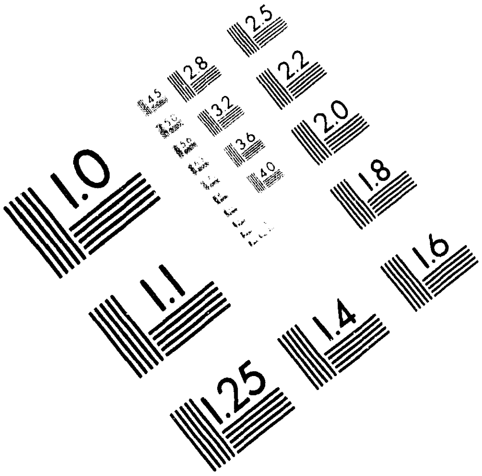

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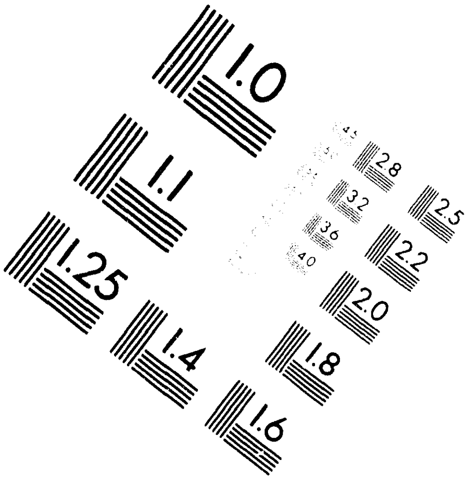

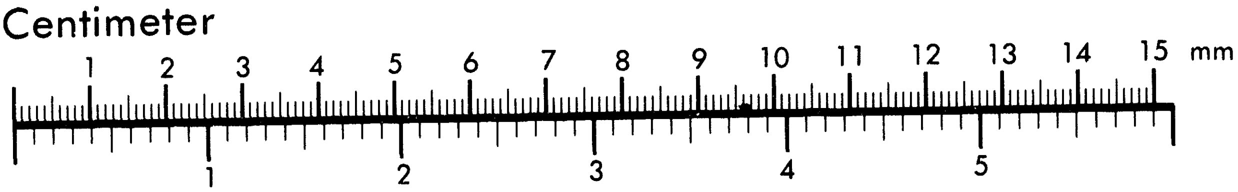

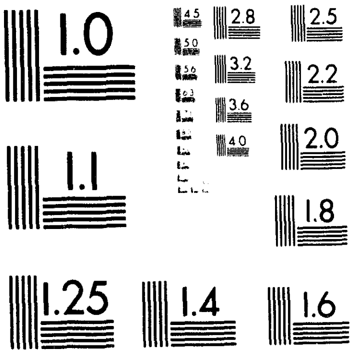

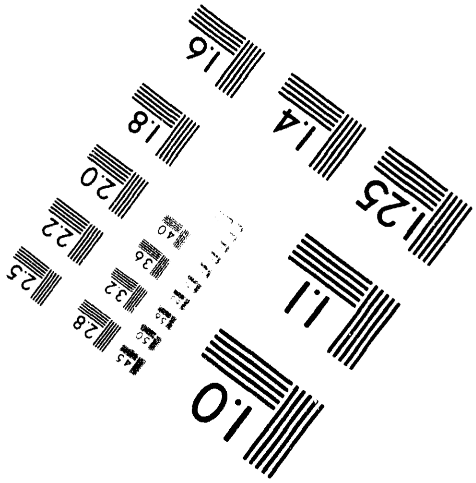

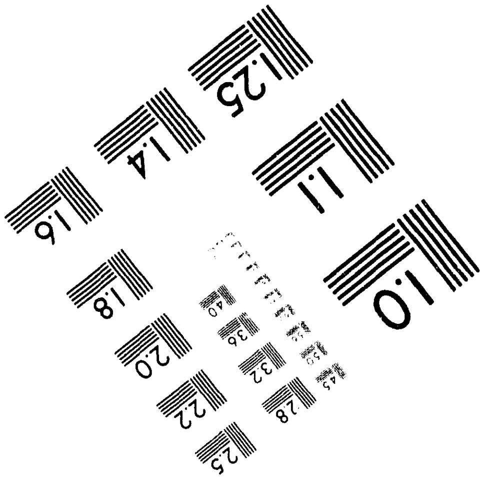

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The ADAPT Concept - An Accelerator Driven System for the Rapid and Efficient Disposal of Plutonium*

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Abstract. A new concept; termed ADAPT; for the rapid and virtually complete burning of plutonium is described. ADAPT employs a high current CW linear accelerator (linac) to generate neutrons in a lead/D_2O target. The neutrons are then absorbed in a surrounding subcritical (K_{eff} ~ 0.95) blanket assembly, that holds small (~ 0.5 cm diameter) graphite beads containing the plutonium to be burned. The graphite beads are coated and sealed to contain all fission products, including the noble gases. After destruction of virtually all ($\geq$ 90%) of the original plutonium loading, the fuel beads are discharged and sent to a geologic repository for ultimate disposal.

