Inherently they could not cause a nuclear explosion despite using highly enriched uranium in the core.

They were very noisy and a later development, the Akula 971 attack submarines were a slower hybrid of the Alfa (Lyra) and Victor III classes.

The SVBR – 100 is expected to be put on-line as a 100 MWe demonstration plant by the end of 2017 as the first civilian power reactor cooled by heavy metal. With 16 such modules, it is expected to supply electricity at lower cost than any other new Russian technology as well as achieving inherent safety and high proliferation resistance. Quoted anticipated production of electricity cost is 6 cents/kW h.

On 28 June WNN stated that approval had been given for the country's first BN-1200 large fast reactor at Beloyarsk as unit 5 to replace the smaller BN-600, which has operated for 22 years, and is due to be shut down by 2020. On 30 June WNN confirmed that the new reactor design (of about 1220 MWe- enough to power Adelaide!) is expected to be completed next year, construction to start in 2015.

On 28 June WNN revealed that France is still a long way behind as Bouygues Construction is to collaborate with France's CEA on design and construction of the Astrid fast reactor prototype.

Appendix 3 – Xenon Poisoning

Poisoning, in the nuclear physics use of the word, is NOT to be confused with poisoning in the biological sense. The term used here relates to significant slowing down of a rate of fission reaction, neither biological damage nor interference with living things' biology.

As a preface, two facts must be understood:

Fission products in any nuclear reactor vary with the composition of its core and with time, as many products are radioactive and cause fission themselves. Two such products that can affect reactors are Xenon-135 and Samarium-149.

To better grasp the subtleties of this we need to understand that the whole exercise is beyond even our top nuclear experts. For the layman it is enough to grasp that fissioning (or splitting) occurs when a <u>slow neutron</u>, about 2-3 km/sec. (q.v.), hits a U-235 atom in a reactor core. Seldom that neutron will be absorbed, forming U-236, but more likely it will split (or fission) the U-235 atom almost immediately. The U-235 atom breaks into two particles which are not of equal size and which are not always of the same elements in different fission events. The details are not predictable, but over many "splits" providing lots of data, mathematics have been derived to fairly accurately predict what usually happens.

The two particles so formed are themselves invariably very unstable. They usually start by ejecting one or two neutrons, more often two, sometimes three. Rarely one or four. The two particles may be of masses (86 + 147) or (99 + 134), (104 + 134), (103 + 131). Once in a blue moon a neutron will penetrate U 238 forming U-239 which quickly changes to a plutonium Pu-239 nucleus.

86 is rubidium+ 147 is promethium; 99 is technetium+ 134 is caesium; 104 could be ruthenium + 134 is caesium; 103 could be rhodium + 131 could be either iodine or xenon?

So it can be seen that details of the process are far too complicated to be explained to people without strong relevant science backgrounds – they include many nuclear physicists who have not studied reactor physics. The physics is explained in some detail in Cohen, 1987 (8), but some details amplifying that lie on p 262 of Glasstone & Sesonske, 1967 (7).

In a nut shell, one short-lived reactor product, tellurium 135, (half life less than a minute) decays to iodine 135 (half life 6.7 hours) which decays to xenon 135 (half life 9.2 hours) which decays to caesium 135 (half life 2.3 million years) which decays to stable barium 135. (Some 38 isotopes of tellurium, 39 of iodine and 41 of xenon are recorded, but only the short lived ones listed above, produced in nuclear reactors, concern us here.) The Xe 135 has such a huge ability to capture thermal neutrons (see glossary – 2.6 million barns) that it effectively shut down the B pile until the gas had decayed enough (about 10 hours) to stop blocking the reactor's supply of those neutrons. Then the reactor started up again.

The problem in Hanford was overcome by increasing the number of fuel pins inserted into the pile and accepting the Xe-135 production as part of the process. This caused extensive study of this uranium-fuelled, graphite moderated reactor – for the technical side of this refer to the Technical Appendix 5 appended. The problem was resolved by Princeton theoretician Archibald Wheeler in an all-night marathon session in 1944.

