GT-MHR SPENT FUEL STORAGE DISPOSAL WITHOUT PROCESSING

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Abstract

Possibility of GT-MHR spent fuel storage during long time without additional processing is discussed in this paper.

Spent fuel elements discharged from this reactor type are ideal waste forms for permanent disposal in a geologic repository. The graphite fuel elements and the ceramic coatings on the fuel particles are as-manufactured engineered barriers that provide excellent near field containment of radionuclides and minimize reliance on the waste package and surrounding geologic media for long-term containment. Because of the high level of plutonium destruction and degradation achieved by GT-MHR, the isotopic composition of residual plutonium in spent fuel elements would not be practical for use in nuclear weapons and for energy production. Dilution of plutonium within the relatively large volume of GT-MHR fuel elements provides excellent resistance to diversion throughout the fuel cycle. This is accomplished without adversely impacting repository land requirements, since repository loading is determined by decay heat load and not by physical volume.

These conditions of safe fuel storage: criticality conditions, conditions of decay heat removing and radiation doses are discussed as well.

BACKGROUND

An important issue for any plutonium disposition strategy, as well as for any high radiotoxicity waste, is the suitability of the final waste form for permanent disposal. For assessing permanent disposal option, it is assumed that spent fuel will be placed in a deep stable geologic repository that is similar to Yucca Mountain in the USA, which is the candidate site for disposal of unreprocessed spent fuel from commercial light water reactors (LWRs). Disposal feasibility considerations may be categorized into:

- Proliferation risks and safeguards requirement;
- Radiological risks to the general public for very long time period following permanent closure of the repository;
- Suitability and licensability of the final waste form for permanent disposal;
- Cost for disposal, including waste package costs, tunneling cost, land-area requirements, and disposal operation.

Proliferation considerations can be categorized into short-term safeguard issues (e.g. diversion of material during temporary storage and transportation to a repository) and long-term issues (e.g. reclamation of material from a repository long after institutional controls and oversight have been abandoned). The high fuel burnup capability of the GT-MHR (approximately 65 % of the initial plutonium and ~ 90 % of the initial Pu-239) without requiring recycle is clearly more effective for destroying and degrading weapons grade

