DETERMINATION OF DECAY HEAT FROM SPENT FUEL UTILIZED IN THE SUB-CRITICAL FAST TRANSMUTATION REACTOR CONCEPT

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ABSTRACT

In the design process for the sub-critical advanced burner reactor (SABR)[3], and spent nuclear fuel repositories, one of the primary engineering considerations for both is the theoretical decay heat produced by spent nuclear fuel. The following paper reports the potential thermal power output of the spent nuclear fuel from SABR, its possible economic and environmental remuneration, and its importance to the reduction in necessary repository size.

I. INTRODUCTION

As nuclear energy becomes more prevalent worldwide, a correlated growth in necessity for repository space is also becoming evident. Currently the Yucca Mountain facility, the newest repository to date, has already reached its engineered limits for spent fuel storage[1]. The total capacity of any spent fuel repository is primarily a function of the decay heat from said fuel[2], and this represents an important and daunting design challenge. While the world is in need of more fission reactors, it cannot sustain expansion without certain remedies to the problem of nuclear waste, and as locations are limited for massive repositories, the ideal solution is to reduce the decay heat from the spent fuel. SABR in concordance with fuel reprocessing presents the answer to this question. The prolonged usage of fuel as a result of reprocessing, and the deep burn achieved by SABR, will effectively reduce the total mass of spent fuel as well as reduce the total decay heat through transmutation of long-lived transuranics. Preliminary studies have shown that a reduction of thermal power from decay heat can be achieved with SABR[3]. This study will show a more complete examination of the decay heat from the spent fuel of SABR, and examine the benefits associated with SABR advancements. Also included in this paper will be an analysis of short term decay heat from fuel immediately after reactor shutdown. Such information will be useful in a topical assessment of loss of coolant accident, or LOCA, scenarios.

II. METHODOLOGY

The first priority of this study was to manually input the percentages of all possible fission products per fission into the ERANOS simulation code†. Using ERANOS[7], a radiation transport code, to calculate the reactivity and flux levels in the reactor, the fuel was burned for a residence time of 3000 days. The isotopic concentrations of the spent fuel were then decayed using ORIGENS[5] part of the SCALE6[6] software package, and the thermal decay power was obtained.

III. RESULTS

Shown in Figure 1, the overall trend of the decay heat curve exhibits normal behavior. The initial thermal output of approximately 425MW represents 14% of the total operating thermal power of SABR. The main contributor to the thermal decay power for the first ten years is due to the decay of fission products, after that, the primary contribution to the decay power is from the actinides. Figure 2 shows the short term thermal power output from the spent fuel which will be utilized later to examine LOCA conditions for SABR. The transmutation rate in SABR is defined as the fissions of initial metal atom, or FIMA and is defined in equation 1.

$$FIMA = 1 - \frac{mass\ of\ spent\ fuel}{mass\ of\ fuel}$$

Where mass of spent fuel is the mass of transuranics in the spent fuel, and the mass of fresh fuel is the mass of transuranics in the fresh fuel. The burn up in SABR is calculated to be 27.1%

† Fission products excluded were those not present in the ERANOS simulation.