The first Soviet reactor failed to start up in November 1945 for that same reason – it, too, was a graphite moderated, uranium fuelled reactor. The xenon poisoning problem eventually became so well known and widely understood that two copies of a relevant 1967 text book, in English, have been on the shelves of the library of the University of Adelaide since the 17th August 1967. They include an explanation of the physics of the problem, while xenon's part in the physics of reactors is also alluded to in an article in 2009 (3).

Appendix 4 – Three Mile Island, March 1979

This accident, in Pennsylvania in eastern USA in 1979, ended with a partial melt down of the core of a commercial nuclear reactor that resulted in the release of small amounts of radioactive iodine and gases into the environment, some 33 years ago.

Confusing communications from officials resulted in an evacuation of 140,000 pregnant women and pre-school age children. The wash-up Kemeny Commission Report concluded that "**THERE WILL EITHER BE NO CASE OF CANCER OR THE NUMBER WILL BE SO SMALL THAT IT WILL NEVER BE POSSIBLE TO DETECT THEM. THE SAME CONCLUSION APPLIES TO OTHER HEALTH EFFECTS**."

Nobody was killed or injured in the plant but the damage to USA's civilian nuclear reactor programme was many times the cost of the clean-up, which officially ended in 1973 with a total cost of about a billion dollars. To date (2012) no related cancers have been detected.

The critical failure was identified by the Nuclear Regulatory Commission as a violation of a key NRC rule that if all auxiliary feed pumps are closed for maintenance, the reactor must be shut down. The partial melt-down occurred because cooling water was shut off, after which the reactor performed an emergency shut down. Within eight seconds control rods were inserted into the reactor's core. This halted the chain reaction, but the reactor continued to generate what is called "decay heat" at about 6% of operating heat, that could not be conducted away in water or steam due to valves remaining closed.

This accident was initiated by poor operator training and an unacceptable level of human-computer interaction design oversights. Those related to ambiguous control room indicators in the power plant's user interface. A key control room indicator misled operators into failing to recognise a loss of cooling accident and then to turning off emergency core cooling pumps in violation of the NRC rule.

In a nut shell, inadequate operator training combined with a failure to comply with externally mandated rules cost the company and the USA a huge amount of money, time and civilian reactor construction, but due to the reactor design, with its primary containment, <u>nobody's life was at risk</u>. Too bad that nobody told the US President Jimmy Carter, formerly a deck officer on US Navy nuclear submarines. Unlike most politicians, he had to have passed a course at post-graduate level in the physics of nuclear reactors to hold his Navy position – see Appendix 2.1 on nuclear reactor powered warships.

Appendix 5 – Chernobyl, April 1986

An explanation in 'simple terms' of the nuclear physics of the cause of the disaster is followed by details of what actually happened and why.

In 1967, two copies of a hard cover text book "Nuclear Reactor Engineering" by Samuel Glasstone, Consultant, United States Atomic Energy Commission and Alexander Sesonske, Professor of Nuclear Engineering, Purdue University, were placed on the shelves of the Barr Smith Library, in the University of Adelaide. They were still there in 2012(7). On p. 262, section 5.90 in "Xenon Poisoning During Operation" dealing with the physics of nuclear action interference,(not poisoning in the biological sense as we know it,) a series of negative beta decay stages were published showing ;-

Tellurium 135 (½ life < 1 minute) decaying to Iodine 135 (½ life 6.7 hours) decaying to Xenon 135 (½ life 9.2 hour) decaying to Caesium 135 (½ life two point three million years) decaying to Barium 135 (stable).

(A beta decay is a change of a neutron in an atom to a positron, maintaining the overall 135 atomic mass (Z), but raising the atomic number, or number of protons (A), by one each time. In this example going from 52 (Te) to 53 (I) to 54 (Xe) to 55(Cs) to 56 (Ba)).

This xenon 135, one of over 30 unstable isotopes of xenon, is a most important fission product 'poison', or slowing down mechanism, as it has a huge thermal neutron capture cross section of about three million barns. That is, it has a great propensity to capture the very neutrons which are most desirable in a man-made nuclear power reactor to cause fission resulting in heat to boil water that forms steam to drive turbines to generate electricity. While it is formed at only about 0.2% by weight as a direct product of fission, about 6.1% of slow-neutron fissions of U-235 (required fuel in all civilian Uranium-fuelled reactors) result in the sequence, given above, of the tellurium 135 negative beta decay chain down to barium 135.