THE ADAPT CONCEPT

Fig. 1 shows the overall layout of ADAPT. The linear accelerator (linac) and target systems for ADAPT are similar in design and operating parameters to the systems developed for the APT concept [1] to produce tritium. The linac delivers a proton current on the order of 100 milliamps at 1 Gev ($=10^9$ev) onto the D_2O cooled lead target. The solid lead pins are contained in aluminum tubes, which are in turn assembled in a lattice inside aluminum pressure tubes, which also serve as the "window" that separates the high vacuum beam line from the pressurized heavy water coolant.

The ADAPT blanket consists of an outer assembly of zircalloy pressure tubes that contain annular beds of the plutonium containing graphite beads (Fig. 2). The fuel beads are held between two concentric porous cylindrical tubes (or "frits"). These frits allow the helium coolant to flow through the packed bead bed, directly cooling them, but hold the beads firmly in place during normal operation. Coolant flow through the packed bed is radially inwards, with the heated outlet gas exiting along the central channel inside the inner "hot" frit.

The directly cooled particle bed arrangement used in the ADAPT concept has been taken from the previous DOD SNTP development program on the Particle Bed Reactor (PBR) nuclear rocket [2]. This approach has a number of important advantages. First, the direct cooling of particles enables very high power densities - for example, the average bed power density in the PBR rocket was 40 Megawatts per Liter - with small ΔT's between the fuel particles and the coolant (typically on the order of 50 to 100K). This power density is much greater than the 0.5 to 1 Megawatts per Liter required for ADAPT, resulting in a very large thermal hydraulic margin. However, this large margin helps to ensure safe operation, and also allows the use of larger diameter particles, as described in the following section.

Second, the use of particulate fuel beads with high integrity coatings similar to those in HTGR fuel particles will enable virtually complete containment of all fission products, including noble gases, at all stages of the fuel cycle. Moreover, after discharge the ADAPT fuel beads will not require reprocessing and can be disposed of in a geologic repository without further

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*This work was performed under the auspices of the U.S. Department of Energy.

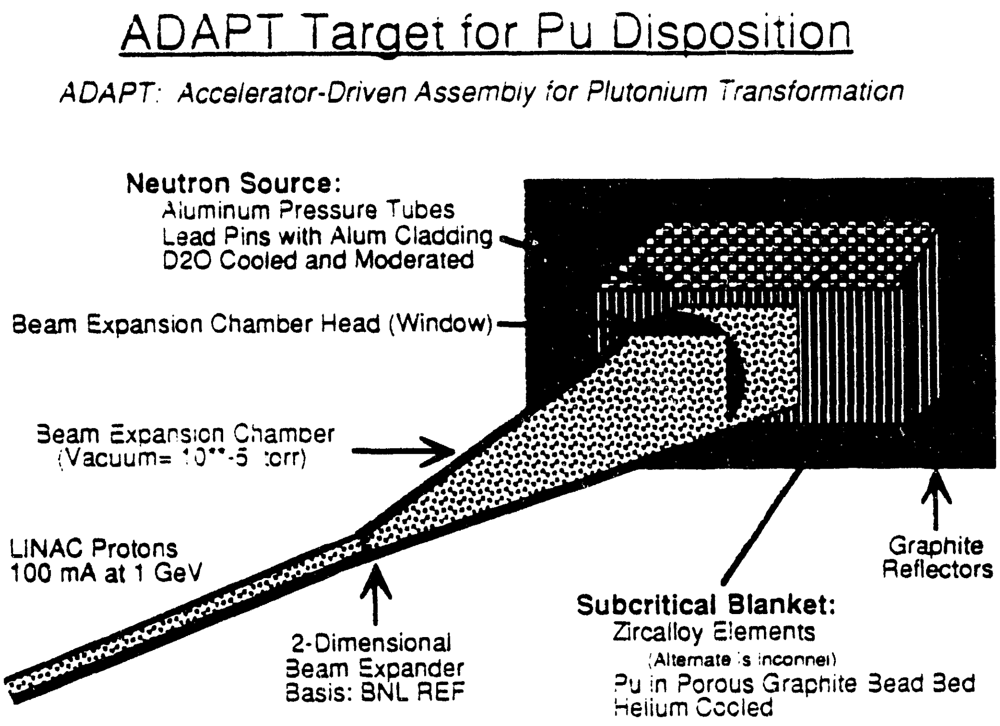


Fig. 1. Overall layout of ADAPT target for transformation of plutonium.

