

DISPOSITION OF WEAPONS-GRADE PLUTONIUM WITH GEM*STAR

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Abstract

An accelerator system like the SNS at ORNL can generate spallation neutrons to convert fertile elements like U238 in spent nuclear fuel (SNF) or Th232 into fissile isotopes to provide high temperature heat using technology developed at the ORNL Molten Salt Reactor Experiment. In the Green Energy Multiplier * Subcritical Technology Alternative Reactor (GEM*STAR) [1], the accelerator allows subcritical operation (no Chernobyls), the molten salt fuel allows volatiles to be continuously removed (no Fukushimas), and the SNF does not need to be enriched or reprocessed (to minimize weapons proliferation concerns). The molten salt fuel and the relaxed availability requirements of process heat applications imply that the required accelerator technology is available now. The accelerator can also be used to control the burning of fissile isotopes developed for weapons. A new opportunity is being considered by Russian and American scientists to use GEM*STAR to reduce the world inventory of weapons-grade plutonium leaving only remnants that are permanently unusable for nuclear weapons. This application could expedite the exploitation of this new accelerator-driven technology.

(gray) and 7% molten salt made up of an appropriate eutectic mixture of lithium, uranium, plutonium, and/or thorium fluorides with a melting point above 500 C. Safety features of the design include the 500 MWt power output design limit, corresponding to not needing 1) a critical mass of fissile material for operation or 2) “defense in depth” measures for loss-of-coolant accidents since the heat generated by decays of fission products after the accelerator is turned off can be dissipated by passive external air cooling.

A helium flow over the hot core removes volatile radioactive isotopes and carries them to a relatively small underground tank where they are separated out cryogenically or with a centrifuge and then safely stored while they decay. This reduces the inventory of volatile isotopes in the reactor by a factor of a million compared to reactors used at Fukushima.

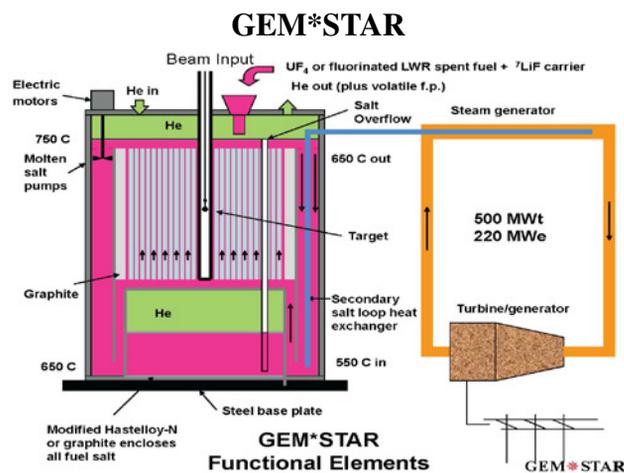


Figure 1: Conceptual arrangement of a GEM*STAR reactor unit configured to produce electricity. To produce diesel fuel, the secondary salt loop heats CH2 and H2O to produce CO and H2 for the Fischer-Tropsch process.

GEM*STAR is a graphite-moderated, thermal-spectrum, molten salt fueled reactor that is operated using an external accelerator to direct protons onto an internal spallation target. GEM*STAR can be operated with many fuels, without redesign, for process heat and/or for electricity generation. Figure 1 shows its basic components, where the active volume is 93% graphite

consider a clear liquid which releases heat when exposed to light, eventually turning a dark purple

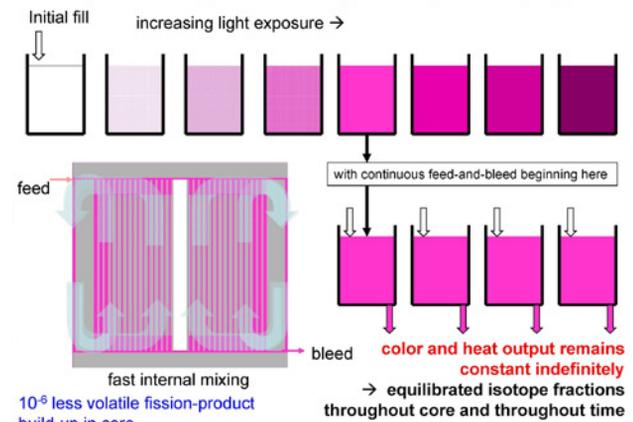


Figure 2: Concept of operating with equal fill and removal rates to maintain a constant reactor performance.

