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RELAP5 Applications in MGR Waste Package Analysis Methods

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1.0 INTRODUCTION

The U.S. Congress charged the U.S. Department of Energy (DOE) with managing the geologic disposal of high-level radioactive waste (HLW) and spent nuclear fuel (SNF) through the Nuclear Waste Policy Act of 1982 and the Nuclear Waste Policy Amendments Act of 1987. An important objective of geologic disposal is keeping the fissionable material in a condition such that a self-sustaining nuclear chain reaction (criticality) is highly unlikely. To meet this objective, a risk-informed methodology (YMP 2000) to analyze the potential for postclosure criticality of the various waste forms in the proposed repository at Yucca Mountain, Nevada, is being proposed to the Nuclear Regulatory Commission (USNRC). This methodology will be used during the licensing process to demonstrate how the potential for postclosure criticality will be limited and to demonstrate that public health and safety are protected against potential postclosure criticality risks.

Limiting the potential for, and consequences of, criticality during the postclosure phase of the geologic repository relies on multiple barriers, both natural and engineered. The natural barrier system consists of the climate around, and the rock formations of, the repository, and includes the geologic, mechanical, chemical, and hydrological properties of the site. As defined within 10 CFR 63 Part 2, the engineered barrier system (EBS) is comprised of the waste packages (WP) and the underground facility in which they are emplaced. The EBS will work in concert with the natural barrier system to minimize the potential for conditions that would be conducive to a criticality event after the repository has been permanently closed.

Part of the risk-informed methodology entails an evaluation of the consequences of potential critical events internal to the WP. There are no identifiable mechanisms leading to a criticality without water as a neutron moderator thus restricting possible critical configurations to degraded (breached) conditions. Water is likewise necessary to provide an aqueous media for possible the subsequent transport of degradation products (both fissile and non-fissile nuclides) into the external environment or into possible segregated zones of fissionable and absorber material.

The WP design consists of two concentric cylindrical shells where the inner shell is composed of stainless steel and provides structural support. The outer shell is composed of high-nickel alloy and serves as a corrosion-resistant barrier. The internal structure for commercial spent nuclear fuel (CSNF) containing either ^{235}U or mixed-oxide (MOX) is a square matrix holding the assemblies (Figure 1). The CSNF arrangement is sufficiently analogous to a nuclear reactor core to permit similar type transient analyses of internal WP criticalities for this waste form as for reactor systems. Designs for other waste forms include a codisposal arrangement that contains a web-shaped basket supporting structure that permits a maximum of five HLW canisters located around the periphery and a center compartment that may contain SNF.