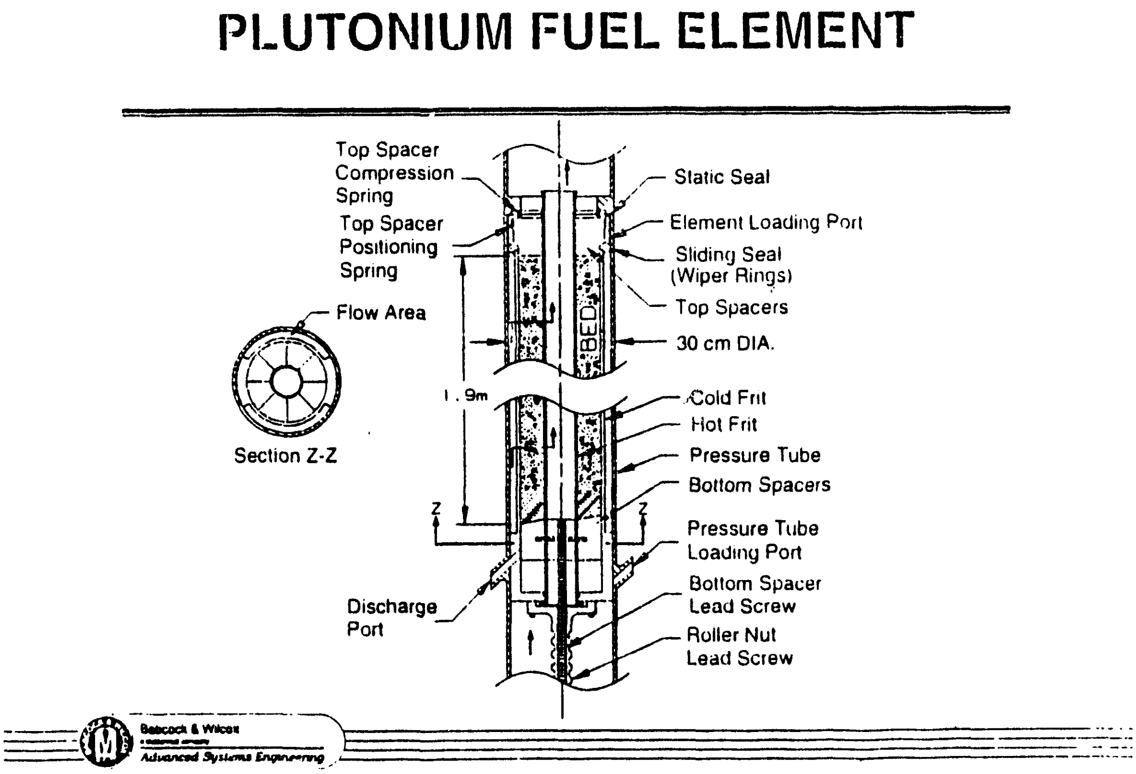


Fig. 2. Fuel element geometry for cooling ADAPT fuel beads.