Herein lay the problems, unrecognised at Chernobyl, when an electrical engineer unwittingly set up the April 1986 nuclear reactor accident that horrified the world. An analysis of the event was published in a 1987 article by Bernard L Cohen (8). He explained extensively a lot of background material in nuclear reactor physics and nuclear explosion physics required for an understanding of what happened and why. He also outlined the significant differences between all civilian US reactors and the Chernobyl one, explaining why this could not happen in USA (Cohen was a lecturer in this topic at the University of Pittsburgh, Pittsburgh, Pennsylvania at the time).

The Chernobyl accident was a result of the authorities allowing an experiment designed to develop a use of stored kinetic energy in the power station's turbo generators to operate water pumps in the event of a failure of off-site electric power after a theoretical accident had shut down the reactor. Worse, someone thought that this was strictly an electrical engineering experiment, so it was directed by an electrical engineer. Neither he nor the operators knew enough reactor physics to appreciate the extreme dangers of their actions. Worse, the operation manuals for the reactor were never delivered to the plant. They stayed on someone's desk in Moscow I have been informed.

At 11 pm on 25 April 1986 reactor power (heat energy) in one reactor was reduced to simulate a power loss, but it was reduced too quickly from 1000 MW (mega watts or thousands of watts) electrical generation level to 700 MW, allowing a rapid build-up of Xe 135. That xenon drove the power down by absorbing far too many thermal neutrons for the reactor to remain critical. Power fell to 30 MW. Manipulable control rods were withdrawn and after two hours, power was steadied at 200 MW.

As per the original experiment's plan, additional water pumps were turned on at 1:05 am, for these to be powered by the stored mechanical energy within the turbo generator – but this was an excessive water supply, forbidden by the reactor's rules because it could lead to prompt criticality (q.v. in Glossary).

Then the water level in the steam separators was observed to be too low, requiring an increased flow of water there (which would automatically increase water flow through the reactor). This was executed at 1:19 am.

Since water is a nuclear "poison," (see Appendix 3) this required further control rod withdrawal. All of the automatic control rods came all the way out of the reactor, but this was still not enough to prevent the power from falling.

At 1:23:04 the test was begun. Steam was diverted away from the turbo generator, which began to run down. This reduced the load on the reactor. Now steam began to increase in the reactor. The water pumps slowed down due to the turbo generator running down. As there was no immediate reduction of heat, more steam was generated. The loss of load reduced the drain off of steam. More steam, less water, less nuclear poison, which means more heat generated – a circular increasing trap. The reactor power began to increase very rapidly. The automatic control rods went all the way in. That set up a situation where energy produced (power) could double in 0.1 second. (Cohen, 1987 p. 1080).This set up a gross overheating in the core.

At 1:22:30 a computer printout indicated that the reactor should be shut down immediately.

At 1:22:40 the shift director ordered insertion of the emergency control rods, but they only got part of the way in before they were jammed !

At 1:24 there were two non-nuclear explosions. (Neither were nuclear as proven by the limited damage to the building and to nearby nuclear facilities. Almost certainly they were a superheated steam explosion followed by a hydrogen explosion which was caused by very hot water or steam attacking the zircalloy fuel pins cladding the nuclear fuel, generating hydrogen which was released into contact with air (and hence to oxygen) following the steam explosion).

Hot fragments were ejected from the top of the reactor building as the core was destroyed. These started about 30 fires.

It is estimated that the generated heat reached 20-100 times the designed maximum operating level.

Firemen arrived by 1:30 am and, although they had fires out by 5:00 am, the graphite moderator blocks in the reactor were burning as well as some material ejected.

In all, 31 men died on site – firemen, helicopter pilots and operators and reactor operators – in this disaster. Some 45 people have died since due to this 'accident.' Total 76! There have been a small number of deaths long after the disaster which may well have been contributed to significantly by the event but no proof has been adduced.

While Three Mile Island had its chain reaction shut down within seconds of its first failure,its reactor core proceeded to a melt down caused by residual radioactivity generating a few percent of the level of power generated by the chain reaction in normal operation. This is what happens when most power reactors, and many others, are shut down without ensuring that heat is conducted away from the core continuously until a safe level of heat generation has been reached.