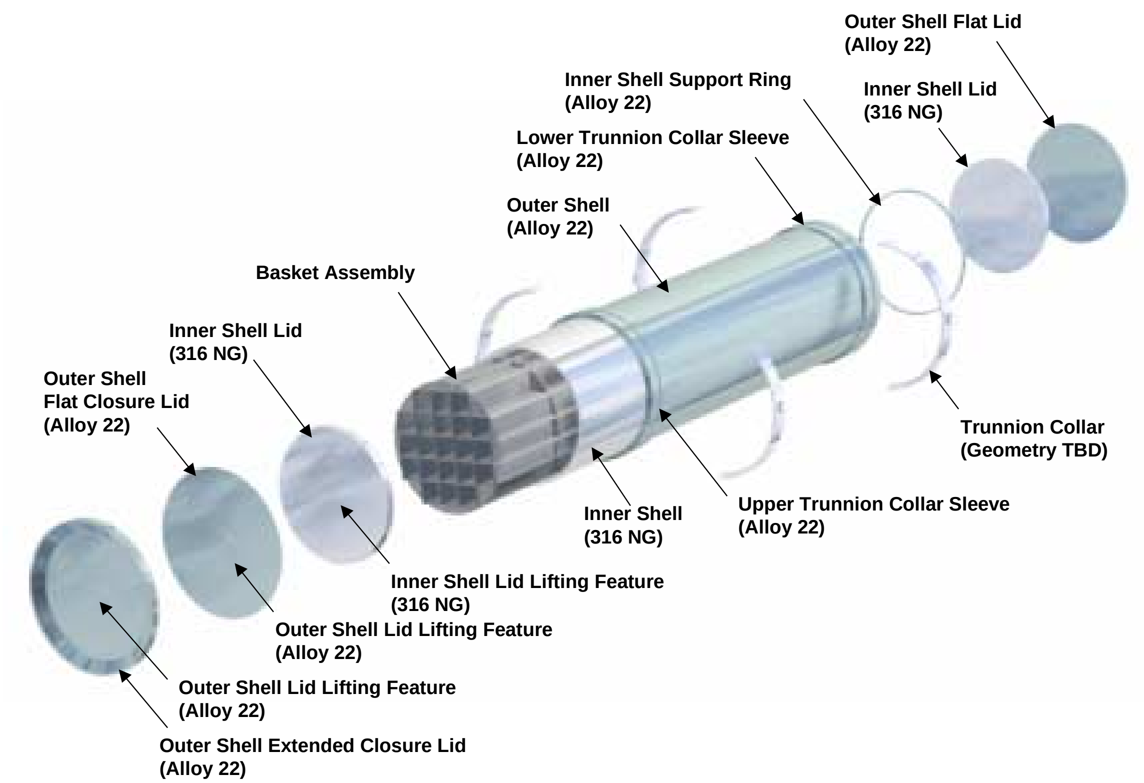

Figure 1. Isometric View of a 21-PWR CSNF Waste Package

The codisposal WP design, in particular cases, is also amenable to transient criticality and thermal-hydraulic analyses. The design for the DOE Fast Flux Test Facility (FFTF) MOX SNF is one that utilizes the center compartment of the basket structure for a DOE SNF canister containing FFTF SNF (Figure 2). The SNF canister also has a basket structure as shown in Figure 3. FFTF driver fuel assemblies (DFA) occupy the outer basket positions and either a DFA or a fuel pin container [Ident-69, Figure 3)] can be placed in the center position. In the latter case, the design requires blocking of one outer basket position (CRWMS M&O 1999a, p. 80) to maintain a sub-critical state. Criticality is possible, however, for some configurations such as misloads. Characteristics of the PWR and FFTF MOX fuel are listed in Table 1.

Table 1. PWR and FFTF MOX Fuel Characteristics

Constituent	Parameter	PWR MOX Fuel (conceptual)	FFTF MOX Fuel
Plutonium	Content (wt%)	4.0	29.28
	Isotopic fraction Pu-239	0.936	0.8711
	Isotopic fraction Pu-240	0.059	0.1163
	Isotopic fraction Pu-241	0.004	0.0102
Uranium	Content (wt%)	0.96	70.72
	Isotopic fraction U-235	0.002	0.002
	Isotopic fraction U-238	0.998	0.998

During a potential criticality event, the PWR WP acts as a single containment system whereas the codisposal WP acts as a multiple containment system where the critical canister is immersed in a secondary pool. Thus the transient criticality evolution in each of these systems followed a different path that is summarized in the following sections.