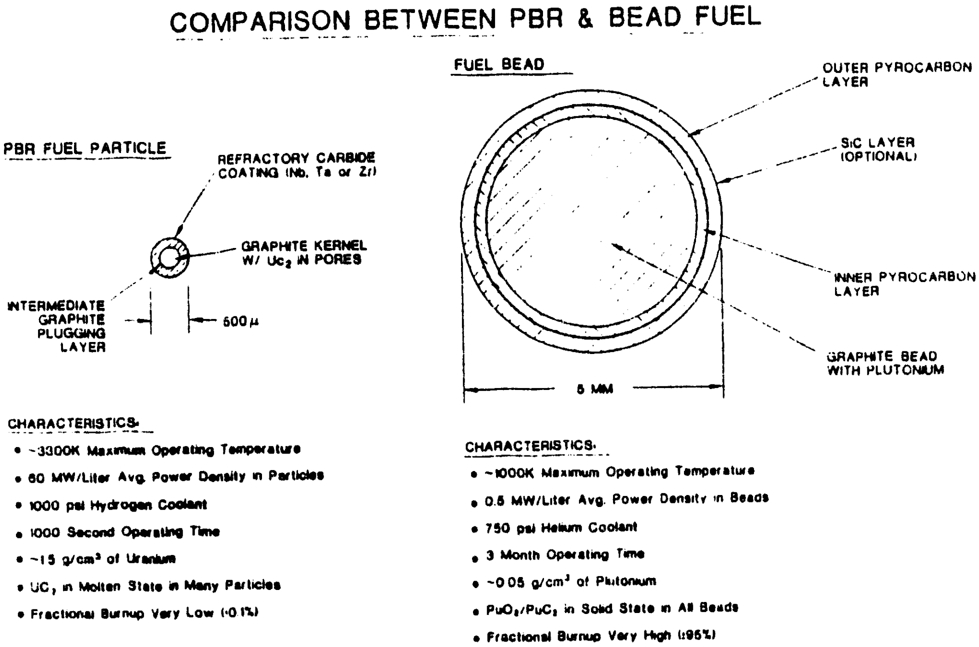
treatment.

Third, the high power densities and fluxes enabled by direct cooling of fuel particles will permit in rapid burnup of the contained plutonium, with total residence times in the blanket on the order of 100 days.

Fourth, the fresh fuel beads can be loaded and spent fuel beads unloaded without inserting and removing fixed structures, using techniques similar to these for the pebble bed HTGR. This will allow fast throughput and minimum inventory of plutonium and fission products. The specific bead transfer arrangement depicted in Fig. 2 was devised by R. DeMars of B&W [3]. Alternate methods of bead transfer are also possible.

ADAPT FUEL DESIGN

Fig. 3 compares the ADAPT fuel bead design with second generation PBR fuel particles. Both use a porous graphite kernel that is loaded with the fissionable material (U-235 for PBR particles, Pu-239 for ADAPT beads) by the solvent impregnation process shown in Fig. 4. The impregnated plutonium nitrate salt is converted to a mixture of PuO_2/PC_2 by heat treatment at 1200K. Although plutonium impregnation using this process has not yet been demonstrated, it should behave much like the uranium and thorium impregnation processes which are very similar and well characterized. The beads would then be coated with pyrocarbon and/or silicon carbide using either a HTGR type CVD (chemical vapor deposition) process, or some alternate process, such as the molten silicon dip process.



CHARACTERISTICS:

- ~3300K Maximum Operating Temperature
- 60 MW/Liter Avg. Power Density in Particles
- 1000 psi Hydrogen Coolant
- 1000 Second Operating Time
- ~15 g/cm³ of Uranium
- UC_2 in Molten State in Many Particles
- Fractional Burnup Very Low (<0.1%)

CHARACTERISTICS:

- ~1000K Maximum Operating Temperature
- 0.5 MW/Liter Avg. Power Density in Beads
- 750 psi Helium Coolant
- 3 Month Operating Time
- ~0.05 g/cm³ of Plutonium
- PuO_2/PuC_2 in Solid State in All Beads
- Fractional Burnup Very High (≥95%)

Fig. 3. Comparative characteristics of PBR fuel particles and ADAPT fuel beads.

The main differences between the two fuel forms, apart from the nature of the fissile material that is impregnated into the graphite matrix, are: 1) particle size, 2) fissile loading, and 3) coating composition. Tests of uranium impregnated graphite have found that maximum loading is uniform throughout the graphite matrix for samples to at least several centimeters in thickness. Thus the impregnation behavior of the larger ADAPT fuel beads is expected to be the same as that of the smaller PBR fuel particles.

Second, the fissile loading for the ADAPT fuel particles will be in the range of 0.05 to 0.1 g/cm^3 of particle (depending on design), as compared to the much higher uranium loadings (~ 1.5 g/cm^3) required for PBR fuel particles. Depending on impregnation process parameters and graphite properties, on the order of 10 to 20 repeated impregnations are necessary to load the desired amount of uranium into PBR particles. For the lower fissile loadings in the ADAPT particles, 1 to 2 impregnations appear sufficient.