Figure 1

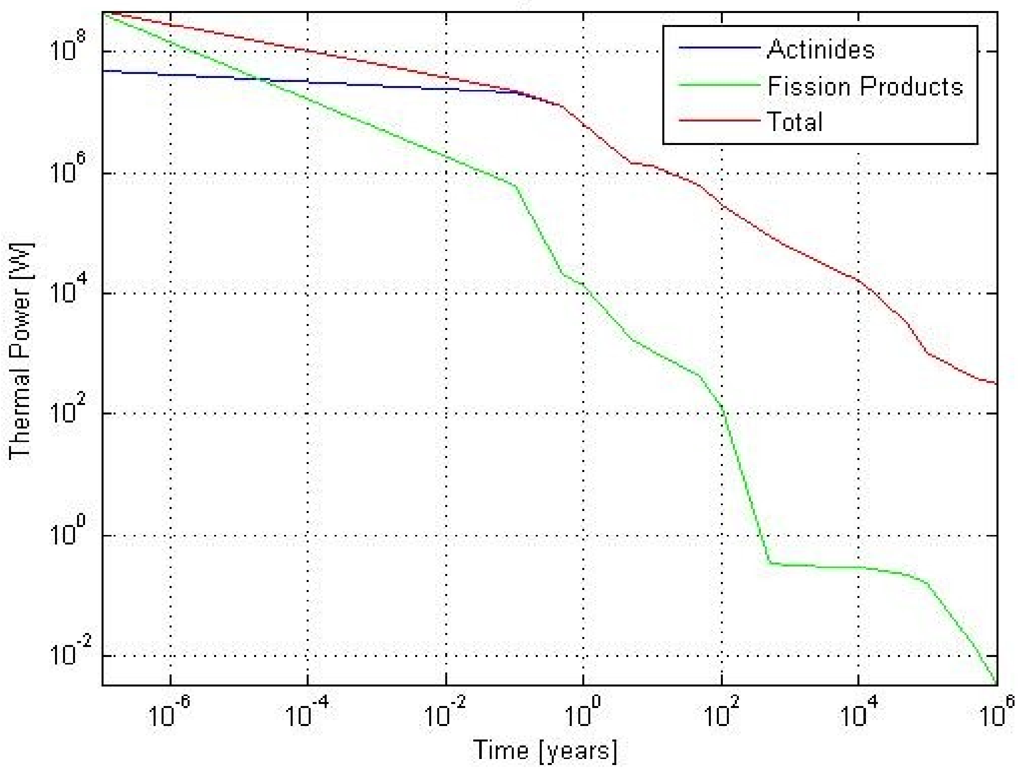
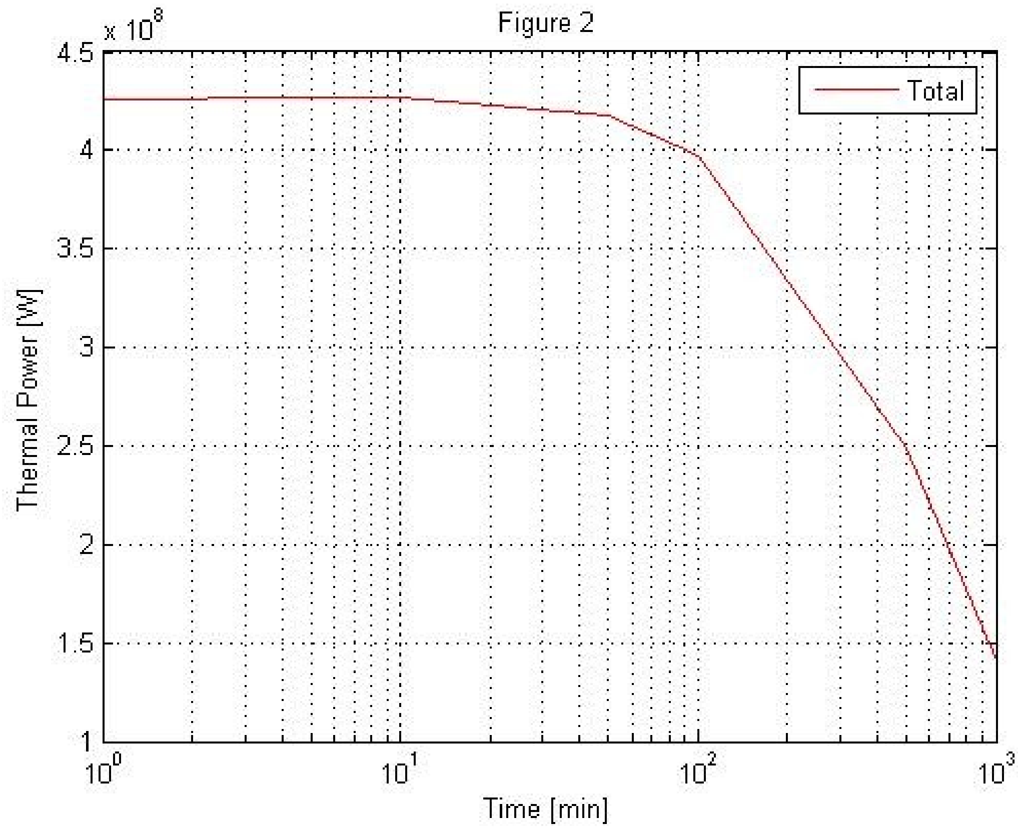