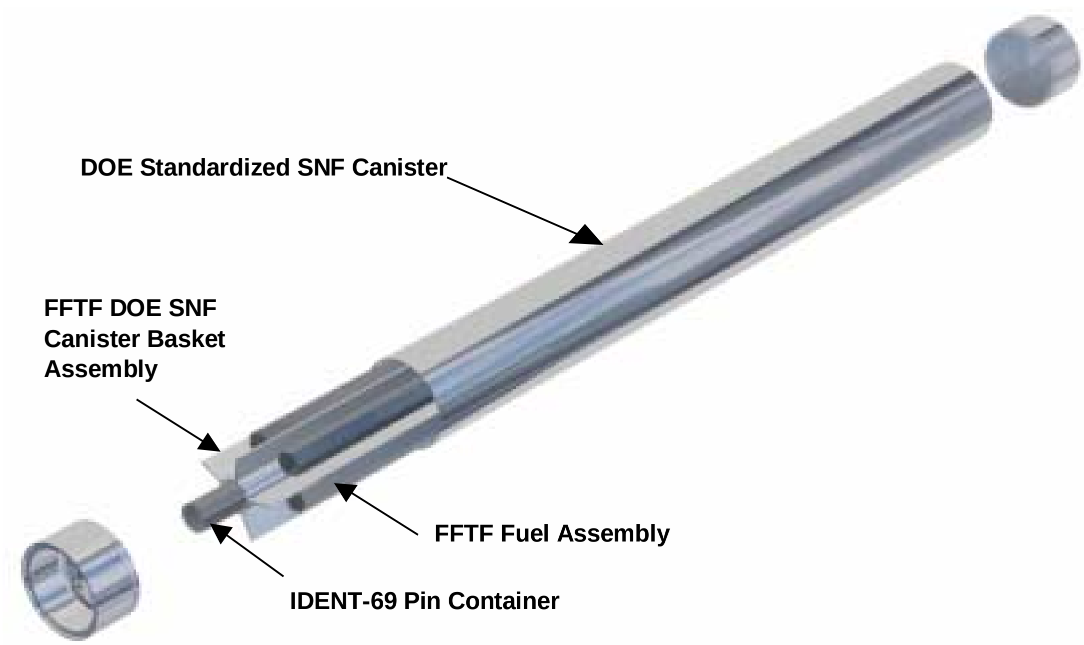

Figure 2. Isometric View of DOE Standardized SNF Canister

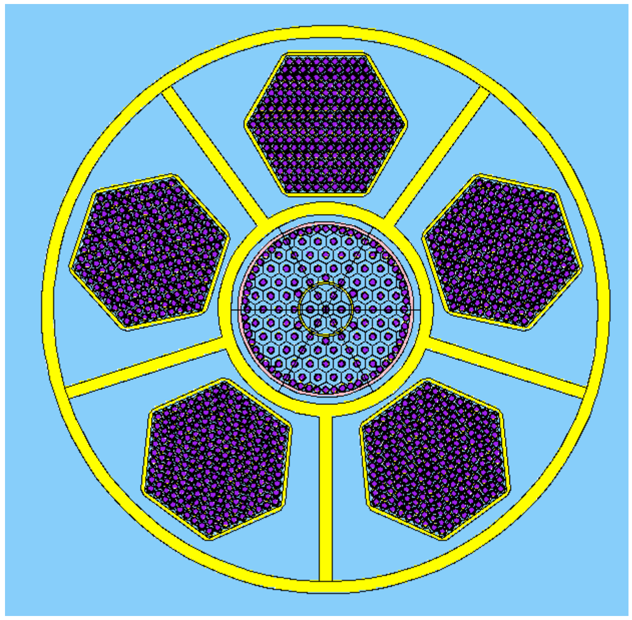

Figure 3. Cross Sectional Diagram of DOE Canister Containing FFTF SNF

2.0 TRANSIENT CRITICALITY APPLICATIONS

A probabilistic analysis of the commercial SNF WP has shown that the corrosion rate of the Zircaloy cladding of the fuel is much slower than the principal materials comprising the basket assembly (carbon steel and borated stainless steel). Therefore, the basket materials will degrade while the SNF, while possibly breached, stays mostly intact. The iron oxide from the degraded basket is very insoluble, and will tend to precipitate, filling the lower portion of the WP. Configurations having criticality potential include relatively intact CSNF with settled or stratified degradation products coupled with the loss of soluble boron absorber in a bathtub arrangement. Configurations of FFTF SNF in a codisposal WP having criticality potential require a relatively intact Ident-69 SNF container immersed in the DOE canister.