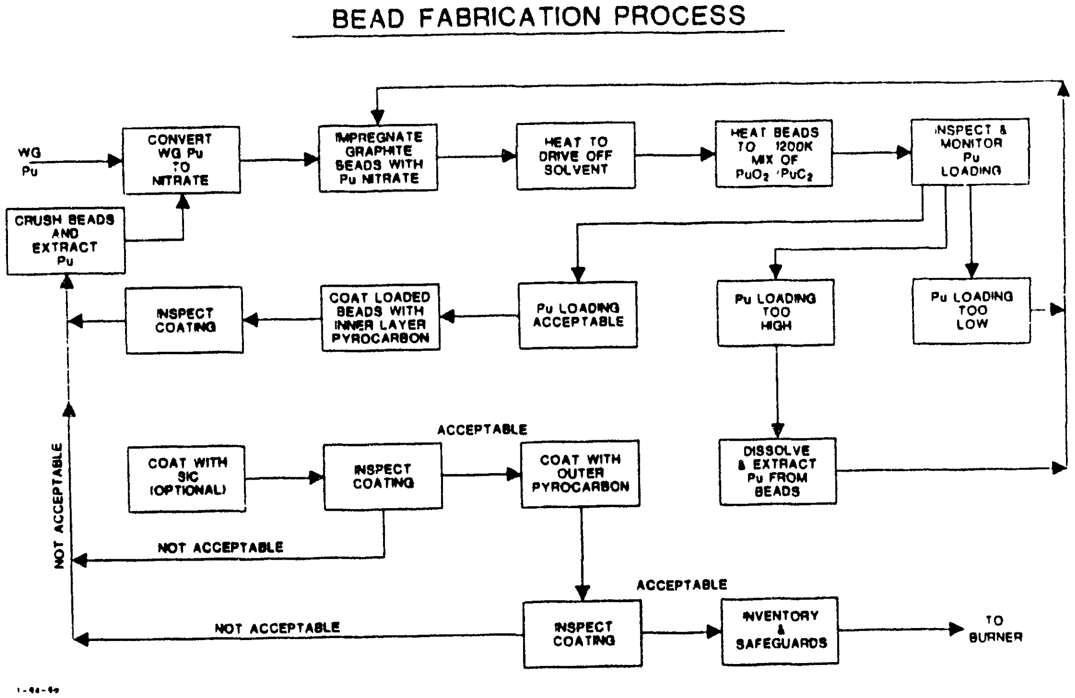


Fig. 4. Solvent impregnation and coating processes for the fabrication of ADAPT fuel beads.

The design value for plutonium loading will depend on the blanket parameters, as well as what fuel cycle is used. A once through cycle (OTTO) can be used, in which the inner and outer blanket regions utilize fuel beads with different fissile loadings, or a cycle (TITO) in which the fuel beads would be shuffled from the inner blanket to the outer after the appropriate burnup level is reached. Other fuel cycle options are possible, using a single fissile loading or several different loading levels in the beads.

Even with high fractional burnup of the fissile plutonium, internal gas pressures in the ADAPT beads will be low, as illustrated in Fig. 5. For a plutonium loading of 0.1 g/cm^3 and 95% burnup, the internal gas pressure will be 80 atmospheres for a 5 millimeter OD bead with a 0.75 millimeter coating thickness. The corresponding tensile stress in the coating will also be low, on the order or 1200 psi, which is much lower than the tensile stress in HTGR fuel particle coatings. Because the ADAPT fuel beads will be under considerably less stressing conditions than HTGR fuel particles, it is expected that they will exhibit even greater integrity than HTGR particles, where a failure rate of only 1 particle out of 10^5 has been achieved.

