Heat Load Calculation in CANDU Spent Fuel Pool

Donghwan Park [a*], Youngae Kim [a]

[a]KHNP Central Research Institute, 1312-70 Yuseongdae-Ro, Yuseong-Gu, Daejeon 305-343, Korea
[*]Corresponding author: donghwan.park@khnp.co.kr

1. Introduction

Heat generation values from nuclear reactions inside and outside the core are required to determine the heat loads on the various heat sink circuits.

The heat loads in the spent fuel pool (or spent fuel storage bay, SFP) are one of the most important to be monitored because the discharged fuel in SFP release decay heat continuously. Decay heat is defined as the heat released as a result of radioactive decay in the fuel. For CANDU reactors most of decay heat outside of core comes mainly from the following sources:

- Unstable fission products that decay via alpha, beta, and gamma emission to stable isotopes;
- Unstable actinides that are formed by successive neutron capture reactions in the uranium and plutonium in the fuel.

A number of fundamental approaches are available to estimate decay heat which obtained the ORIGEN code, ANSI/ANS-5.1, and ISO-10645 standards [1][2][3]. Formulations based on empirical measurements and summation calculations of ANSI/ANS-5.1 were used for this study.

In this study the heat load in SFP were calculated to evaluate the coolability the heat for all fuel bundles.

The heat loads assumed to be generated the fuels discharged over the reactor normal operation and full-core fuel bundles discharged from the reactor core after reactor shutdown.

2. Heat Loads Calculation

In this section two types of heat loads are calculated in the SFP. First, the heat load from fuel bundle discharged over the reactor normal operation. Second, heat loads from full-core fuel bundles discharged from reactor core after reactor shutdown over 5 channels per day. The reactor operation and conditions for discharged fuel in SFP to estimate heat loads shown in Table I.

Table I: Conditions for Discharged Fuel in SFP

No. of Fuel Bundles	:	Reactor Core : 4560 SFP : 28,170
Reactor Cooling Time after Shutdown (Days)	:	462 Days (After Shutdown)
Reactor Capacity(%)	:	90%
Average Burnup (MWh/kgU)	:	Reactor Core : 92.56 SFP : 166.18
Capacity of Heat Exchanger in SFP	:	3.0 MWth

2.1 Heat Loads from Fuel Bundles Discharged

The heat load from the discharged fuels in the SFP was found using the expression [1].

$$F(t,T) = \sum_{i=1}^{23} \frac{\alpha_i}{\lambda_i} e^{-\lambda_i t} \left(1 - e^{-\lambda_i t}\right) \quad (1)$$

where F(t,T) is the decay power at t seconds after an operating period of T seconds at a constant fission rate(MeV/s per fission/s). α_i and λ_i are values for thermal fission of U-235[4].

The decay heat from the fuel bundles with decay time in the interval, t to t+dt is as follows

$$\mathrm{dQ} = D_r P F(t,T) \Delta t \quad (2)$$

where dQ is the decay power from bundles(MeV/s), D_r is the rate of bundles discharged(bundles/s), $\Delta t$is the interval of decay time at t(s), F(t,T) is the decay power(MeV/s per fission/s), and P is the average power of the bundle(fissions/s).

The total decay heat(Q) in the SFP will be

$$Q = P D_r \sum_{n=1}^{n=t'} \left[\sum_{i=1}^{23} \frac{\alpha_i}{\lambda_i} e^{-\lambda_i (n-0.95)\Delta t} \left(1 - e^{-\lambda_i T}\right)\right] \quad (3)$$

where D_r is 14.4 bundles/day at 90% capacity factor, t´ is the 2418 days(5.36 years + 462 days). This is plotted in Fig 1. The heat load from the 28,170 irradiated fuel bundles in the SFP full-core discharged was about 1.586MWth just after last fuel bundle discharged. After 462 days cooling time, the heat decayed to 0.2887MWth.