Figure 2



IV. ANALYSIS

A. Corollaries to Repository Capacity

As the nuclear industry grows, an increasing demand in spent fuel waste management is becoming evident. Large underground repositories represent the primary answer to this problem but their economic, environmental, and socio-political consequences are overwhelming and limit their availability. Therefore, it is of the utmost importance that space is maximized through improved fuel cycles. The limits of these repositories are given by the structural thermal limits of the surrounding earth, usually some rock form.[2] The Yucca Mountain facility is currently the only prospective repository in the United States, and has an engineered limit of 120,000 MTHM[1] and a legislative limit of 70,000 MTHM[2]. This capacity is determined by the integrated heat load of the spent fuel, and is approximated by equations 2, 3, and 4.[4]

$$HL = \int_{t_1}^{t_2} q(t)dt \qquad IDHL_l = \frac{\int_0^{1500} q(t)dt}{MTHM} \qquad RC = \frac{1\times10^{10}}{IDHL_l - 1408.9}[MTHM]$$

**Time (t) given in Years*

HL, or heat load, represents the thermal power integrated with respect to time. IDHL, or integrated decay heat load, is equal to the heat load integrated over 1500 years and divided by the MTHM, or metric tons of heavy metal, from the cycle. RC is the theoretical repository capacity of Yucca Mountain based on the thermal modeling done by Li and Yim[4]. Integrating the thermal power output of the spent fuel from SABR over the given time intervals and evaluating the RC equation for the given criteria gives a theoretical repository capacity of 481,600 MTHM. This represents the theoretical capacity of the Yucca Mountain Facility if filled with spent fuel from SABR, and an overall increase in capacity of ~400%. The capacity given here is based on a once-thru cycle in SABR, and with the potential of reprocessing; this capacity represents a modest estimate of overall improvement.

B. Decay Heat Considerations During a LOCA

Figure 2, shown on page 2, displays the behavior of the decay heat curve in the time period immediately following reactor shutdown at 3000 days. Initial power outputs of ~425MW occur for the first 10 minutes, and after 100 minutes the power drops exponentially. This pattern is primarily due to the decay of I135 after shutdown, and with a half life of ~6.5h, the decay curve of I135 dictates the temperature conditions following shutdown. The conditions presented here will be important parameters in the engineering considerations made to prevent a catastrophic failure during accident scenarios such as a LOCA or LOFA (loss of flow accident). These estimates of decay heat will also be a useful tool in any calculations regarding the thermal hydraulics of said scenarios.

V. CONCLUSION

The high burn-up of transuranics achieved with SABR results in a reduction of total decay heat, and by reducing the concentration of actinides the long term thermal power output is significantly reduced. By lowering the overall decay heat of the spent fuel from SABR a couple of conclusions can be drawn. Lower temperatures would mean shorter wet cooling periods before storage, shorter storage periods before repository sealing, higher repository capacities, and improved nuclear waste management. Reduced decay heat is also one of the primary design concerns and advantages of SABR. Lower total decay heat will also provide incentive for future construction.

Further analysis of the spent fuel should give some focus to the buildup of I135 during reactor operation. In these results I135 is the primary contributor to initial decay heat, and if there are any errors in the calculations done for this study regarding I135, the initial decay heat will change significantly. Barring any errors in this investigation, with its short half-life, reducing the initial concentration of I135 in the spent fuel should be a major concern of any future research.

All of the calculations and analysis in this study were done using a once-thru cycle in SABR. No analytical considerations were given to reprocessing of the spent fuel. Any improvements in the cycle would represent an even greater performance of SABR in reduction of spent fuel decay heat. By displaying a frugal estimate of the overall ability of SABR it has been shown that utilization of this transmutation cycle can effectively decrease the decay heat from spent nuclear fuel, and increase the capacity of spent fuel repositories, both of which represent the economic and environmental advantages of SABR.

VI. REFERENCES

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