Brief to the Nuclear Waste Management Organization III (NWMO)
Reprocessing and Transmutation

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Acknowledgement and preface

Thanks to Donna Pawlowski for providing a hard copy of David P. Jackson's NWMO background paper 6.4: Status of Nuclear Fuel Reprocessing, Partitioning and Transmutation. The question I raised at the hearing in North Bay, 27 March, was the energy cost of transmutation by accelerator methods, implying charged particle impact. I suggested at that time that a paper be commissioned by the NWMO on that subject, a proposal that will be modified in the present Brief.

The purpose of this Brief is twofold: to highlight the parts of David Jackson's paper that are particularly relevant to the NWMO's present mandate, and to point out the paper's few errors, misconceptions and mistakes, mostly minor, many of these being relegated to an annex. In addition the present Brief discusses the hidden, unjustified assumption within the nuclear establishment that, if plutonium is to be burned as a fuel in thermal nuclear reactors, then it must be in the form of plutonium oxide mixed with uranium oxide. This Brief points out that this practice minimizes the reduction of the plutonium inventory.

Contents

1. Central theses in Background Paper 6.4 relevant to the NWMO

Of the five paragraphs in Jackson's conclusions, pp.36-37, only the last two appear to be immediately relevant to the NWMO. In his fourth paragraph, he claims that transmutation "offers the potential for the ultimate mitigation of fuel waste, but only in the long term." I disagree that this could be accomplished within the terms set for the NWMO, namely that it could be done economically, and I doubt furthermore that it is practicable at all if by "ultimate mitigation" one means getting rid of essentially all the radioactive waste (see also section 3 of this Brief). Furthermore, his text suggests that present transmutation methods will only succeed for one of the several isotopes with which the NWMO must deal. I would suggest that NWMO simply set aside transmutation, except for the possibility of reprocessing, which would mean that the plutonium would be recycled through a reactor and partially disposed of at each recycling. Plutonium recycling, with the consequent transmutation of that element by fission, is the only transmutation reaction that the NWMO need consider. Despite the huge negative factors in reprocessing, cost and additional forms of low level waste to name only two, the fact that plutonium, the Earth's most objectionable element, could actually be reduced substantially in quantity by recycling, means that the NWMO cannot altogether ignore that route.

The fifth paragraph of the conclusions is germane to the NWMO's mandate. It raises the spectre of reprocessing as a means for reducing the volume of nuclear waste (discussed also on p.31 of the report). Thus reprocessing is put forward for two independent reasons. However, I would warn against even raising the spectre of reprocessing without first going into the whole question of low level radiation and its effects on health. This is a medical area on which the experts are not in agreement. I shall offer a fourth Brief to the NWMO on low level radiation and on the matter of protecting workers at nuclear plants, especially in relation to the storage of nuclear wastes and what that should imply in the short term. Burning reprocessed plutonium in reactors is further discussed in section 2 of this Brief.

Missing from the information given to the participants at North Bay (5 March and 27 March) was any detail of how the spent fuel bundles are put into their containers for dry, above-ground storage, and how those containers are then moved into the storage bunkers. These questions are relevant to the status quo of nuclear waste storage, not merely its future, because you (the NWMO staff) and I as a participant in the deliberations need to know how much additional dose a worker receives as a result of participating in those activities. It is most important to have the facts, not a statement from Ontario Power Generation (or the Quebec and New Brunswick organizations) that "the dose received was in all cases below the maximum occupational limit." That isn't good enough information. The information needed is the actual additional dosages to which workers are subjected when carrying out duties connected with spent fuel (in this case, putting it into dry storage). If the NWMO cannot obtain that additional information, it cannot adequately do its work. You will recollect that Shirley Farlinger, who was present at the North Bay 27 March discussions, was representing the International Institute of Concern for Public Health (IICPH). The danger associated with low-level radiation has been a major focus with IICPH since the Institute was founded. The additional information we are asking for is most important.