An essential feature of the design is the concept of feeding the reactor with a steady flow of fuel such that the concentration of fission products within the reactor stays constant for most of the 40-year reactor lifetime. As the fuel is fed into the reactor at a rate that maintains the 500 MWt output, an equal amount leaves the core through the salt overflow shown in figure 1 into a storage area under the core. Figure 2 shows an equivalent diagram of how the concentration of fission products reaches an equilibrium that can be maintained by this concept of adding molten salt fuel and removing it at the same rate.

Although the first approach to equilibrium takes some time (~5 years), a subsequent reactor can use the molten salt accumulated under the first reactor to start in an equilibrated state. Note that the heat from decaying reaction products will keep the overflow liquid from

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solidifying and that the radioactive fuel under the core can be moved to the next reactor using helium gas pressure.

We take the 1 MWb performance of the SNS SRF Linac at less than 10% duty factor as an existence proof that a CW Linac could make at least 10 MWb. Further, molten salt fuel for off-line process heat is an “end-run” around the reliability questions that have usually been raised regarding accelerator-driven reactors. The most stringent requirement has been the need to avoid accelerator trips of even a few seconds because of thermal stresses and consequent fatigue of solid pellets in fuel pins. This objection is not applicable to molten salt fuels. Longer-term interruptions that may affect electricity production are also not very important for off-line production of diesel fuel, which is our first objective.

One of the required safety aspects of GEM*STAR is the use of a proton accelerator to allow subcritical operation. Without a critical mass in the core, fission stops when the accelerator is turned off. In addition, GEM*STAR with accelerator, molten salt fuel, and graphite moderator allows the reactor itself to be simpler, less expensive, and intrinsically safe. Namely, GEM*STAR does not need mechanical control rods, a containment vessel to protect against escaping volatile radioactive elements, or a pressure vessel. Expensive chemical reprocessing is not needed for several fuel cycles such that it can be put off for 200 years.

In short, the complexity of modern nuclear reactors that many people are concerned by is shifted in GEM*STAR such that the complexity is in the accelerator, not the reactor or the fuel.

People sometimes cite problems with graphite reactors due to the Wigner Effect, wherein accumulated neutron-induced atomic displacements suddenly realign and cause an energy spike. In early days of graphite reactors, the temperature had to be periodically raised above 250 C to anneal the graphite to prevent this (see the Wikipedia articles on Wigner Effect and Windscale Fire). Annealing is not necessary in the GEM*STAR design, which operates above the annealing temperature.

Fast spectrum reactors or breeder reactors are often cited as a method to do what we want to do with GEM*STAR. The usual question is “why use an accelerator to do what can be done with a control rod?”

Here are some reasons. Compared to a thermal spectrum made possible by graphite moderator, the fission cross-sections for a fast reactor are many times smaller and the relative sensitivity to fission products is greater. This means you need many more neutrons (requiring more than 100 critical masses in the reactor), more responsive control rod feedback (the fraction of delayed neutrons is less than in a normal reactor), and the fuel has to be reprocessed to remove the fission products (chemically separated, which is a weapons proliferation concern, and an added expense).

WEAPONS GRADE PLUTONIUM (W-Pu)

The GEM*STAR design is appropriate for many fuels, especially to convert fertile material to fissile ones (U238

to Pu239 and Th232 to U233). Where the need is greatest depends on the country and situation. In the US, SNF is a growing issue that could be addressed with GEM*STAR, while in India, thorium is abundant and power needs are great.