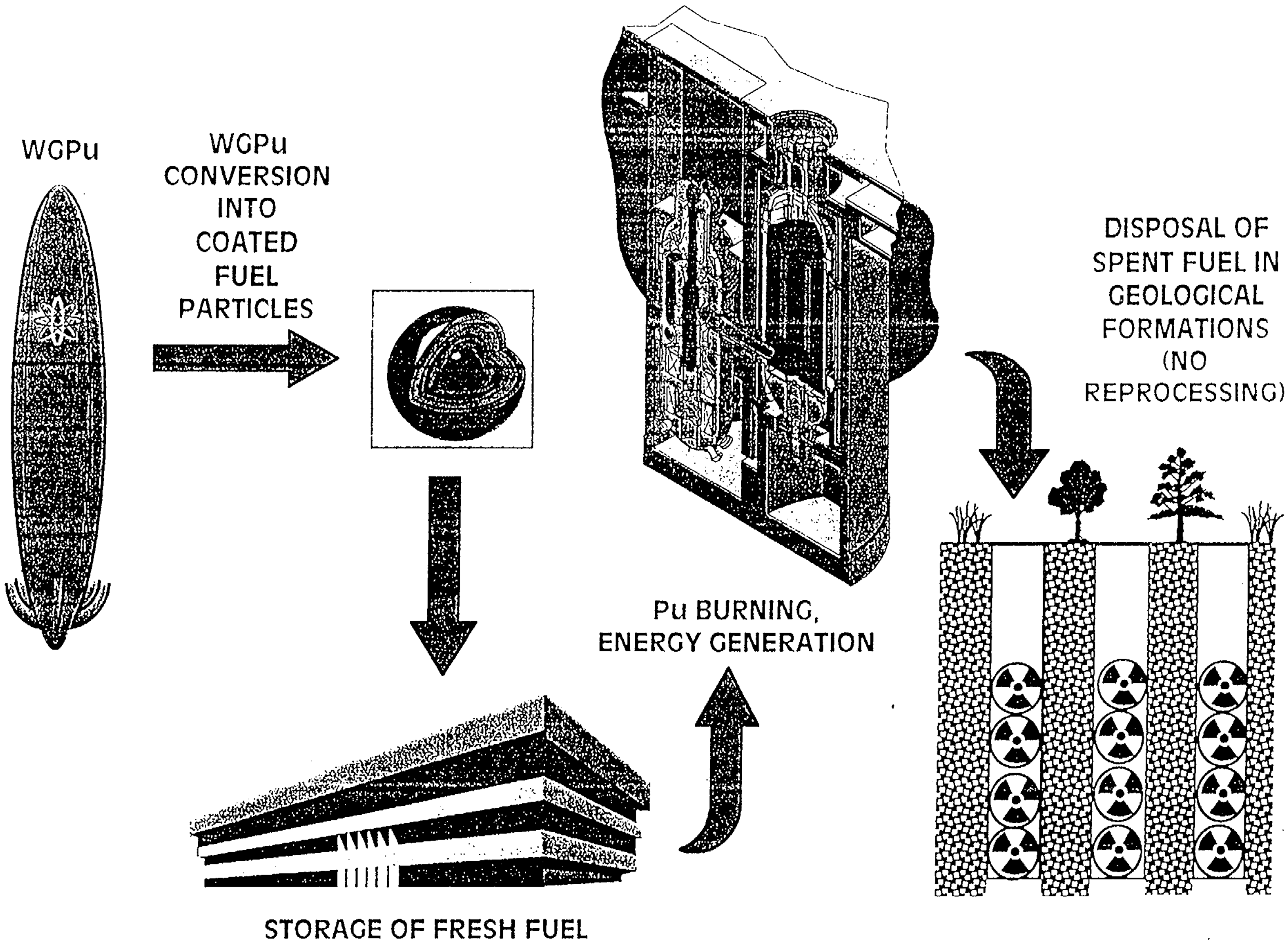

FIG. 1. Disposition of WGPu.

plutonium (WGPu) than direct vitrification, indefinite storage, or any other reactor-based strategy currently under consideration that incorporates an once-through cycle without reprocessing.

Whole - fuel elements disposal of GT-MHR spent fuel has been recommended as the preferred option because of advantages related to ease of implementation, proliferation risks, safeguards requirements, cost and schedule. This recommendation is corresponding with previous studies conducted by Oak Ridge National Laboratory [1] and in Germany [2] , which concluded that whole elements of HTGR spent fuel containing uranium and thorium coated fuel particles repository and should perform better than unreprocessed LWR spent fuel. Also, whole - elements disposal of spent GT-MHR fuel is directly analogous to options being developed for disposal of commercial LWR spent fuel in unprocessed, whole - assembly form.

Detailed evaluations of whole - elements were performed, including an assessment of the technical criteria for use of a multipurpose conister (MPC) as for LWR spent fuel storage to meet requirements for temporary dry on-site storage, transportation to the repository, and final disposal within the repository. It was concluded that spent fuel elements discharged from GT-MHR are ideal waste forms for permanent disposal in a geologic repository. The graphite fuel elements and the ceramic coatings on the fuel particles are as-manufactured engineered barriers that provide excellent near-field containment of radionuclides and minimize reliance on the waste package and surrounding geologic media for long-term containment. No technical issues should preclude whole - elements disposal of GT-MHR spent fuel within MPCs in a geologic repository.

The general scheme of WGPu utilization through GT-MHR is shown in Fig. 1.

WASTE DISPOSAL DESCRIPTION

The current conception of management with spent fuel from GT-MHR is the following:

- after interim storage in the local in-site storage facility of reactor plant area spent fuel is moved to on-site long term storage (see Fig. 2);
- some storage methods have been considered:
  - concrete storage casks (current preferred choice);
  - dual purpose casks;
  - expanded in-plant storage facility;
  - modular vault dry storage (currently used at Fort St. Vrain).