The Light Water Reactor (LWR) transient analysis code (INEEL 1995), RELAP5/MOD3.2, has been used for analyses of transient criticality events internal to a WP containing conceptual designed PWR MOX SNF and DOE FFTF MOX SNF (CRWMS M&O 1999, BSC 2002). The containment WP (and canister) though breached is assumed to be sufficiently intact that the potential exists for water to accumulate within the WP. A transient internal criticality may be initiated through some relatively rapid (seconds to hours) event that shifts the internal WP geometric arrangement increasing the fissile mass and/or decreasing the amount of neutron absorber present.

One of the principal variables influencing the evolution of transient criticality events in a WP is the area of the leakage paths from the containment vessel. The power rise from the transient criticality event is limited initially by the negative SNF Doppler reactivity. Ultimately, the negative reactivity from voiding the system becomes dominant, and the criticality event terminates. The immediate effect on the system from a limited leakage area is to reduce the negative reactivity effect of voiding the WP because the water/vapor escape rate may be lowered. This, in turn, leads to higher heat output, higher internal pressure, and higher temperatures. The higher pressure and density of the water vapor will increase the mass flow out of the waste package eventually forcing termination of the criticality event as the negative reactivity from voiding the system becomes the dominant reactivity factor. Moderator exits the WP into the drift region with no possibility of reflood, limiting the transient criticality event to a single pulse. Energy (and fission number) is inversely proportional to the exit area. This sequence of events is characteristic of single containment configurations such as the PWR SNF WP.

A different sequence occurs with configurations having multiple containment vessels surrounding the critical region such as the codisposal WP where the FFTF fuel in the Ident-69 vessel is submerged within the DOE canister. This configuration initially follows the above sequence but has the capability for reflooding the critical volume generating multiple pulses before ultimately terminating the event through moderator loss.

Each of the simulated criticality events were driven by a linear rate of reactivity insertion until reaching a maximum value and held constant thereafter simulating a rearrangement of fissile and/or absorber material. Figures 4 and 5 show transient criticality analysis results from the PWR MOX SNF single containment configuration. The internal pressure (Figure 4) increases slowly with decreasing exit flow area until the flow rate is sufficiently restricted to cause a significant increase in the pressure. The transient criticality for this configuration consists of a single power pulse as shown in Figure 5. The fission energy generation for this configuration was inversely proportional to the critical volume flow area.

Transient criticality analysis results from the FFTF MOX SNF codisposal WP system with a multiple containment configuration are shown in Figures 6-8. The initial evolution of the transient event was similar to the PWR single containment system with an initial power pulse. The subsequent evolution was controlled by the reflood rate of the critical volume and the thermal energy distribution among the containment volumes resulting in a series of power pulses as shown in Figure 6. The critical event ultimately terminated when sufficient moderator was lost from the WP to prevent further reflooding of the critical volume. The transient pressure increases were of nominal value with the maximum values associated with the smaller exit areas from the critical volume (Figure 7). The fission energy generation for the multiple containment configuration was proportional to the critical volume flow area but bounded as shown in Figure 8.

