THORIUM FUEL CYCLES FOR LWRs:
FUEL DIVERSION ASSESSMENTS AND RECYCLE REQUIREMENTS*

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A number of fuel cycles have been proposed for evaluation in the nonproliferation alternative systems assessment program. Among these systems are light water reactors (LWR) operating on the thorium-uranium cycle or the plutonium-thorium cycle either inside or outside energy centers. These proposals support the President's nuclear power policy of accelerating research into alternative fuel cycles that do not permit direct access to materials usable for nuclear weapons but still retain the benefits of nuclear power.

Reprocessing and refabrication (often referred to as the "back cycle") constitute a portion of the overall fuel cycle and represent potential access points to fissionable materials, which, in many cases, may be in a rather attractive form for diversion. These operations for LWR thorium-uranium and plutonium-thorium fuels were analyzed to assess and rate the diversion or proliferation potential of each major operation. The study was performed at level 1 complexity* with regard to functional flow diagrams. Reprocessing and refabrication evaluations per se constitute insufficient data for rating the acceptability of an entire fuel cycle and must be considered along with reactor analysis, environmental data, resource utilization, and political factors.

Each back cycle operation has been evaluated according to needed development, material location, material description, convertibility and radiation hazard. Needed development relates to the state of the art of the operation and identifies the stage to which the development has progressed.

*Level 1 complexity identifies only major operations or systems in reprocessing and refabrication.
Material location and material description describe the form of the fissile material and the type of facility in which it would be found (e.g., nitrate solution in a hot cell or oxide pellets in a glove box).

Convertibility is the element of the evaluation that rates the usefulness of diverted material for the fabrication of a weapon. The grading is based on an arbitrary scale that considers the types of operations that would be required to upgrade the diverted material to weapon quality. Lastly, the danger to personnel in handling diverted fissile material from fission product or other radioactive species such as $^{232}$U is assessed. It is presupposed that fissile material is removed from its containment, and further operations with the material may be conducted without adequate radiation protection. Similarly, a radiation hazard assessment is applicable to rating the attractiveness of clandestine maneuvers for altering existing equipment in a process operation to produce unauthorized products.

Reprocessing operations for LWRs operating either on the thorium-uranium or plutonium-thorium cycle can be represented by one headend functional flow diagram and seven dissolution and separation functional flow diagrams. The Thorex process is utilized; however, the modified Thorex process is selected if plutonium is present. The various diagrams depict the process options: (1) complete partition of thorium-uranium-plutonium, (2) coprocessing to obtain all three of the elements in a single product stream or two of the nuclides coprocessed but partitioned from the third, and (3) plutonium stowaway with aqueous waste while thorium and uranium are recovered as partitioned or coprocessed species. Refabrication, on the other hand, requires only one functional flow diagram since the same operations pertain regardless of fuel composition.

The refabrication plant has more areas that are sensitive to diversion of fissile materials than the reprocessing plant because the purified materials are treated in refabrication. Additionally, the fissile material is frequently in a chemical form that is suitable for a weapon with little or no further treatment. Perhaps the operation most sensitive to diversion is scrap recovery that must handle assorted off-specification materials on a
demand basis without the benefit of rigidly controlled material flow. Excepting the product conversion step in reprocessing, the plant operations yield fissile products that require additional chemical treatment for upgrading to weapon material. However, in some cases, the upgrading can be done with unsophisticated engineering equipment. The rework and recycle operation appears to be a vulnerable area to diversion because controlled mass flows and inventory management are more difficult to maintain.

Thorium fuel cycles for LWRs are unique in that the bred fissile nuclide contains a built-in deterrent to proliferation because $^{232}\text{U}$ may be present in concentrations as high as several thousands parts per million. Energetic gamma emissions from nuclides in the decay chain make handling hazardous even at much lower concentrations and also make detection easier. Denatured uranium containing $^{233}\text{U}$ (<15% fissile) has the least attractive convertibility rating because gamma radiation from $^{232}\text{U}$ daughters makes increasing the fissile concentration more expensive and difficult. Irradiation of denatured $^{233}\text{U}$, however, results in the formation of plutonium which is a sensitive material for proliferation.

Streams of coprocessed materials in either reprocessing or refabrication are resistant to diversion because of the additional steps required to remove the fertile (thorium) component; however, the separations technology for uranium-thorium, plutonium-thorium, or plutonium-uranium is rather well known and does not require sophisticated equipment. A processing option may be chosen for denatured uranium-thorium fuels that rejects plutonium to the aqueous waste from which recovery is difficult without adequately shielded processing cells. However, relatively simple changes in the reprocessing flowsheet would allow the plutonium to be recovered without being rejected to waste.

Thorium-uranium fuel containing low concentrations of $^{232}\text{U}$ has been fabricated for use in reactors; however, this fuel is not typical of recycled thorium-uranium fuel. Remote operation and maintenance requirements for these initial fuels were considerably less stringent than the requirements for a fully developed thorium-uranium fuel cycle. Reference procedures need to be
perfected for remote operation. Fuel pellet sintering, fuel pin assembly and fuel element assembly for \((^{233}U,Th)O_2\) or \((^{233,235,238}U,Th)O_2\) need to be investigated in engineering studies performed under remote conditions. Equipment and remote techniques must be developed. Pellet preparation and sintering for \((Pu,Th)O_2\) should be investigated and perfected at laboratory and engineering stages. Additionally, scrap recovery procedures are needed for handling reject materials. A sol-gel, sphere-pac flowsheet may have advantages for remote fabrication; however, this flowsheet probably offers no significant improvement with respect to proliferation resistance.

The Thorex process is a developed operation for thorium-uranium fuels, and no major problems are anticipated in modifying the process for treating plutonium-uranium-thorium fuel. However, major improvements are required in the headend to dissolve Zircaloy-clad ThO\(_2\) fuel. Chop-leach procedures employed in the dissolution of uranium fuels might not be adaptable. The effect of fluoride ion on waste treatment and fixation has not been fully determined, and research will be required at laboratory and engineering levels. For those cycles that reject plutonium to waste, an approved waste form and storage procedure needs to be developed. Off-gas treatment for recycled thorium fuels requires an additional step in the customary off-gas processing train to trap radon \(^{220}\text{Rn}\). This treatment is also required for off-gases from storage facilities containing thorium solutions. Radon removal has not been demonstrated and needs development.

Reference