Program for Disposition of Weapons Grade Plutonium in a Plutonium-Thorium Cycle

An Assessment of the Program

April 2005

Westinghouse Electric Company LLC, a BNFL Group company

Program for Disposition of Weapons Grade Plutonium (WGP) in a Plutonium-Thorium Fuel Cycle

An Assessment of the Program by Westinghouse

The Oak Ridge National Laboratory monitors a program managed and performed by the Kurchatov Institute (KI) and sub-contractors in Russia to design a Plutonium-Thorium fuel cycle for the disposition of 34 M-T weapons grade plutonium and 5 M-T of commercial plutonium in VVER-1000 reactors. The US government provides funding for this program, under the terms of PuMDA, for the development, evaluation and testing of a unique plutonium-thorium seed and blanket fuel cycle, also known as the Radkowski Thorium Plutonium Incinerator (RTPI). Westinghouse is assisting the Oak Ridge National Laboratory (ORNL) to review the technical and economical merits of this program.

Ultimately, the success of implementing the RTPI fuel cycle will depend on the depth of the engineering effort, the thoroughness of testing and adequate funding. The risks appear to be manageable for implementing RTPI, but not as well understood as the risks of implementing a MOX fuel cycle, which has already been demonstrated. However, the projected cost for MOX, according to KI, would be substantially higher and would extend the WGP disposition over a much longer time. The basis for the Westinghouse appraisal is that the Th/U oxide fuel technology has already been proven in the 1960's when several fuel loads were implemented in US commercial reactors (e.g., Indian Point) and at Shippingport. In addition, the Russian experience with metal fuels, though of a smaller length and with U-Zr, does support a positive evaluation of the technical feasibility of their concept.

The documentation and information provided by KI, through ORNL, consisted of a large volume of documents (mostly in draft form and some in machine translation from Russian to English) which resulted in ambiguities in interpreting the documentation and made the review more time-consuming. A visit to KI and contact with KI personnel was helpful in providing an understanding of the technical concept and the KI and sub-contractors capabilities. It was obvious that KI focused on the fabrication aspects of the fuel for the proposed fuel cycle, the nuclear and thermo-hydraulic evaluation, and secondarily on some of the other commitments in their contract with ORNL. Since November 2004, additional documentation of the concept design details, which quantify merits of the concept, has been provided.

The essential features of the RTPI concept, based on the presented material, can be described as follows:

- The plutonium is burned in seed assemblies, adopted from proven naval reactor fuel assemblies, which were modified to increase the moderator to fuel volume ratio and the Pu burnup-rate. The seed assembly consists of

108 star-shaped (3-lobed), twisted rods per assembly with plutonium-zirconium metal (or Cermet) as driver fuel. The seed assembly is a self-contained structure, which is inserted into the center region of a blanket assembly.

- The blanket assembly has the outside configuration of a regular VVER-1000 fuel assembly. It surrounds the seed fuel with 228 blanket rods fueled with a mixture of ThO_2-UO_2. The uranium is 20% enriched in U235. The blanket region captures neutrons from the seed fuel and breeds and burns U233.
- New in this concept and requiring qualification are:
    - <u>In the seed</u>
        - Increase the length from the 1 m long co-extruded metallic naval fuel rods to about 3 m VVER fuel rods
        - Draw the fuel in a twisted star-shape with plutonium fuel (which has already been done for uranium fuel of shorter lengths)
        - Make an assessment how the Pu-Zr fuel performance differs from that of the U-Zr fuel of the naval reactors
        - Provide thermal-hydraulic test data to provide the necessary correlations for reactor safety and performance predictions
    - <u>Blanket</u>
        - Model the performance of the ThO_2-UO_2 fuel with data from on-going capsule (ampoule) tests in the IR-8 reactor
        - Perform an assessment whether the cladding on the relatively low power blanket rods can achieve a 100 MWd/kg-HM burnup in 9 years without exceeding corrosion allowances
        - Model the blanket fuel performance

<u>The status of the design can be described as follows:</u>

- The RPTI conceptual design nears completion
- The major design choices are firm, the documentation to initiate preliminary design, initially for three lead test assemblies (LTAs), appears to be in place
- Thermal hydraulic testing of assembly models is in progress
- The nuclear, thermal-hydraulic evaluation of the concept appears to be near completion
- The project apparently benefits from an earlier program, monitored by the Brookhaven National Lab., in which the seed fuel was U-Zr
- The LTA Irradiation in the Kalininskaya NPP, a near term objective of the program, has been planned and the cost estimated by KI to be $33 Million The total Irradiation time of the three LTAs is 9 years, and includes a detailed scheme of interim non-destructive and destructive post-irradiation examinations. The cost estimate for the LTAs goes into considerable detail.
- The estimated total cost of the disposition of 34 M-T of WGP in 3 Kalininskaya stations is $1.16 Billion (without taking credit for the

displaced uranium fuel). The duration of the Pu disposition in the RTPI cycle is 42 reactor years, or in 3 reactors ~14 years. Based on checking some costs, the estimate appears to be conservative, assuming that the required manufacturing facilities for the RTPI do not need to start from a green field state, but can utilize existing facilities with modifications.