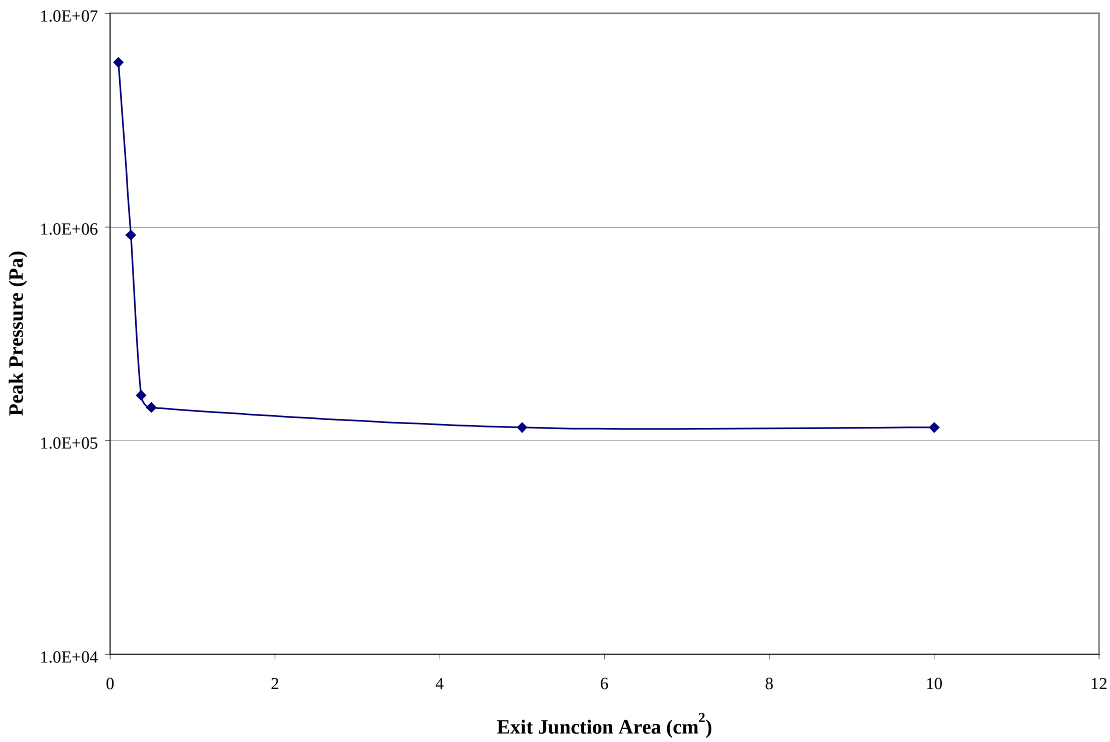

Figure 4. Peak WP Pressures for PWR MOX SNF (Single Containment)