However, with no change in design, GEM*STAR can provide neutrons to control reaction rates for fissile materials that were produced for weapons. As we will show, it destroys W-Pu so well that it is the most compelling first application. That it can turn a \$50B expense into a profit for the US also adds to its attraction.

A plutonium bomb uses high explosives to compress Pu239 to form a critical mass. At just the right time in the compression, neutrons are injected into the mass to initiate the explosion. If enough Pu240, a neutron emitter, is in the mass, it can cause the explosion to start prematurely and reduce the effectiveness of the explosion. Weapons-grade plutonium, then, requires less than 7% Pu240. The US and Russia made many tonnes of W-Pu. According to the year 2000 U.S.-Russian Plutonium Management and Disposition Agreement [2], each country should each destroy at least 34 tonnes of it. The agreement specifies that each country must agree to how the other achieves this goal and that the two countries should destroy the W-Pu in lock step.

The present situation is that the US has decided to mix the W-Pu with uranium as oxides (MOX) to be placed in fuel rods to be burned in conventional light water reactors. Russia’s plan is to use a fast breeder reactor.

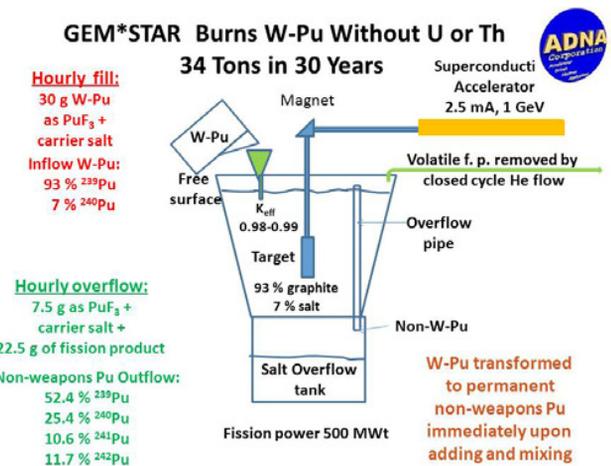


Figure 3: A GEM*STAR unit to generate heat by burning W-Pu while making remnants unusable for nuclear weapons. Four GEM*STAR units will treat 34 tonnes of W-Pu to provide 80 billion gallons of diesel fuel, which is about what the DOD needs for the next 30 years.

Figure 3 shows a conceptual picture of W-Pu utilization in GEM*STAR. A 2.5 MWb accelerator generates 500 MWt, reducing 30 g of W-Pu to 7.5 g per hour and adding the neutron generating isotopes Pu240 and Pu242. Figures 4 and 5 show the qualities of the W-Pu (back row-red) compared to the outputs of GEM*STAR (green), the

Russian BN800 Fast Breeder (dark red), and the US MOX plan using Light Water Reactors (yellow). By passing the fuel through the reactor a second time, additional benefits can be seen. However, in the case of MOX, the fuel has to be reprocessed to remove fission products. GEM*STAR does not require reprocessing for a second pass.

Figure 4 is a comparison of the isotopes produced by the present plans of Russia and the US and by GEM*STAR. GEM*STAR does better because of the effectiveness of the thermal neutron spectrum both to produce Pu240 and Pu242, and to be less sensitive to fission products than MOX-LWR. Pu242 is even more effective than Pu240 to cause premature explosions in that it is a neutron emitter with a lifetime longer than Pu239.