There was possibly a small hydrogen explosion there, but certainly no nuclear explosion. Although TMI was a financial disaster, no human lives were at risk from the accident at the time or over time since.

This was a thermally stable, light water moderated reactor. Any water loss would have stopped the chain reaction very quickly. It also had a solid primary containment shell.

Chernobyl was an RBMK-1000, graphite-moderated reactor. This type is inherently thermally unstable against temperature increase, such that any loss of cooling water will accelerate the chain reaction !

Worse, while TMI's fully functioning concrete shield acted, as designed, to prevent the escape of any significant radiation or radioactive products in the event of a malfunction, operation mistake or a rupture of a machine containing radioactive material, CHERNOBYL HAD NO PRIMARY CONCRETE CONTAINMENT. It was designed to be a two-function reactor producing both electrical power and the bomb-grade plutonium isotope Pu 239, which requires fuel pins to be irradiated for 28-35 days only, then extracted from the reactor. Weapons grade Pu 239 (about 0.1 % of the extracted core material) has to be then dissolved out of them. Fuel changing must be done without shutting down the reactor. That would cause power failures which would have to continue throughout the extended shut-down and restart procedures. This, in itself, means that a very significant amount of working space is needed above the reactor. So much so that a one-metre thick, very heavily reinforced concrete shell lined with steel plate – the normal primary containment of a light water moderated reactor to prevent ingress or egress – becomes impractical. Even after the Chernobyl disaster, Soviet scientists remained convinced that it would not be possible to add such containment to their RBMK-1000 reactors. All Western World and many other reactors have such a containment shield as that at TMI, capable of withstanding a crashing mid-sized passenger jet-powered aircraft.

Not only did the xenon really exacerbate the reactor going out of control, but, due to lack of forethought on the part of the Russian authorities, tablets of the only stable iodine isotope were not issued to all exposed children as soon as the fire was notified.

(Of the 39 known iodine isotopes, only one, iodine-127, is <u>not</u> radioactive)

If they had been issued, the childrens' thyroid glands would not have been able to take up lethal doses of other iodine isotopes, which caused at least nine child deaths and several long-term related illnesses.

Finally, on Sunday 8 April, 2012, Travel Directors published an advertisement in an Adelaide, South Australia, newspaper including the following: 'Starting in the Ukraine capital Kiev, you will visit the site of the world's worst nuclear accident, Chernobyl. Travel Directors says 25 years on, with radiation levels "normalised" you will be able to visit the infamous plant, the abandoned town of Pripyat and have lunch with the villagers who have now resettled.' (Sunday Mail, p 14). This is about 120 km NW from Chernobyl.

A study published in 2005 (9), Entwhistle et al., gives details of some of the remaining radioactivity. On their p 18 they wrote "The bulk of the Pu and Am is still concentrated in upper 0 to 10 cm, with linear vertical migration rates in the EZ in the order of 1.2 cm a^{-1} ^{241}Am." This negates land rehabilitation over many hundreds of years unless a major programme of soil re-mediation takes place. The EZ site is "near to the reactor site" and is shown on their Fig. 1 as 20 km N of Chernobyl.

The Advertiser (Adelaide) reported on Monday, April 19, 2012 on p 76 that the final "New Safe Confinement" or NSC is expected to cost $1.36 billion, that the reactor buildings will be disassembled as soon as it is safe, radiologically to do so and that the entire site is to be cleared by 2065 AD.

A TV programme on 12 March, 2012 (SBS 2, Adelaide) reviewed the scene in which the totally ignorant media reported major scare stories which took a long time to refute. In fact the scare stories are still being produced.

Quite incorrectly, many media people did not appreciate that there was no chance of an atomic bomb explosion possible, much less had one eventuated there. Chernobyl could not equate to, nor generate a nuclear explosion. But that would destroy a really scary story. The Economist, for example, reported on p 15 of its special report on nuclear energy of March 10th, 2012 that "one of the reactors... ran out of control and exploded, killing workers there..." when it was driven out of control by an ignorant engineer and the explosion was not a fission bomb but, as detailed above, was of two phases, steam then hydrogen, and certainly was not related to a hydrogen bomb, or an atomic one.