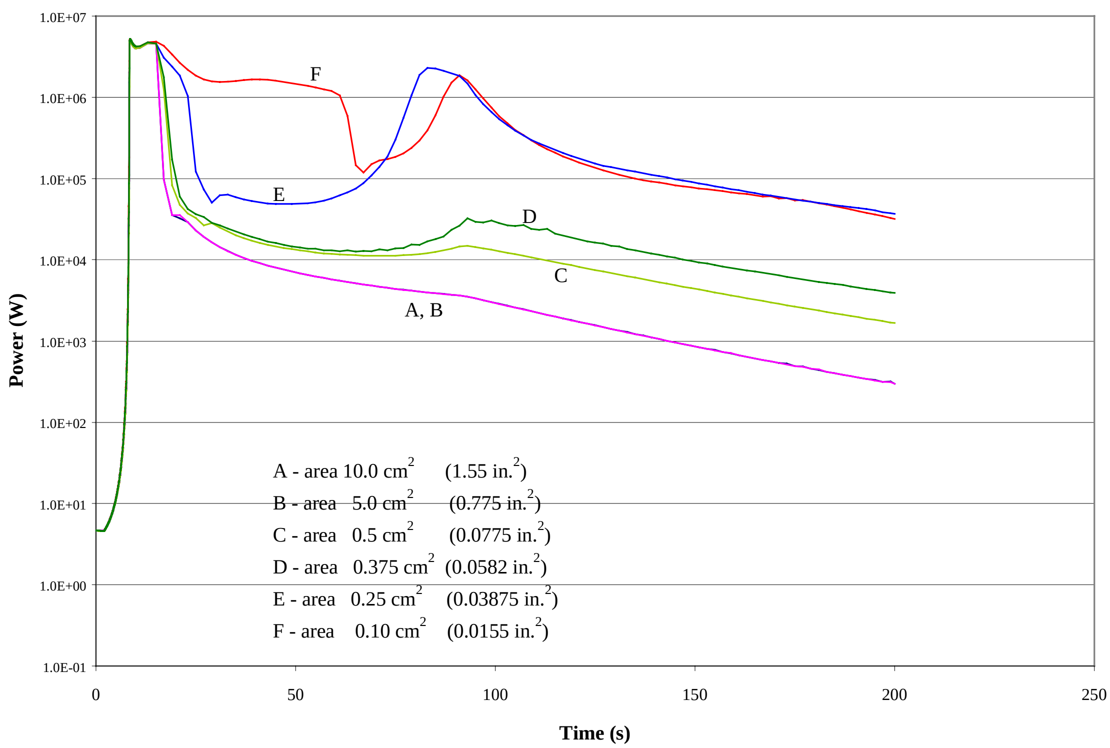

Figure 5. Fission Power Evolution for PWR MOX SNF (Single Containment)

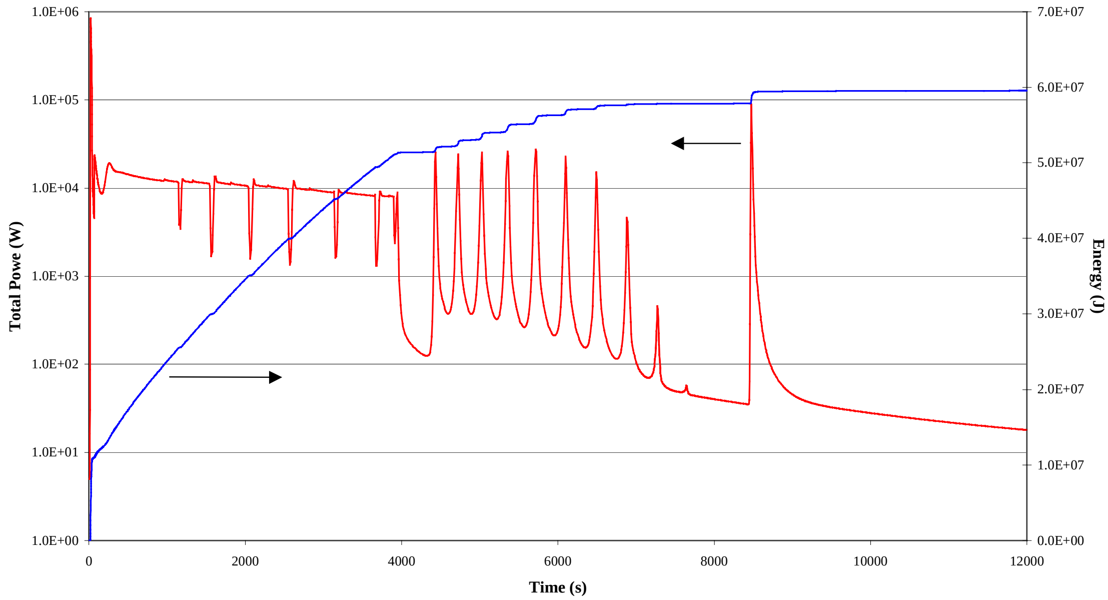

Figure 6. Typical Power and Energy Generation with Containment Reflood for FFTF MOX SNF (Multiple Containment)