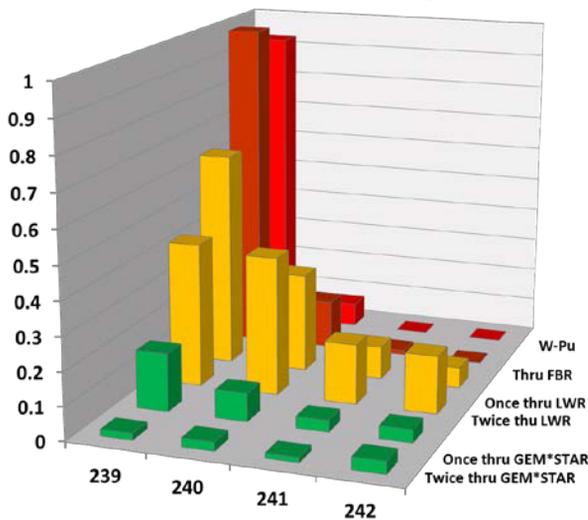


Figure 4: Isotopes remaining from the original W-Pu (red, 0.93 Pu239, 0.07 Pu240) after burning in the Russian FBR (dark red), once and twice in MOX-LWR (yellow), and once and twice in GEM*STAR (green).

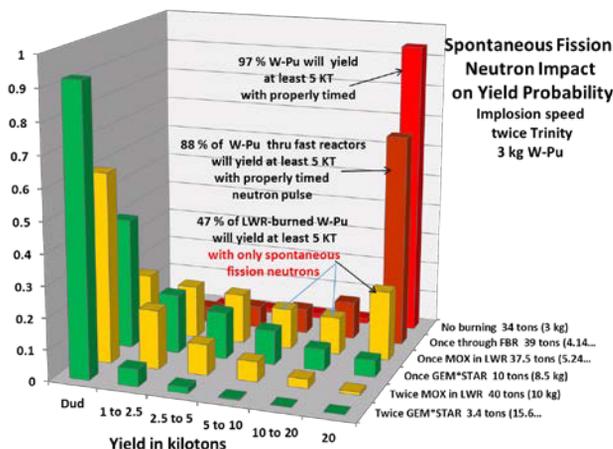


Figure 5: Yield probability of a nuclear weapon made from the output of the three reactors shown in Figure 4.

Figure 5 compares the yield probability for nuclear weapons material made from the output of the three reactors described in figure 4. The numbers have been scaled from calculations by J. Carson Mark [3]. Twice

through GEM*STAR is clearly the best in that the amount of Pu239 is greatly reduced as is its utility for a weapon.

SUMMARY

The benefits of GEM*STAR for disposing of W-Pu can be summarized as follows:

- Burned W-Pu never useful for weapons
- Burned W-Pu never decays back to weapons useful material
- Conversion to non-W-Pu in minutes
- Pu isotopic mixture can be reduced from 34 tons to 0.2 tons if desired
- Also converts Commercial Pu (C-Pu) to-non-weapons-useful material
- Never requires a critical mass - no control rods
- No reprocessing or enrichment required
- No conversion to MOX; simple conversion of Pu metal and PuO₂ to PuF₃
- Fission energy converted to diesel and sold as green fuel to DOD
- No stored large volatile fission product inventory as in LWRs (Fukushima)
- Liquid fuel moved by He pressure; no radiation exposure to humans
- Operates at atmospheric pressure - No pressure vessel
- Passive recovery from a loss of coolant accident (LOCA)

The 2000 U.S.-Russian Plutonium Management and Disposition Agreement may be stalled because MOX plant costs at Savannah River have overrun, LWR sites in the US have not agreed to use the MOX fuel, and because the Russian breeder reactor solution lacks funding. The GEM*STAR design has been made to address many safety questions and to solve several problems. As discussed above, GEM*STAR can reduce weapons stockpiles more effectively than MOX or FBR and make a substantial profit doing it. We believe that following this approach in carrying out the US-Russian Agreement will demonstrate the unique features of GEM*STAR that will then lead to other successes in reducing SNF stockpiles and giving a jump-start to a new nuclear technology.

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 [2] <http://www.state.gov/r/pa/prs/ps/2010/04/140097.htm>
 [3] Science & Global Security, 1993, Volume 4, pp.111-128. Copyright 1993 Gordon and Breach Science Publishers S.A.