GEM*STAR CONSORTIUM PROPOSAL TO BUILD A DEMONSTRATION ACCELERATOR DRIVEN SYSTEM

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Abstract

The GEM*STAR Consortium of four companies, two universities, and two US national laboratories has formed Mu*STAR, a new company, to fund and build a profitable pilot plant to demonstrate the advantages of subcritical molten-salt-fueled nuclear reactors driven by superconducting RF proton linacs. The GEM*STAR multipurpose reactor design features new accelerator power capabilities, an internal spallation neutron target, and high temperature molten salt fuel with continuous purging of volatile radioactive fission products such that the reactor contains less than a critical mass and almost a million times fewer volatile radioactive fission products than conventional reactors. GEM*STAR is a reactor that without redesign will burn spent nuclear fuel (SNF), natural uranium, thorium, or surplus weapons material. It will operate without the need for a critical core, fuel enrichment, or reprocessing, making it an excellent design overall, and a strong candidate for export. We describe the design and plans for funding a pilot plant that could profitably dispose of excess weapons-grade plutonium.

GEM*STAR

GEM*STAR [1] is a transformative and disruptive technology that has the potential to revitalize the nuclear power industry and lay the groundwork for a path to a viable future for many centuries. It is a commercial venture to combine proven technologies in order to provide a completely new approach to the safety of nuclear reactors, to the management of nuclear waste, and to the disposition of plutonium. The primary technologies involved, a molten-salt reactor and a high-power proton accelerator, are not new, and have already been proven: the former in the Molten Salt Reactor Experiment at ORNL, and the latter in operation at many accelerator facilities around the world including the SNS at ORNL.

The GEM*STAR functional elements are shown in Figure 1. The width of the reactor is 6 m and is designed to produce 500 MWt of thermal power, corresponding to 220 MWe of electrical power. The pilot plant application to burn weapons-grade plutonium (WGPu) requires a 1 GeV proton beam of 2.5 MWb; we believe the 34 tons of WGPu to be destroyed would provide process heat for the Fischer-Tropsch process to supply the DOD with 42 billion gallons of green diesel fuel.

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The advent of superconducting linacs has completely changed the cost, efficiency, and availability of high-power accelerators, and the issues that made accelerator-driven systems untenable in the past are readily avoidable today. The enormous cost estimates made in the 1990s for accelerator capital and operation are no longer relevant (e.g. the Accelerator Transmutation of Waste project at LANL [2]). Today, the superconducting RF accelerator for GEM*STAR will provide comparable power but cost more than an order of magnitude less and the wall plug to beam power efficiency can be higher than 50%. Accelerator trip rate concerns are addressed in two ways: by the use of molten-salt fuel, and by using the initial systems for process-heat generation, not driving the electrical grid with its associated high-availability requirements.

A molten-salt eutectic fuel is used, which avoids the beam-trip thermal-stress problems of solid fuel. The feed/bleed fuel flow and uniquely integrated core-target design reduce neutron losses sufficiently to make existing megawatt-power beams sufficient for commercial viability, with no need to wait for ten-plus MW beams deemed necessary by a recent DOE study [3]. GEM*STAR is designed to be commercially profitable and politically adoptable from its first pilot plant (it is not a 'conceptual testing facility' like MYRRHA [4]).

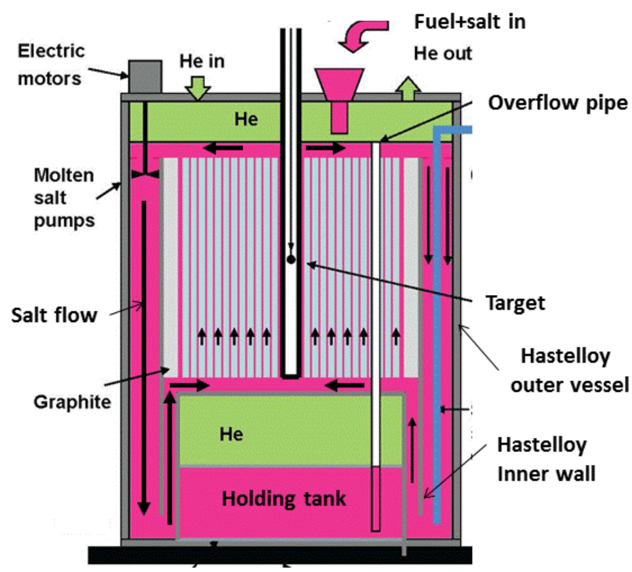

Figure 1: GEM*STAR functional elements, comprising a subcritical, accelerator-driven, thermal-spectrum, graphite moderated, molten-salt fueled reactor featuring continuous purging of volatile fission products.