As a preferable spent fuel disposal method the following operations are considered:

- Place spent fuel in multi-purpose canisters (MPC) in reactor service building. A conceptual design has been developed for a multipurpose canister (see Fig. 3), which would be used for storage, transportation, and permanent disposal of spent fuel. The GT-MHR MPC would contain 42 fuel hexagonal graphite elements of 0,8 m in length and 0,36 m across the flats, arranged as seven columns with six fuel elements per column. Each fuel element contains ~ 20 million fuel coated particles.
- Load canister into concrete cask (Fig. 4);
- Move cask to storage facility;
- Store 10 years or until final disposal facility is available;
- Load multi-purpose canister into shipping cask (see Fig 5);
- Ship spent fuel in multi-purpose canister to final disposal facility.

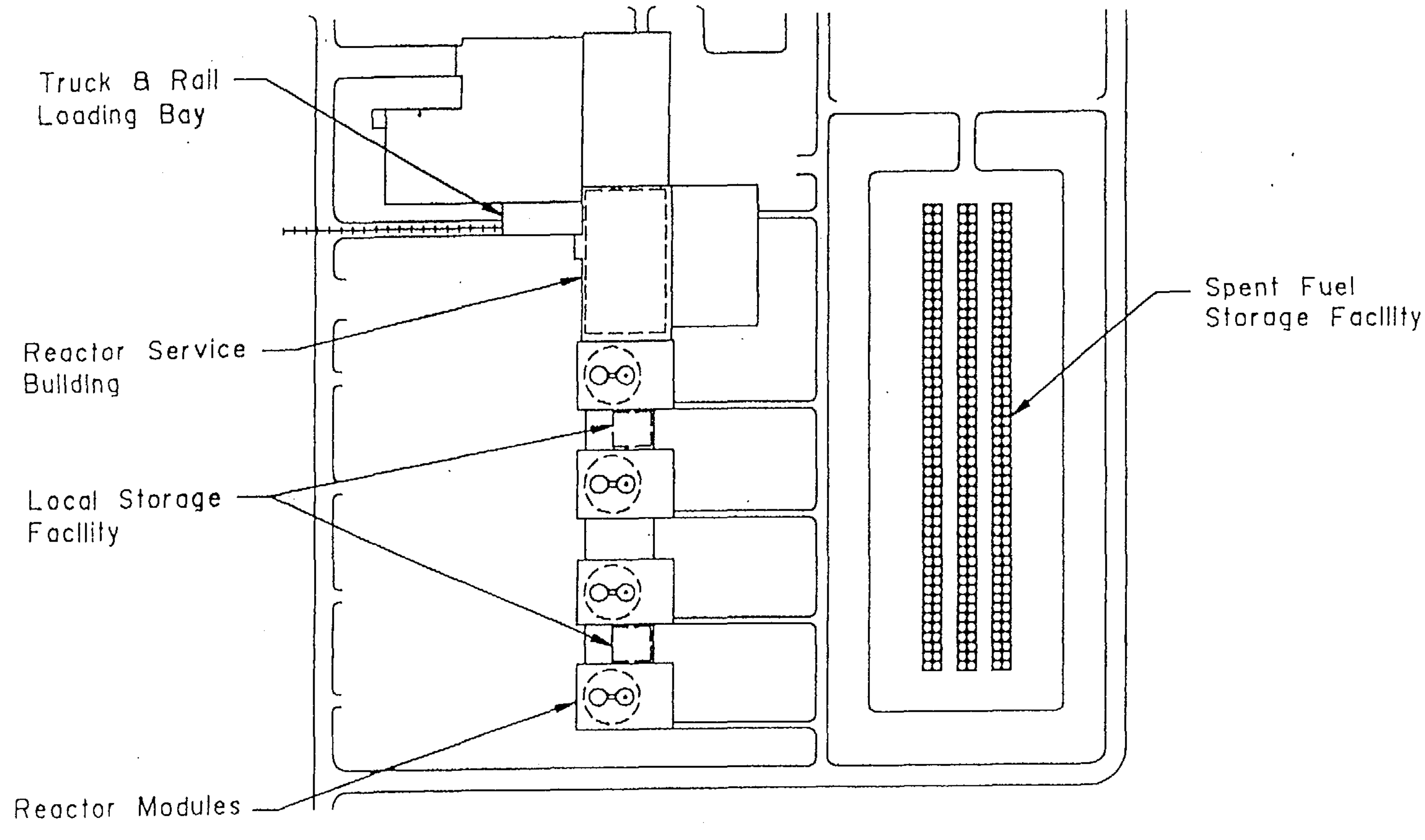

FIG. 2. Spent Fuel Storage Facility.