Next I turn to page 16 of David Jackson's report where the paragraph beginning "The volatile gases . . ." reveals two astonishing statements, one about how reprocessing organizations have routinely vented krypton-85 into the air, and the other about the routine release of iodine-129 into the sea. Evidently Canada condones these practices, as we have never heard of diplomatic protests against this systematic pollution of the global commons. It would furthermore be incongruous if Canada continued to condone the release of these radioactivities while denying itself the right to consider waste fuel placement in the mud of the deep Atlantic, where it would not be "on the sea bed" but rather below it, and where the radioactivity would not be detectable on the sea bed. It is doubtful whether such nuclear waste burial would in fact violate the anti-dumping conventions, whereas the release of iodine-129 into the sea must surely be a violation. Are we to live in a regime where nuclear bomb builders may defy international conventions, and the rest may not do so?

Returning to the matter of reprocessing, there is a remark on page 16 of Jackson's paper on the necessity for tight physical security at a nuclear reprocessing plant, in order to make possible strict accountability for the dangerous fissile materials — plutonium. Not discussed, however, is the fact that perfect accountability has never been achieved in reprocessing plants, so difficult is the question of knowing how much plutonium there really was in any given fuel segment and being sure where it all went in the reprocessing. This factor will also be important if the NWMO decides to explore the ramifications of reprocessing.

2. Errors and misconceptions in Background Paper 6.4

On page 8, the fact that the removal of zirconium-92 from natural zirconium would avoid the formation of radioactive zirconium-93 is correct, but isotopic separations are extremely expensive. The introduction of this idea for bulk amounts of zirconium metal is surely impractical.

On page 11, under table 5, Jackson states that there is "more of everything present in the LWR spent fuel compared to the CANDU fuel." This is correct in the limited context that he chose. Looked at in another way, the CANDU spent fuel contains 0.23 percent of uranium-235, having started with 0.72 percent. Thus it burned 49/72 or 68 percent of what was available in the natural uranium. In the LWR case, the usage of the uranium 235 depends on how much was left in the depleted uranium. Assuming the uranium enrichment process leaves us with depleted uranium having 0.2 percent of uranium-235, some simple arithmetic then shows that 1 part of uranium-235 goes into depleted uranium for every 3.3 parts put into the reactor. To estimate how much uranium-235 overall is used by LWR means adding 1 percent to the 0.81 percent shown in table 5 as well as adding 1 percent to the 3.3 percent for calculating the effective burn-up. The result is that the enrichment + LWR burning uses 2.49/4.3, or 58 percent of all the original uranium-235 prior to the separation process, less by 10 percent than in the CANDU case. Note also, that much more plutonium is produced by the CANDU per uranium atom at the start. This shows the much greater fuel efficiency of CANDU reactors, which was of course a reason for developing this style of reactor. Jackson is right about the lower concentration of fission fragments in CANDU spent fuel, at about a quarter of the concentrations in the LWR spent fuel. There are, however, metallurgical problems with fuel bundles left too long in a reactor, which are thus more likely to afflict the LWR than CANDU. The cladding encasing the fuel pellets tends to get brittle and to give rise to cracks through which radioactive materials can be leached by the cooling water. It does not follow, therefore that it is always wise to exploit the fuel bundles to their maximum capabilities for producing energy. The argument at the end of the same paragraph below table 5, namely, that the incentive to reprocess is greater for LWR than for CANDU fuel is correct especially as some uranium-235 is thrown away in the depleted uranium. To sum up, for long-term fuel conservation, CANDU is much better than LWR, though LWR owners can compensate by reprocessing.

The combination of fuel enrichment for light-water reactors has led indirectly to a great surplus of depleted uranim, with a sad consequence of misuse of that material for munitions by the US military; other countries have also used uranium munitions in wars. Much of the military use of depleted uranium is for armour-piercing projectiles, which have been responsible for contaminating parts of several countries with unwanted radioactivities. While this may not appear relevant to this Brief, it must be mentioned that depleted uranium is the world's best shielding material against nuclear X-rays and gamma rays. Depleted uranium shielding could be relevant to long-term storage above ground of nuclear high-level waste. The uranium would, in such cases, be in metallic form, but plated so as to prevent oxidation. [Uranium is pyrophoric and oxidises very rapidly in air.]