Examples of scary stories are that as up to 10 milli-sieverts of radiation were expected in Kiev, the death toll there was guessed at 5,000 people. Near the site, when 500 msieverts were projected, the death toll was estimated at 20,200 ! ! While further away, where radiation levels were guessed at 125 mSv, the toll was foretold at 1,800 humans.

"High risk" levels, estimated as the equivalent of 50 chest x-rays or 2,000 millisieverts, was accepted as the accurate upper tolerable level in 1958. This whole game has been radically reviewed as more relevant data have come to light.

Even thyroid cancer deaths were guessed at 4,000, when a check in 2005 showed that number to have been a total of nine.

Cancer deaths predicted were hundreds of times higher than experienced by those on site and the vast numbers of health complaints expected did not eventuate.

The mutations anticipated just did not show up.

The reality was totally at variance with these xenophobic scary projections in every way.

While a deadly disaster, Chernobyl was nowhere near as dangerous as predicted or expected, but the number of forced abortions in Europe, initiated by the fear factor, as far away as Denmark and Sweden, which did experience radioactive cloud impacts, will never be known, although an estimate of 100,000 to 200,000 was published in 2008, -see the last paragraph of Appendix 8.

Twenty years after the disaster, cancer studies of the area in the Ukraine and of other affected areas, such as Denmark and Sweden, indicated that although some six to ten times natural levels of radiation had impacted them, there was no significant increase in cancers causing deaths there.

This sort of information reflects a growing understanding of levels of radiation that are beneficial to human health and those that, while not so, pose no threats. Unfortunately, irresponsible and ignorant executives and operatives in the world's media still remain convinced that the end (sales revenue) justifies the means of generating unfounded fear of the unknown.

The writer is indebted to Dr Doug Boreham, radiation safety and health expert at the eight 800 MW Candu reactors at the Bruce power station in Ontario, Canada for the relatively recent presentations on these matters given in Adelaide, SA .

Appendix 6 – Fukushima Dai-ichi, March 2011

On March 11, 2011 a violent submarine earthquake followed by a big tsunami (a so-called 'tidal wave') sent a huge wave of water into the forty-year-old Fukushima Dai-ichi I Nuclear Power Plant situated on the east coast of the Japanese island of Honshu, about 40 km east of the eponymous town, some 250 line-km NNE of Tokyo. Unit one, a 439 MWe type BWR 3,(boiling water reactor) was built in July 1967, and first delivered bus bar power in March 1971. So these were old reactors.

The plant had six old nuclear reactors, two of which, nos. 5 & 6, were in cold shutdown at the time. Reactor 4 had no fuel in its core at the time. The others automatically shut down, as they were designed to do, when struck by a significant earthquake. Emergency generators came on line, as designed, to control electronics and to maintain cooling.

The history of the plant contains abundant data showing a willingness to ignore precautions, predictions, planning and authoritative regulations etc. relating to protective measures to keep the shutdowns working (as residual radiation and hence heat, (some 6-10% of operating heat) requires adequate cooling for several days). The tsunami was much higher than planned for, but which should have been expected, so those systems failed when the back-up generators' rooms were flooded. Connection to the reactors' power grid was also disrupted. The remaining three reactors then were heated by their own residual radiation beyond their design limits.

This resulted in both Chernobyl-type hydrogen generation (see Appendix 5,) with subsequent explosions and also in melt downs of cores without release of radiation.

As primary containment of each reactor vessel did not extend much above the steam dryer unit of these Boiling Water Reactors, which lies above the reactor above control rods, there was no containment dome, such as that at Three Mile Island, above the spent pool area which lay outside of the secondary concrete shield wall.

This was a disaster made to happen. Wikipedia, obtained on 12 May 2012, cites a long history of incompetent management and refusal to accept criticism requiring action.

A record of a similar sized tsunami more than 100 years ago in that region was ignored in planning! Recent publication re this is in "Elements" Vol. 8 June, 2012.

On July 5th 2012 WNN advised that the Japanese Diet's Fukushima Nuclear Accident Independent Investigation Commission had issued an 88-page executive summary elaborating in detail the organisational, cultural and technical failings that allowed the accident to occur, confirming the statement above.

Fortunately, on 23 May 2012 a preliminary report from the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) revealed: "No visible effects detected on workers in Japan nuclear plant UN assessment finds."