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Assembling known technology for an *ab initio* optimized accelerator-driven system, where the accelerator is integral to the reactor design and not an 'add-on' feature, avoids misplaced concerns and opens a commercial path to energy production, with:

- Much better safety (sub-critical, low-pressure, continuous removal of volatile fission products, passive accident response)
- Less waste (deeper burn, continuous destruction of heavy actinides)
- Absence proliferation-prone technologies (no isotopic enrichment, no radio-chemical reprocessing)
- Cost competitive high-quality heat (higher temperature, efficient production of syn-gas for diesel fuel, better Carnot efficiency for turbines).

GEM*STAR is a reactor system that can profitably burn spent nuclear fuel, natural uranium, depleted uranium, or surplus weapons material, all essentially without redesign (only changing the molten-salt eutectic). Given the decision to put the MOX project for weapons plutonium disposition (at the Savannah River Site) on "cold-standby", the U.S. is looking for better disposition options. A potential first application of GEM*STAR is to burn 34 tons of excess weapons grade plutonium (WGPu) as an important step in nuclear disarmament under the 2000 Plutonium Management and Disposition Agreement [5]. Being a driven system, GEM*STAR burns WGPu more completely than other approaches, leaving remnants that are permanently useless for nuclear weapons.

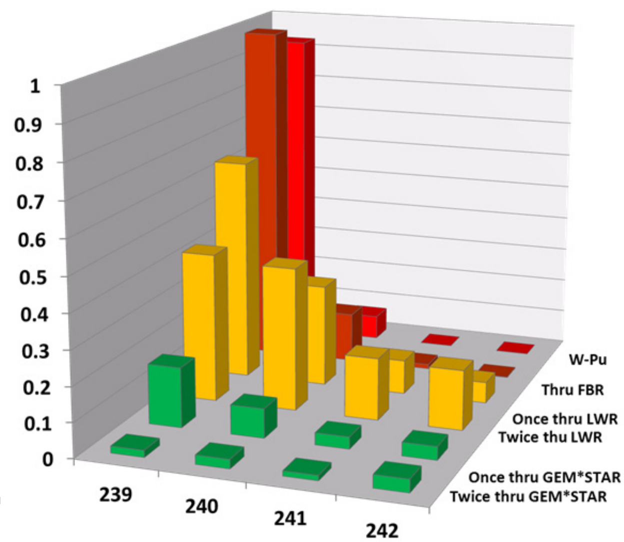

Figure 2: Comparison of plutonium disposition methods by isotopic quantity and distribution relative to the original WGPu (red: 0.93 ^{239}Pu, 0.07 ^{240}Pu) for the Russian Fast Breeder Reactor (FBR dark red), the US MOX-LWR (yellow), and GEM*STAR (green).

*GEM*STAR Advantage*

The advantages of using GEM*STAR technology are shown in Figure 2, which shows the added benefit of passing the fuel through the MOX-LWR and GEM*STAR reactors a second time. The Russian FBR plan produces more ^{239}Pu but enough ^{240}Pu that it is not technically weapons grade. The MOX-LWR plan recovers the 35% of the ^{239}Pu energy in one pass and a total of 57% if two passes are used. The GEM*STAR method recovers 87% of the ^{239}Pu in one pass and a total of 98% if two passes are used. The large fraction of ^{242}Pu in the remaining 2% precludes its use for nuclear weapons. In the case of MOX-LWR, a second pass involves reprocessing the fuel from the first pass and remaking solid fuel pins. The second pass for GEM*STAR directly uses the output molten-salt fuel from the first pass with higher beam power.

Figure 3 shows more details of the continuous feed and bleed scheme of GEM*STAR for WGPu disposition. The molten-salt fuel from the overflow tank can be moved for a second pass using helium pressure.

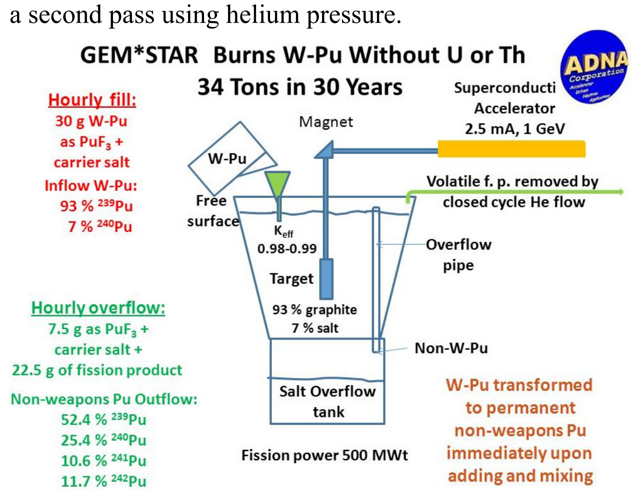

Figure 3: Details of WGPu disposal using GEM*STAR.