On page 30, the last sentence reads, "According to their various advocates, renewable energy or fusion power may come on stream before all the uranium is exhausted." In this paragraph only, the author reveals his hitherto hidden preference for nuclear power, his ignorance of renewable energy and its current and growing usage, and of its immense potential for near-term adoption. The coupling of renewable energy in the same phrase with the possibilities of fusion reactions is incongruous — a technology totally unproven linked to various proven and generally benign developments. Use of wind and solar power are growing exponentially, which nothing else in electrical power generation is doing. Even the expensive solar electricity option may require rather little to make it fully practical in northern climes (see, for example, John Bacher, "Petrotyranny" and the concept of a price-busting plant to produce solar film. Price busting means production on a large enough scale to make the film cheap, which is thought by several experts to be possible already). By contrast, nuclear fusion, if it can ever be made to work economically, will depend on the supply of tritium for the first many years, and this will require nuclear reactors, preferably of the CANDU type, unless a self-sustaining tritium source can be achieved at the fusion reactor site. No such device has been tested. Therefore the statement that "fusion power may come on stream before all the uranium is exhausted" seems strange, as the fusion appears as of now to require CANDUs to feed it fuel, possibly five CANDU reactors for every fusion reactor of similar power!

Page 31 third line from bottom: "Transmutation does offer the prospect of truly disposing of radioactive isotopes." The text, however, indicates that the transmutation method available today is likely only to work for the zirconium-93 isotope. Readers unfamiliar with transmutation should be aware that all nuclear reactions are random events, subject to overall probabilities that can be determined. To take the case of converting zirconium-93 to radioactive zirconium-94, which will then decay radioactively to something stable, it is important to recognise that the new, stable isotope will also capture neutrons to become yet another isotope. If that one is also stable, then we are part way out of the worst trouble, but we have also ignored the fact that the isotope zirconium-94 can also absorb a neutron to become zirconium-95. This illustrates a general feature of transmutation, that unwanted isotopes can be and are produced along with the elimination of the selected, undesired isotope. The desired transmutation can be made cleaner by repeated chemical removal of elements produced in the target, so that the irradiated sample is always chemically what you want it to be. However, as the transmutation proceeds, the isotope you want to eliminate becomes more and more dilute in your sample, and it cannot therefore be totally eliminated, but merely reduced to a lower concentration. This characteristic of transmutation is fundamental to all methods. It applies equally to eliminating plutonium by burning it in reactors. There will always be some of it left when the last reactor closes down. Therefore Jackson's statement should read that transmutation offers the prospect of reducing the quantity of any given isotope, rather than of disposing of it.

3. A widespread hidden assumption

Page 7, third bullet of Jackson's Paper contains a statement beginning "Based on the variety of actinides present . . ." This ambiguous statement contains one of two hidden assumptions, either that the actinides to be irradiated all have atomic numbers between 89 and 91, or that the neutron irradiation will take place in the presence of a large amount of uranium 238. The implied presence of uranium brings to mind a hidden assumption that has unaccountably been very widespread.

In all considerations of using reprocessed fuels in thermal reactors it has generally been assumed that the reprocessed plutonium (oxide) would be mixed with uranium oxide. Any such mixture is known as MOX. As with so many hidden assumptions, nobody appears ever to need to explain it. But the question remains, why MOX? One presumption would be that, by having the reprocessed fuel bundle very similar to the new fuel bundles, direct substitution of one for the other is practical, and this minimises the research needed to achieve a usable reprocessed fuel. However, all such burning of reprocessed fuel does little to decrease the world's huge separated plutonium inventory, since the presence of large amounts of uranium-238 guarantees the production of new plutonium, on a scale similar to that of the once-through nuclear cycle (tables 1 and 5 in Jackson's report). Thus MOX burning minimises the rate of disposing of plutonium, the world's most objectionable element.

The possibility of reducing the plutonium inventory much more rapidly, by burning the plutonium in new types of fuel rod not containing any uranium 238, seems to have received little attention. The suggestion here is that, should NWMO favour fuel reprocessing as a means of reduction of waste volume, then it would be logical to suggest developing plutonium fuel rods that do not contain any uranium-238, so as to forestall the further production of new plutonium. The design of such fuel rods would turn out to be an attractive problem-solving exercise, or series of such exercises.