As of 31 January 2012, 20,115 workers had been involved in operations following the accident, and although several workers were irradiated after contamination of their skin, no clinically observable effects have been reported. According to the findings, six workers have died since the accident but none of the deaths were linked to irradiation.

UNSCEAR's final report is scheduled to be presented "towards the end of 2013."

The psychological and financial costs are, and will be huge.

Appendix 7 – Reactor Accidents Summary

A review of the three worst 'civilian' atomic power electricity generating plant accidents, given in Appendices 4, 5 & 6, clearly shows that human interaction failures, when combined with sensation-seeking, highly irresponsible media releases, have given the safest major electric power source technology known to man a very bad, undeserved image, promoting widespread unwarranted fear about the technology.

In 2007 the US Nuclear Regulatory Commission launched a State-of-the Art Reactor Consequence Analyses research project. On February 02, 2012 World Nuclear News announced that the draft report "has now been completed and opened to public comment". The main conclusion was:

"A severe accident at a US nuclear power plant would not be likely to cause any immediate deaths, while the risks of fatal cancers caused by such an accident would be millions of times lower than the general risks of dying of cancer, a long-running research study has found."

Part of the problem has been the failure to up-date the 1958 radioactivity linear dose threshold model. People with no relevant background rely on the "authorities" to advise about such matters. Without data to contain it, the out-dated model stated that from a zero dose of radioactivity up to quite high levels there is a risk of damage to the human body directly proportional to the level of incident radiation. Looking around the world would have shown that to be a nonsense, e.g. in India the zone of the Kerala coast has extremely high background levels coming from monazite in the beach sands, yet there is no record of an abnormally high incidence of health problems there. More recent research has indicated strongly that a small dosage is logically beneficial. Probably the radiation impacts on aircraft pilots, flight crews, passengers and populations dwelling at high altitudes have confirmed these conclusions.

Appendix 8 – Australia's Atomic Energy Commission, (AAEC) etc

During 1953 the Atomic Energy Act was passed in Australia and the early work of the AAEC "was devoted to research and development directed towards harnessing nuclear fission for peaceful purposes, in other words, developing nuclear power reactors." (Alder, 1996 p8 (10).

Many sensation-seeking journalists have written implying or stating that the AAEC had a motive relating to nuclear explosives. This Keith F Alder strongly rejected in Notes about the Author on p 6 of his book, "Australia's Uranium Opportunities", published by his wife, Pauline M Alder, in 1996. (He was a senior staff member and then Deputy Director, from 1960 to 1962. He was appointed a Member of the Commission in 1968. Then from 1975 to retirement in 1982 he was the General Manager of the AAEC.). On p 12 he also wrote "…military secrecy has never been relaxed."

There are two sides to every coin. On p8 he wrote "the criticisms of the AAEC almost all apply to work it did on the topic of nuclear power, uranium, and the nuclear fuel cycle." In the paragraph preceding that is "on several occasions several of us with some knowledge of nuclear explosive technology acquired elsewhere before the AAEC existed were asked by other agencies of government for advice to assist in intelligence matters. This we gave on request. But all, repeat all, of the Commission's own work was directed at all times to the peaceful uses of Atomic Energy, and those who say otherwise are remoulding history to suit their own false views and political purposes."

On the next page Alder discussed "…applications of isotopes, radiation, and nuclear physics and technology" that have been "world class." He went on to write about Environmental Science in its infancy in the 1950s. Of this, the first such unit "was set up at Lucas Heights in 1956-7 to establish natural background and to conduct the continuing survey of the surroundings of the Research Establishment."

He ruefully stated: "These activities, not directly related to nuclear power, have not attracted the criticism (and odium) heaped upon the early programmes of the AAEC, principally by politicians, the media, and numerous anti-nuclear organisations, …"

The Jervis Bay, NSW, nuclear power project fiasco is well described on pp 37-41 and 48-51, including reference to the 5-7 tons (sic) of paper work received in response to the tenders closing on 15 June 1970 following expressions of interest from 14 overseas organisations to construct a 500 megawatt nuclear power station on Commonwealth Territory, either in ACT or at the later selected site.