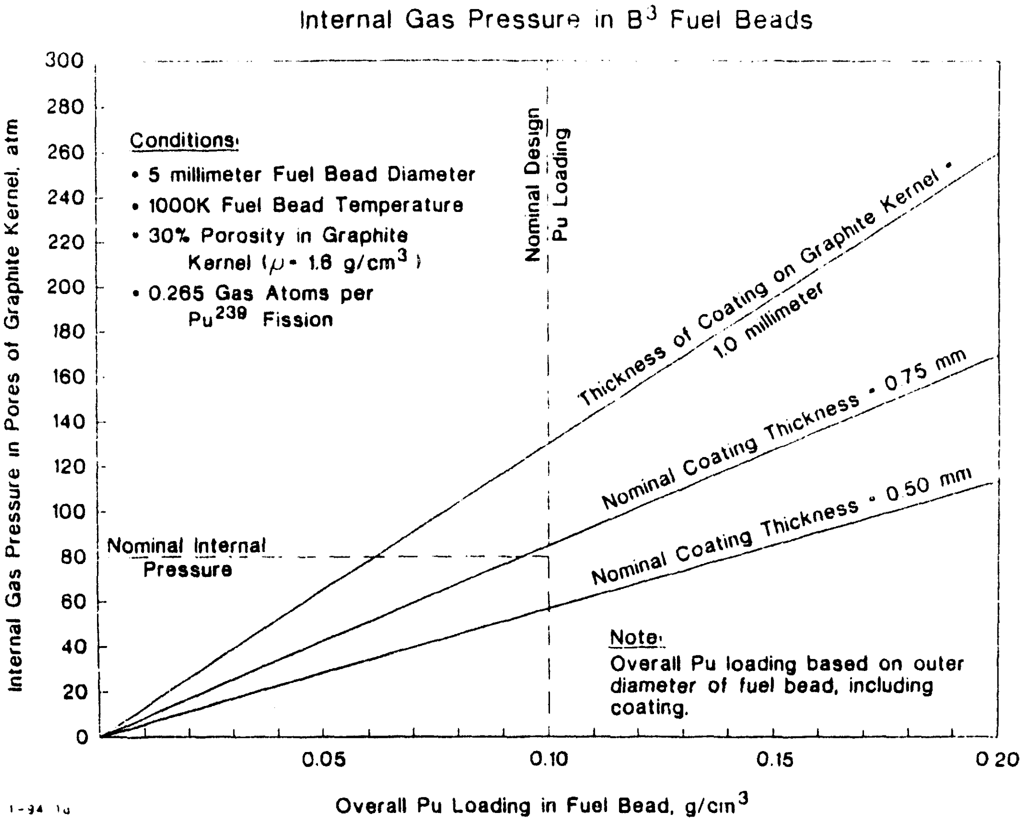


Fig. 5. Internal gas pressure in ADAPT fuel beads as a function of coating thickness and overall plutonium loading.

ADAPT NEUTRONICS AND BURNUP

Neutrons generated in the ADAPT lead D_2O target by spallation reactions from the 1 Gev proton beam enter the surrounding blanket assembly, inducing fission in the plutonium loaded fuel beads. The resultant K_{eff} of the blanket/target assembly depends on its geometry, the thickness of the blanket, plutonium loading in the fuel beads, and the nature of the neutron reflector surrounding the blanket assembly.

Fig. 6 shows a MCNP neutronics analysis of how K_{eff} varies with plutonium loading in the beads, for a typical ADAPT blanket assembly that is reflected by graphite. The height of the blanket assembly is 1.9 meters, and the radial thickness is 0.5 meters. For this particular lattice, a value of 0.95 is attained for K_{eff} at a plutonium loading of 0.08 g/cm^3. At a loading of 0.05 g/cm^3, which would correspond to the average loading in a shuffled lattice fed with fresh beads at a loading of 0.1 g/cm^3, the value of K_{eff} is 0.92.

With design optimization and improved neutron economy, it appears likely that a quasi steady state value of ~0.95 can be obtained for a shuffled lattice fed with beads that are initially loaded at 0.1 g/cm^3.

Fig. 7 shows the fractional burnup of the plutonium loadings as a function of time in the blanket, for initial loadings of 0.05, 0.10 and 0.20 g/cm^3, assuming an average bed power density of 1 Megawatt per Liter. For a 0.1 g/cm^3 loading, and a fractional burnup of 95% of the original Pu-239, the fuel beads would reside in the blanket for a total of 200 days.