Conclusion

The only practicable transmutation of dangerous radioactive elements in spent fuel is the burning of plutonium in reactors. This requires reprocessing. If the purpose of reprocessing is to reduce the plutonium inventory, then the plutonium should not be mixed with uranium as it is in MOX. This author neither favours nor precludes fuel reprocessing. Of the known methods of waste fuel management, none is fully satisfactory. The best of the practicable methods (in the absence of recycling plutonium) would be injection into the mud of the deep ocean bed, somewhat east or west of the mid-Atlantic ridge. However, even this method would not be practicable in wartime, because the seas would not be safe for nuclear waste transport. By the same token, the whole nuclear industry would pose an impossibly dangerous set of targets in war, so that a nuclear phase-out is desirable, particularly in the present increasingly militarised and war-bent world.

Annex

Slips, and not-so-minor errors in Background Paper 6.4 that are easily fixed

Page 3 fourth paragraph under the heading "Reprocessing", line 9: here and in one or two places further on in this document, "uranium-235" and "plutonium-239" should be replaced by "uranium" and "plutonium" since the chemical separation the author is discussing does not single out particular isotopes. The repeated occurrences would thus mislead novices in this field.

Page 5 The reaction at the bottom of the page stating that uranium-238 plus a neutron leads to plutonium-239 is a telescoping of a three-stage process, and this condensation is justified here. However, the description could better have been written so as to indicate that the intermediate stages were being omitted.

Page 7 below table 3: the presence of the fissile fuels uranium-235 and plutonium-239 in spent fuel provides an impetus for reprocessing in certain jurisdictions, not in North America at the present time. This becomes clear as the paper proceeds, but a minor change could make it clear right away that the point of view expressed here is not currently shared in North America.

Page 11 the sentence immediately preceding the section 2.4 heading is unclear; I have read it many times and do not know at all what it means.

Page 13 sentence "This make-up fuel could be produced by other means such as an accelerator." Making bulk fuel by means of an accelerator would be heinously expensive, even if the fuel were only a small percentage of the thorium content. The points in this section are only important for nuclear conservationists who want to see nuclear fuel conserved for the longest possible nuclear future. [WB Lewis, the founder of nuclear energy in Canada, was such a conservationist.] There are, however, problems with thorium-based nuclear reactors that are not discussed in Paper 6.4 and indeed do not require discussion there. They are, however, relevant to the extended nuclear future the nuclear conservationists have envisioned.

Page 30 section 6.1 third paragraph, sentence beginning, "Some reprocessed plutonium-239 is now consumed as MOX fuel . ." The author means, "In some other countries plutonium-239 is included in mixed oxide fuel (MOX) for reactors. In Canada no MOX has been used except for tests.

In the same paragraph the worst "boner" in this paper occurs. We find, "In addition, the current trend to nuclear disarmament is freeing up for civilian use significant quantities of plutonium . . ."

The freeing up is correct, but the world has never been further from a trend to nuclear disarmament since the 1960s. The nuclear bomb materials that have given rise to this available plutonium were the result of START Treaties that in effect dismantle obsolete missiles for which Russia and the United States had no more use anyway. Regarding real disarmament efforts toward a nuclear bomb-free world, all negotiations have been stalled for many years, and the Committee on Disarmament in Geneva is furthermore stalled on all fronts. It is important to realise that both Russian and American nuclear missiles are maintained on high alert, so that we all could be destroyed in 45 minutes, just as could have happened in the Cold War. At any time of day and night therefore, the NWMO can only count on its premises and staff not being destroyed by nuclear war for the ensuing 45 minutes. This surely requires a one-line correction in Dr Jackson's paper.

Page 31 section 6.2 line 3. The cladding is around the spent fuel, not just the uranium-238 and plutonium 239.

Page 35 section 6.8 third paragraph: "There is another type of accident unique to nuclear facilities, known as a criticality accident." Correct, but it leads the reader to think that the Chernobyl accident may not have been due to criticality. In fact there are two types of criticality, the normal type occurring in nuclear reactors, which depends on the phenomenon of delayed neutrons, and "prompt criticality" that does not. The Chernobyl accident was due to a part of the reactor going prompt critical, which caused the explosion that was so devastating. Another minor slip occurs here, namely, that the Tokai accident was in fact not "easily avoided" (see last line of the paragraph), but rather, prior to the accident it could easily have been avoided.