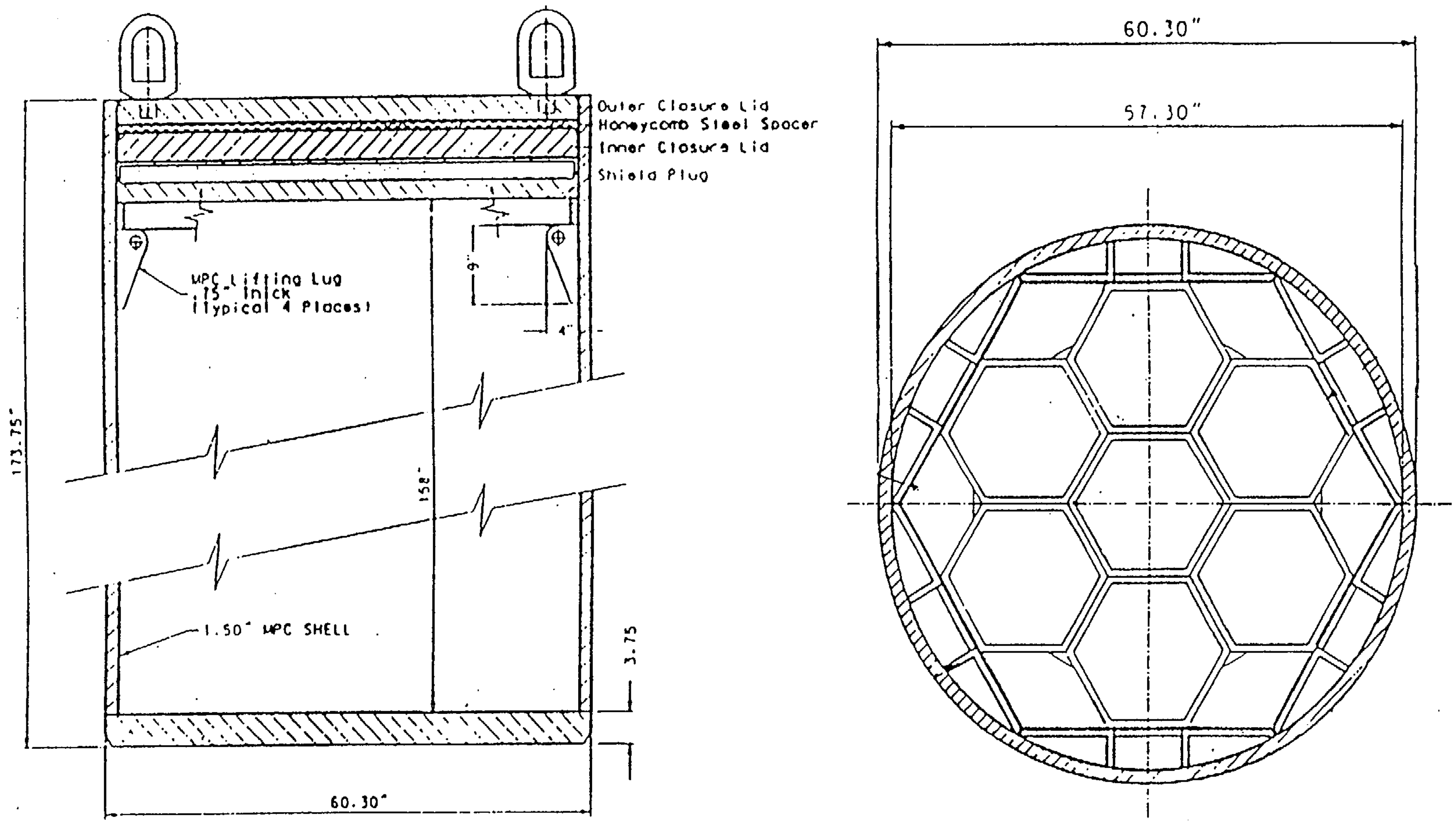

FIG. 3. Multi-Purpose Canister.