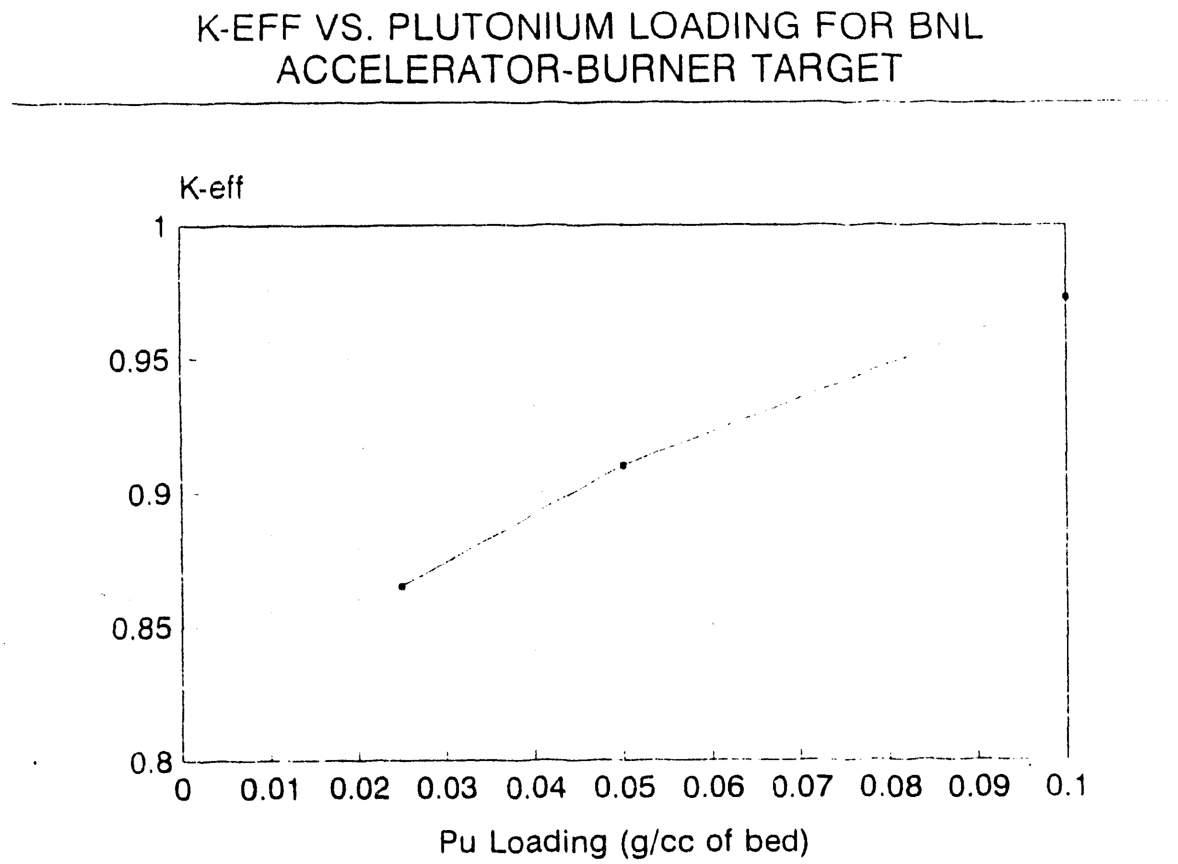


Fig. 6. K_{eff} of the ADAPT blanket/target assembly as a function of plutonium loading in the fuel beads.

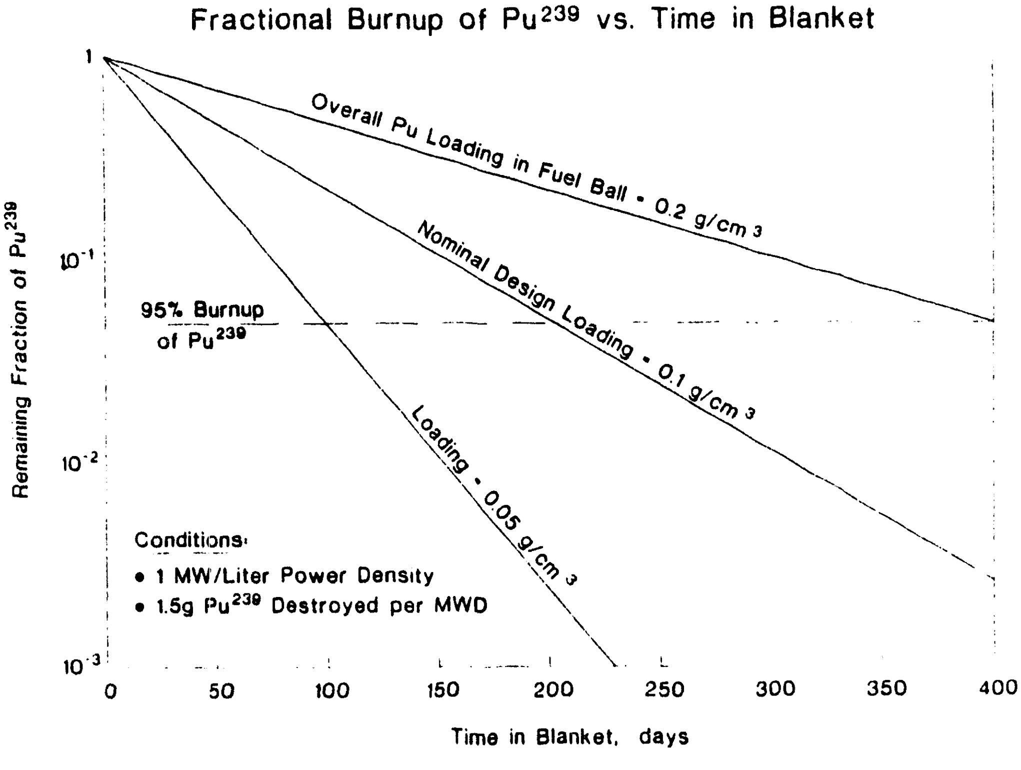


Fig. 7. Fractural burnup of plutonium fuel loading as a function of loading amount and residence time in the ADAPT blanket.