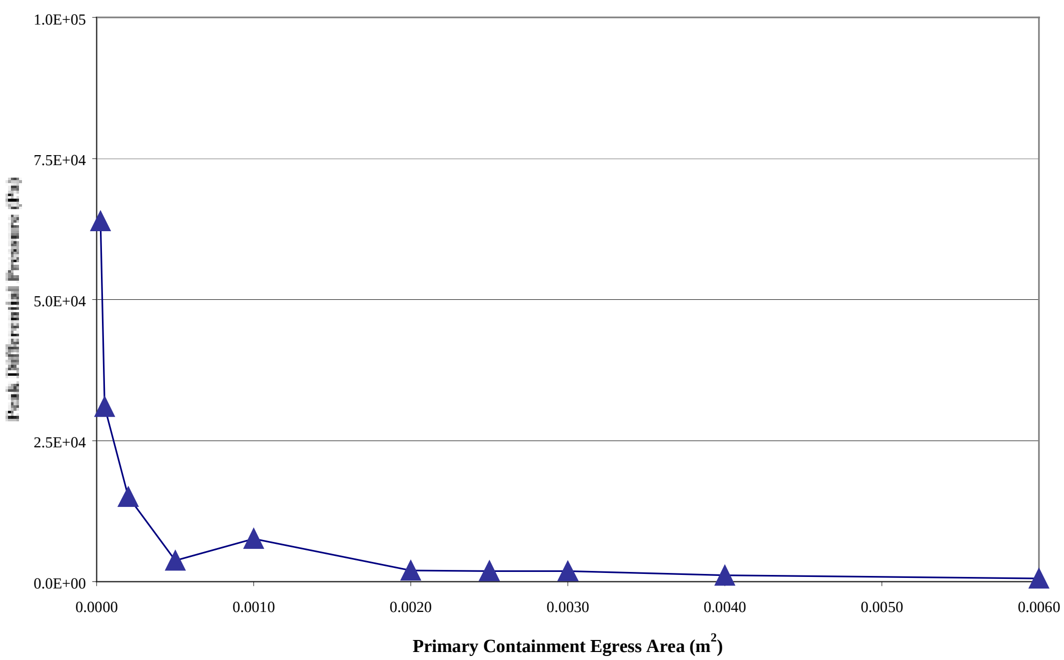

Figure 7. Peak Differential Pressure in Primary Containment for FFTF MOX SNF

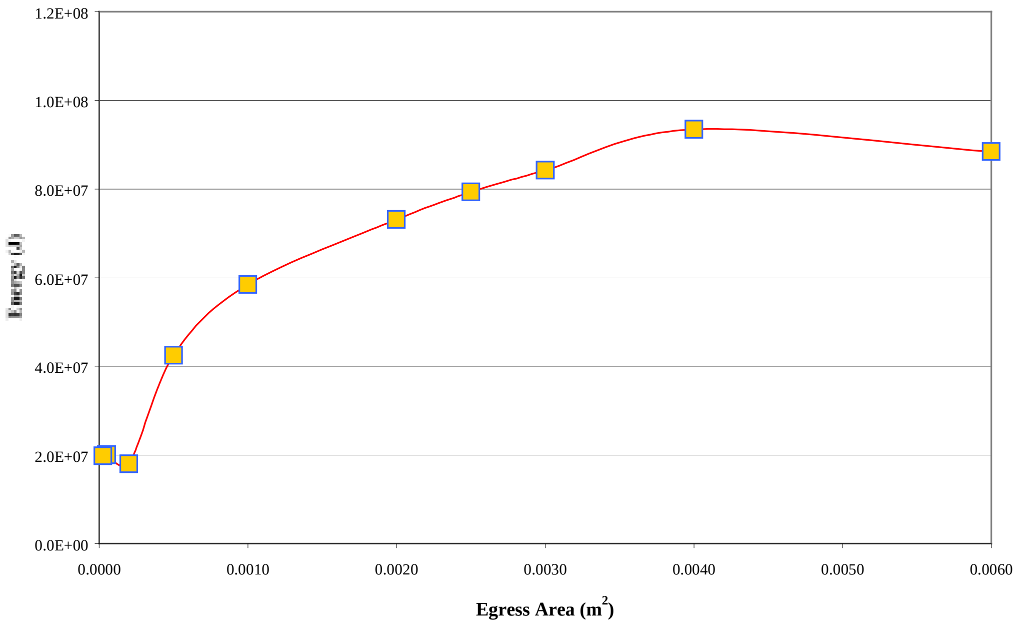

Figure 8. Total Energy Generated for FFTF MOX SNF (Multiple Containment)

3.0 References

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