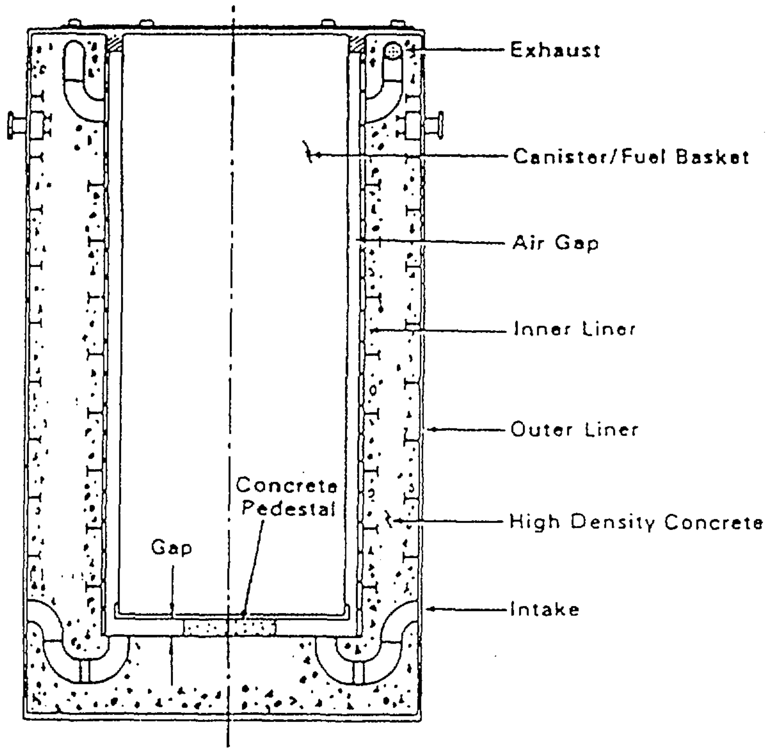

FIG. 4. Concrete Storage Cask.