The 14 embraced seven groups in the USA, UK, Germany and Canada, covering five different reactor types. This gives the reader of this tract some idea of the wide variety of reactor types then in operation – too many to be discussed in detail here. Naturally Soviet Russian types were not on the list – see Chernobyl - but the dominance of pressurised water (PWR) types (most common in naval applications throughout the world both then and since) and heavy water moderated and cooled types (CANDU) was evident, although a British steam generating heavy water (SGHW) reactor was eventually selected. This was chosen for technical reasons as the economic (and subsequent overseas construction costs) showed no major advantages held by any of the other short listed systems.

The calculated cost of electricity delivered to the switchyard was 0.6 cents per kilowatt-hour. Highly competitive with bulk coal fired power costs at the time.

Despite the AAEC attaining world leadership in uranium enrichment by centrifuge technology, the Government took AAEC out of the uranium exploration and mining business in 1976 and abolished the Commission in 1987. Apparently because of political ideology, ignorance and xenophobia, although there must be a question that many senior Australian politicians had become fearful of international criticism of nuclear proliferation and wished Australia to be seen as detached from that scene.

The pseudo replacement, ANSTO, runs the replacement OPAL reactor. This 20 MW open pool type Argentine-designed reactor went on line in early 2007 but was closed for ten months in July 2007. Its core of about 20% enriched U 235, as plates with aluminium, sent from the makers had to be replaced with a new core from France when it was found to be failing. Full details are on Wikipedia, should one wish to know.

In the Forward to Alder's book Sir John Proud included the following: "When their Australian research demonstrated the capacity to successfully and efficiently enrich uranium – using our own design of centrifuges – Australia had the world at its feet."

And we now have pseudo-experts deluding the public with the full backing of our media.

Just one example should suffice: a highly rated "Special Report on Nuclear Energy" pushed out by The Economist in 2012 (11). At the top of p15 one finds "No technology can solve the climate problem on its own." This relates to the quasi-religious type of "belief" that is spelled out in the following sentences re 'global warming' or 'climate change' – call it what you will. They should have omitted the last three words "on its own." This ignorance of science is exemplified on their p4 where TMI is attributed incorrectly as having been "caused by a faulty valve, which led to a small release of radioactivity and the temporary evacuation of the area;" As detailed in Appendix 4, The cause was disobedience of an NRC Regulation prohibiting, by law, the shutting down of a reactor's cooling system before closing the reaction. Also, as shown in Appendix 5 of this article, Chernobyl was not a case of "a chain reaction got out of control" (reference 11, p4). As shown in Appendix 5, it was sent out of control by an operator who should never have been free to conduct what he thought was an electrical experiment (on a nuclear reactor). Unwittingly, he drove the reactor out of control by trying to achieve a balanced reduced power output without first shutting down the reactor and starting again. And, using emotive words out of place, The Economist wrote (ref, 11) that "a reactor blew up," implying, falsely, to intelligent laymen that it was a nuclear explosion that destroyed the reactor when it was not, as proven by the neighbouring reactor continuing to operate. That is highly irresponsible reporting leading to enhanced xenophobia. A few other examples, such as the comment on p9 that the three Fukushima buildings "blew up," without any hint that the reactor cores were monitored, showing that they remained at normal pressures while hydrogen explosions took the top structures off the buildings. Their ref 11 shows deep understanding of the political and economic scene. But not of the reactor physics.

In the leader to the main magazine, on its p 15, we find "…. One of the reactors at the Chernobyl plant in Ukraine ran out of control and exploded, killing the workers there at the time and some of those sent in to clean up.." and "The harm done by radiation remains unknown to this day;" This is highly irresponsible fear-mongering – (see Appendix 5 above.)

What a pity that the fear factor and technical ignorance were allowed to downgrade an otherwise good attempt to educate the public.

As far back as 2008 Professor Pamela Sykes, the Chief Medical Scientist at Adelaide's Flinders University, was quoted as reporting that "small amounts of extra radiation could kick the body into protection mode" and went on to state "[w]e are constantly bathed in radiation from our environment, causing a cycle of DNA damage and repair every day." and "[t]here is radiation in the rocks, the air, the soil, coming from outer space. We've evolved on a planet with radiation." She also reported that scientists had monitored some people from areas near Chernobyl that had only twice the radiation it had before, but after 20 years there had been no evidence of genetic defects in children. (The Advertiser, April 28, p 11).

She knew what she was talking about.

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