- Not included in the estimates are the startup-times for design, analysis, and testing, licensing, fabrication until the LTAs can be inserted into the reactor and the time for the start-up of the disposition program. Planning of these phases of the project requires funding profiles, which are apparently not available.
- The overall cost of the program appears to be reasonable. The detailed planning of the funding for different activities to resolve design issues may be more than is needed in some areas, but may not be sufficient in other areas.
- Finally, KI is aware of and has identified design issues in the concept and has defined plans to resolve those issues.
- However, the reviewers still have many questions about some of the technical details. In many cases this is partly due to the draft form and machine translation of the supplied documentation.

<u>Westinghouse assessment of the program status is:</u>
The RTPI fuel cycle evaluated by KI burns the WGP faster and more completely than the MOX fuel cycle due to the inherent advantages of the RTPI concept, in 42 reactor years in RTPI versus 120 reactor years for 1/3 of the core with MOX fuel. The cost comparison presented by KI indicates a significant cost advantage of the RPTI fuel cycle over the MOX fuel cycle. Westinghouse has not been briefed on the approach selected by Russian organizations to dispose of WGP in a MOX fuel cycle. According to KI, big cost adders for the MOX option are the cost of a new MOX fuel manufacturing facility, a need to process much greater amount of material and reactor modifications required to add control-rod positions and a change of the reactor head and upper internals (in the case that more than 1/3 of core is MOX fuel). Even if the KI cost estimate for RTPI is low, because the project is less mature and costs traditionally rise as the design matures, there will likely remain significant cost advantages for the RTPI fuel cycle due to need for handling (e.g., manufacturing and irradiating) of less fuel.

The design margins in the RTPI concept are apparently larger than in a conventional VVER-1000 due to the low temperatures in the seed fuel and the low power in the blanket. Based on the evidence, without the possibility to dig into the details but with some spot-checks, we have no reason to question the presented results. The documentation recently supplied to Westinghouse indicates that the approaches in design and planning pursued by KI and subcontractors are not very different from US engineering practices.

Table 1. Technological extrapolations that are needed to implement RTPI

Existing		Extrapolation needed for RTPI
Hexagonal fuel assembly	VVER	Hexagonal fuel assembly with detachable central part (seed subassembly) after multiple irradiation
Non-cylindrical finned fuel shapes	Russian proprietary technology	Different, 3-lobed shape –fuel performance modeling required
1 m long extruded fuel		>3m long extruded fuel Larger press needed
U-Zr fuel in a boron-free environment		Pu-Zr fuel in a soluble boron environment
Oxide fuel, up to ~62 GWd/tU Licensed	LWR experience	Up to 100 GWd/tU (for Th)2-UO2 blanket)
Oxide fuel cladding corrosion resistance, up to ~5 years core residence time	LWR experience	Up to 9 years core residence time with E110 cladding in VVER water chemistry

The implementation of the RTPI concept appears to be feasible, and proven technology is applied in the seed and blanket where possible. Significant extrapolations beyond that proven technology have been identified which require engineering solutions (see Table 1). We do not see any technological show stoppers at this point. However, some of the goals, for example achieving the target blanket burnup, may not be achievable without a learning process. The documentation indicates significant effort, without giving all the details in:

- Nuclear evaluations
- Thermo-hydraulic design
- Safety evaluations
- Planning of the testing and data development
- Planning of a LTA irradiation and Pu disposition fuel cycle

Most of the costs for the engineering and data development effort appear to be in the cost estimate for the LTAs. The time frame for this effort, including licensing, has not been identified. The US nuclear community has not had a recent opportunity to implement a major program such as the RTPI, and therefore lacks current cost and schedule data, based on experience, for deploying a major new and innovative fuel design. In the commercial environment deployment of the LTAs would require approximately 5 years.

The costs presented by KI are apparently funding needs for the program to deploy the fuel. We have no ability to question these estimates without going into the details and fully understanding the Russian development and deployment structure and its associated costs. The costs presented are not the fuel cycle cost. Estimates of the commercial fuel cycle costs include the cost for the fissile material (not only the conversion cost presented by KI), cost of downtime required for refueling, waste disposition cost (some included by KI), and the revenue from producing power. The Pu disposition programs are unique, because the fissile Pu is free. Note also that a summary assumption in the KI cost estimate for RTPI appears to be that current manufacturing facilities will be used with only modifications as required.

In summary, based on the overall assessment of the risks and potential benefits of pursuing the RTPI concept, it is Westinghouse's opinion that proceeding to the LTA stage is prudent. From the review that we have performed to date, it appears that the technology is well founded and has a good prospect for success based on our previous US experience and Russian experience with metal fuels. The true economics of this plutonium disposition approach compared to the MOX approach are likely to be favorable if existing facilities can be used with only the modifications necessary to accomplish the fabrication of the plutonium-thorium seed and blanket fuel.