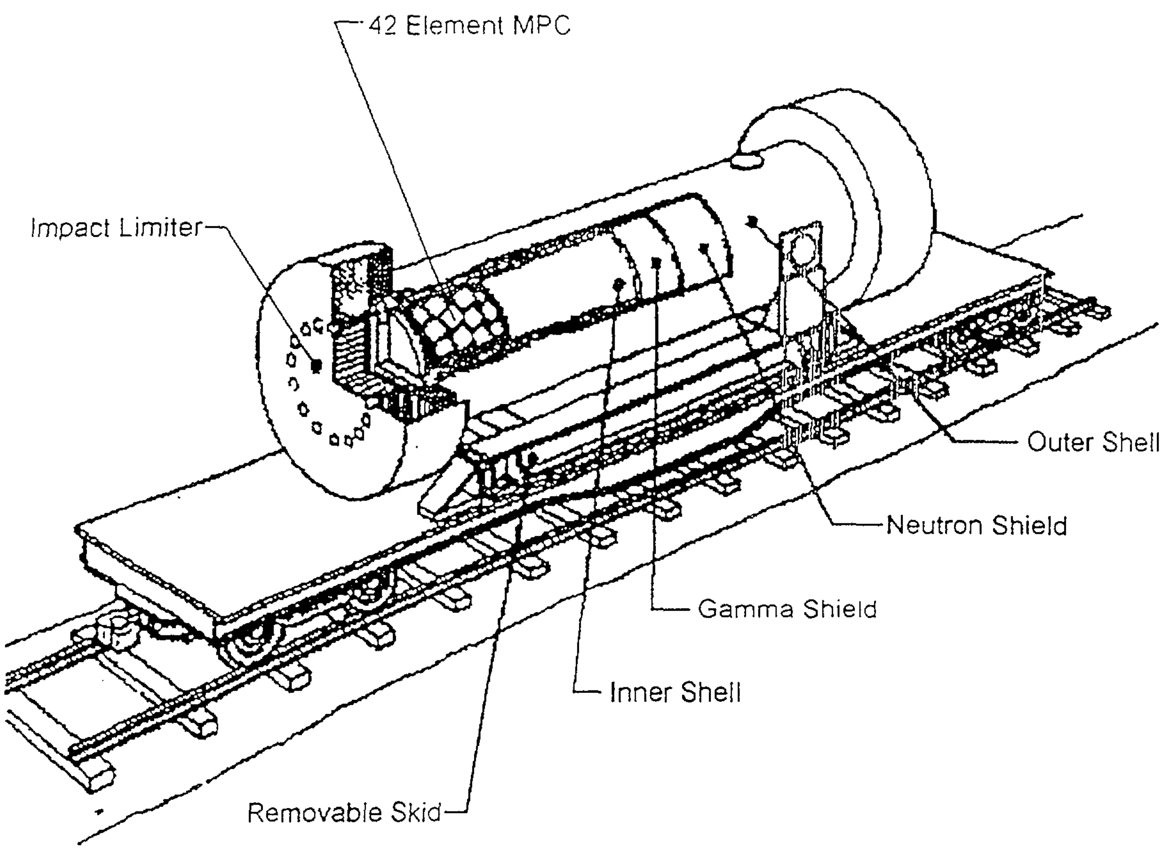

FIG. 5. Shipping Cask.

THE MAIN RESULTS FROM EVALUATIONS OF WHOLE-ELEMENTS DISPOSAL

The following results have been obtained from evaluations of whole-elements disposal:

- Graphite comprises most of the volume of GT-MHR spent fuel. Because of very low level of impurities in nuclear-grade graphite and excellent irradiation performance of coated particle fuel, the graphite does not become highly radioactive during irradiation. The high-purity, nuclear-grade graphite fuel elements are noncombustiable by conventional standards, and oxidation of graphite and other fuel element components at repository temperatures would be negligible over geologic time period.

- Because of the relatively low volumetric decay heat for GT-MHR waste packages, the peak fuel/graphite temperatures are significantly lower than the corresponding fuel/cladding temperatures within LWR waste packages. The GT-MHR peak fuel temperatures are $\sim 220\,^{\circ}C$ versus $\sim 350\,^{\circ}C$ LWR fuel.

- GT-MHR TRISO-coated particle fuel offers the benefit of long-term containment for radionuclides without having to rely on performance of the waste package or geologic media. Quantitative assessment show that the TRISO coating is capable to maintain its integrity for hundreds of thousands to millions of years in a repository environment. (For comparison, the expected lifetime of zircalloy cladding in a repository is less than 1000 years, even under dry conditions, [3]). Previous experimental studies [4,5] have shown that the corrosion rates of pyrocarbon, SiC, and nuclear-grade graphite are very low (even relative to waste glass) and are ideal components of an engineered barrier for a waste-management system. A key conclusion from the ORNL study [4] was that coated particle waste provides much better long-term containment of radionuclides than glassified waste forms. Key results of the ORNL investigations are described below:

  - Coated waste parcels (including those coated with pyrocarbon only) are leached at rates slower than could be detected by sensitive analytical techniques, including atomic absorption and inductively assumed to be at the detection limit, the rates are still 100 to 10.000 less than the rates measured for borosilicate glass.

  - Coated particle waste is especially effective for immobilizing cesium, which readily leaches from glassified waste because of its high solubility and tendency to partition into leachable phases.