Anticipated impacts of the project include 1) providing less-costly future nuclear power that does not require fuel enrichment or reprocessing 2) safely reducing inventories of nuclear weapons material, 3) addressing the problem of disposition of spent fuel including long-lived actinides from conventional nuclear reactors, thereby extending their useful lifetime, 4) directly providing a source of renewable carbon-based liquid fuel for the DOD and other customers, and 5) shortening the time and expense of Nuclear Regulatory Commission (NRC) licensing by alleviating or eliminating many of the safety and operational concerns of conventional (critical) reactors.

The future of the nuclear power industry in the U.S. is not going to be process heat and plutonium disposal, this is just the first application we see that permits us to use existing technology in a pilot plant that will be profitable. At present, all high-power accelerators in the world are used for scientific research, and high availability was not as important in their design and operation as energy and intensity. The accelerator in GEM*STAR will be designed for high availability, and the experience we gain in building and operating the pilot plant will demonstrate the ability to build and operate systems with a reliability commensurate with feeding the electrical power grid.

One of the most interesting aspects of this proposed project is that with a fleet of accelerator-driven systems like GEM*STAR, there is enough uranium *out of the ground today* to supply the current U.S. electrical power usage for more than 1,000 years. This of course includes all of the high-level nuclear waste (spent nuclear fuel) generated by existing nuclear power plants. These systems can also burn the uranium and thorium still in the ground, without enrichment. The extraordinary safety features of GEM*STAR are described in Cummings et al. TUPOY043 at this IPAC16 conference.

PROJECT OBJECTIVES

The goal of this project is to strategically advance towards a full-functioning pilot plant (potentially at a DOE/NNSA site). The Consortium participants will use their expertise, numerical simulations, and experimental facilities to assess feasibility questions, solve technical issues, address licensing challenges, and complete the demonstration of the technical viability of the concept features. First year activities will include the completion of the Conceptual Design Report (CDR) and the analysis by our national lab partners of its veracity. Subsequent years will involve the completion of a Technical Design Report (TDR) for a complete plant to process WGPu or SNF and a Site-Specific TDR for a profitable pilot plant. Progress will enable us to attract private funding and/or enable guaranteed loans for the pilot plant construction.

Technology Readiness Levels

In Table 1 we apply the technology readiness levels described by the DOD [6] to the major components:

1. Basic principles observed and reported.
2. Technology concept application formulated.
3. Analytical and experimental critical function and/or characteristic proof of concept.
4. Component and/or breadboard validation in a laboratory environment.
5. Component and/or breadboard validation in a relevant environment.
6. System/subsystem model or prototype demonstration in a relevant environment.
7. System prototype demonstration in an operational environment.
8. Actual system completed and qualified through test and demonstration.
9. Actual system proven through mission operations.

Table 1: Component Technology Readiness

Component	Level	Comment / Example
Accelerator – 1 MW	9	SNS at ORNL
Accelerator – 10 MW	7	SNS is a "prototype": 1 MW with < 10% duty factor
Molten-Salt Reactor	6	Molten Salt Reactor Experiment at ORNL
Spallation Target	6	Other designs (in many places) are level 9
Fischer-Tropsch	9	Numerous operational plants e.g. SASOL in South Africa
MS Heat transfer to F-T	4	Prototype at BCLF Corp. (C. D. Bowman)

Detailed lists of year-by-year tasks and deliverables are available. The major objectives are to provide all the documentation needed to satisfy the DOE/NNSA Critical Decision criteria for CD-0 (Approve Mission Need), CD-1 (Approve Alternate Selection and Cost Range), CD-2 (Approve Performance Baseline), and CD-3 (Approve Start of Construction). We will also start civilian licensing discussions with the NRC.

MU*STAR, INC.

Mu*STAR Inc. is a new company to promote high-power superconducting accelerators driving subcritical GEM*STAR small modular systems. It has been created to support a consortium of private companies, universities, and national laboratories to design, build, and exploit this new approach to nuclear energy.

Last year the GEM*STAR Consortium of

- ADNA Corp
- George Washington University
- Jefferson Lab
- Muons, Inc.
- Newport News Shipbuilding
- Niowave, Inc.
- Oak Ridge National Lab
- Virginia Tech

proposed to the US DOE to design and build a pilot plant to dispose of 34 tons of WGPu. The pilot plant will burn SNF, Pu and U weapons materials, natural U or natural Th, without redesign. The pilot plant can be augmented with more RF power and 3 additional GEM*STAR units to burn the 34 T in 30 years, providing 42 B gallons of green diesel fuel for the DOD by converting natural gas and renewable carbon using the Fischer-Tropsch process. This team is uniquely ready to carry out these tasks by virtue of their complementary skills, experience, assets, and leadership.

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[4] http://myrrha.sckcen.be/

[5] http://www.state.gov/r/pa/prs/ps/2010/04/140097.htm

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