DISPOSAL OF ADAPT WASTES

At high fractional burnups, i.e., in excess of 90% of the original Pu-239, most of the plutonium remaining in the fuel beads would be present as Pu-240 and higher isotopes, rendering it unsuitable for use in nuclear weapons. Since the fuel beads then do not represent a proliferation hazard, are inert, and will have high integrity over geologic time intervals, they can be disposed of in a geologic repository without reprocessing.

Fig. 8 shows a possible approach for final disposal of the ADAPT fuel beads. The spent beads are imbedded in tar, and enclosed in a tar impregnated graphite container. This provides three lines of defense against leakage of long lived actinides and fission products. The first line of defense is the high integrity coatings on the fuel beads. The beads and coatings are chemically inert over geologic times in all types of environments. The failure rate for ADAPT beads is expected to be even lower than the very low failure rates measured for HTGR particles, i.e., less than 1 in 10^5.

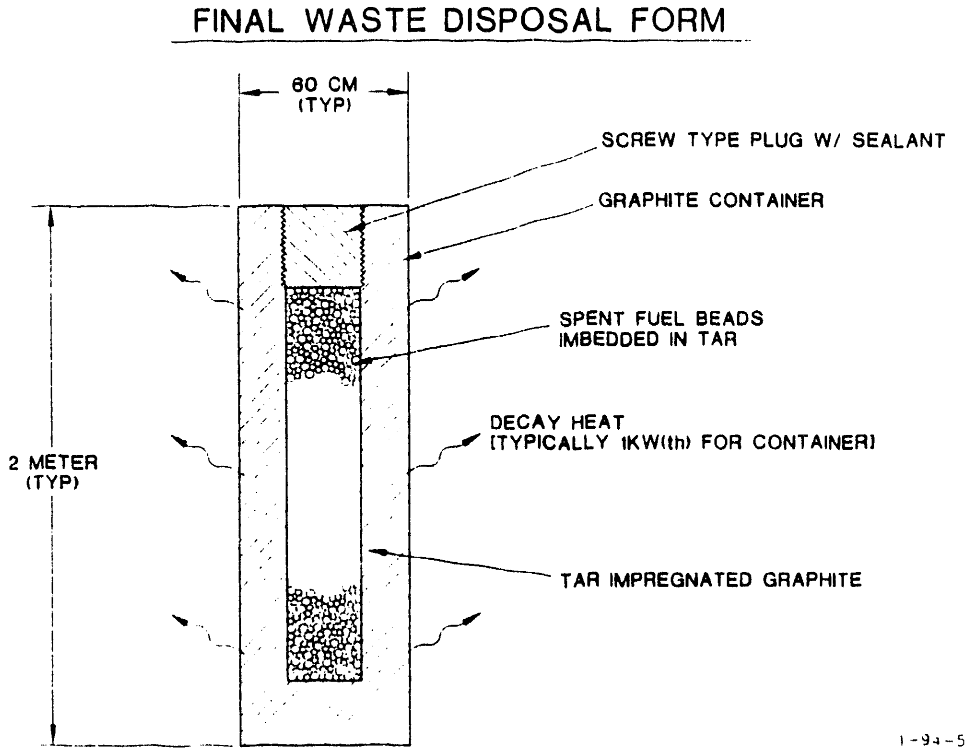


Fig. 8. Proposed containment approach for ADAPT fuel beads enabling burial in a geologic repository.

The second line of defense is provided by imbedding the beads in a tar matrix, and the third line by containing the tar matrix in a mechanically strong graphite container. As with the fuel beads, the tar matrix and the graphite container are chemically inert in a wide range of geologic environments over geologic time periods.

The proposed disposal method appears to offer an attractive combination of excellent containment capability, and minimum requirements for handling and reprocessing.

SUMMARY AND CONCLUSIONS

The ADAPT concept for plutonium burning appears very promising. It provides high integrity containment for plutonium and fission products, utilizes HTGR technology, has high temperature capability, uses inert coolants and materials, does not require reprocessing of spent fuel, and enables a simple, effective waste disposal approach. More detailed study of the concept is recommended, with particular attention to neutronic burnup analyses and fuel shuffling strategies. Experiments on the fabrication of fuel beads and their capability for high burnup are also recommended.

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