- For release by groundwater transport, only nuclides with high mobility are expected to reach the accessible environment within the 10.000 year time period currently specified by the US Environmental Protection Agency (EPA). The nuclide of most concern is carbon-14, because nearly all of the inventory is external to the coated particles and can be releases by groundwater leaching of the graphite. Conservative estimates of release and transport show that the dose rates resulting from aqueous carbon-14 release are well below the applicable EPA criteria for any anticipated GT-MHR spent fuel disposition strategy. The preliminary estimations show that C-14 activity may be reach to 1,5 Ci/m^3 which is more than five times less of criterion given in EPA requirements (8 Ci/m^3) for low-level waste.

As for plutonium release, which limit requirement of allowable fuel fraction is $5{,}5 \cdot 10^{-5}$ it is necessary notice that in discharge fuel particles the fraction of failed particles not exceeds of 10^{-5} even after different abnormal conditions.

• Preliminary evaluations of a GT-MHR MPC conceptual design show that all regulatory requirements for storage, transportation and disposal are met with significant margin. The GT-MHR MPC containing 42 fuel elements has overall dimensions nearly identical to those for an LWR MPC designed for 21 pressurized water reactor (PWR) fuel assemblies, but the weight with spent fuel is be about one-half that of the PWR MPC. The GT-MHR MPC decay heat load is significantly lower: 760 W for GT-MHR vs. 13.200 W for the LWR MPC (with both values based on a decay time of 10 years following discharge from the reactor). These advantages allow to store MPC without active cooling. GT-MHR MPC contains only ~ 11,3 kg discharge plutonium and the following content of the most important isotopes:

Pu-239 - 27,81 %	Am-241 - 0,97 %	Cm-242 - 0,057 %
Pu-240 - 29,05 %	Am-242m - 0,16 %	Cm-243 - 0,001 %
Pu-241 - 29,10 %	Am-243 - 0,97 %	Cm-244 - 0,39 %
Pu-242 - 10,71 %		Cm-245 - 0,021 %
		Cm-246 - 0,001 %
		Cm-247 < 0,001 %
		Cm-248 < 0,001 %

The shielding and criticality-control requirements for the GT-MHR MPC are also less than those for the LWR MPC. As for criticality-control requirement (in any case the value of $K_{eff} \leq 0,95$), this requirement is performed for 42 fuel element MPC even under a flooded condition with the necessary margin ($K_{eff} \sim 0,89$).

The estimated maximum dose rate determined by of actinides activity after 1000 years disposal is amount to ~ 10 mrems/year that is less than dose-rate limit from EPA requirement for controlled area of fuel storage (~ 25 mrems/year).

These factors result in a simpler and less expensive MPC design for the GT-MHR. The unit cost for the 42 GT-MHR MPC is estimated to be about $ 75.000 vs. about $154.000 for the 21 LWR MPC.

• The large volume of GT-MHR spent fuel relatively to that of the LWR, which results primarily from dilution of the plutonium within the graphite fuel elements and results in significant safeguards and security advantages for the GT-MHR, does not adversely affect repository land requirements. Land requirements are determined primarily by decay heat load and not by physical volume of spent fuel. On a per unit electrical energy basis, the GT-MHR MPCs and thermal / mechanical design requirements for the repository itself, the GT-MHR will requires less repository area. For the current reference areal power density limit of ~ 14 kW/m^2 (57 kW/acre), GT-MHR spent fuel requires about one-half of the repository land area of LWR spent fuel per MWe-year. The corresponding number of waste package that can be loaded into the repository per a square meters are about 19 for the GT-MHR vs. only one for the LWR.

CONCLUSION

For any permanent high-level waste form, desirable qualities include the following:

1) the primary waste-containment barrier should provide defense-in-depth and should last as long as possible;

2) the quantity of waste contained by the primary barrier should be as small as practical, which minimizes the fraction of exposed waste if the barrier does fail;
3) the short-term and long-term safeguards requirements and the potential for reusing fissile materials should be minimized;
4) the risks of diversion and proliferation of fissile materials should be reduced as much as possible.

GT-MHR spent fuel elements, with their TRISO-coated particle fuel, achieve these qualities to a much greater degree than other waste forms, including spent zircalloy-clad fuel rods irradiated in the LWR. GT-MHR spent whole elements are an excellent waste form for permanent disposal.

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