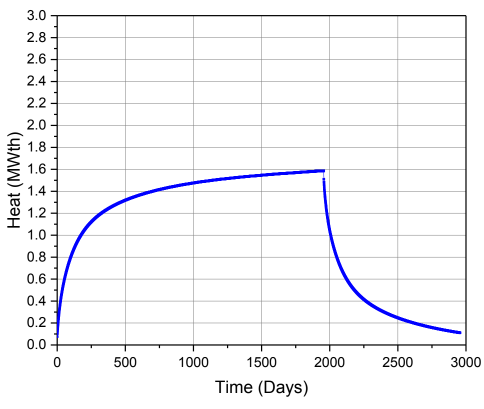


Fig. 1 SFP Heat Loads from Discharged Fuel Accumulated over 5.36 Years + 1000 Cooling Days

2.2 Heat Loads from Full-Core Fuels Discharged

Based on Equation (1), (2), (3), the heat load in the SFP from the full-core discharge can be estimated from F(t,T). At any decay time t, the heat load Q_c is

$$Q_c = NPF(t, T') \quad (4)$$

where N is the number of the fuel bundles discharged from the core, P is the average power of the bundle (fissions/s) at time t, and F(t,T´) is the decay power of the bundles (MeV/s per fission/s).

The decay heat for full-core fuel bundles was evaluated at one day interval as shown in Fig 2.

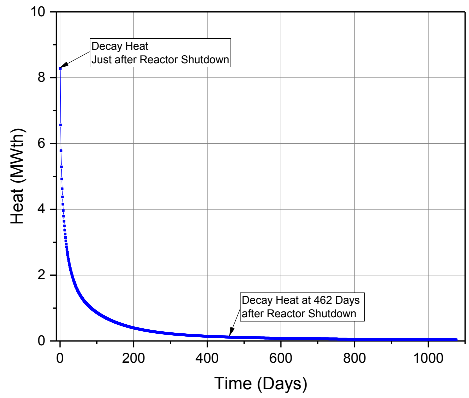


Fig. 2 Decay Heat for Full-Core Fuel Bundles

The expression for or full-core fuel bundles was evaluated at one day interval as shown in Fig 3. It was considered 462 days reactor cooling time after shutdown. The heat load from full-core discharged over 76 days was about 0.0933MWth.

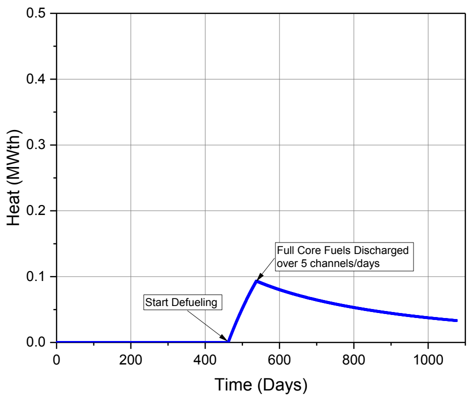
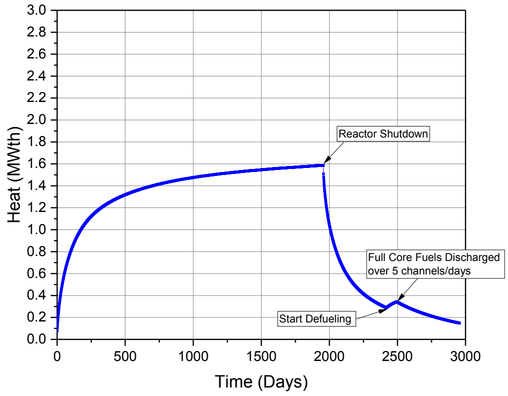


Fig. 3 SFP Heat Loads from Discharged Fuel Accumulated over Full-Core Discharge

The total heat loads from fuel bundle discharged over the reactor normal operation and from the full-core fuel bundles discharged from reactor core after reactor shutdown over 76 days was combined shown in Fig 4.

The maximum heat load in SFP during defueling over 76 days was 0.34MWth.



3. Conclusions

To evaluate the robustness of cooling system of SFP before all fuel bundles discharged from the core. The heat load was calculated using the formulations based on empirical measurements and summation calculations of ANSI/ANS-5.1. The heat loads from fuel bundle discharged over the reactor normal operation and from full-core fuel bundles discharged from reactor core after reactor shutdown over 5 channels per day was evaluated.

The maximum heat load in SFP during defueling over 76 days was 0.34MWth. It is much lower than 3.0MWth SFP heat exchangers. The coolability for the irradiated fuels in SFP and the discharged full-core fuels from the core could be cooled during defueling and after.

REFERENCES

[1] I.C. Gauld, et al, "ORIGEN-S" Volume II, Book 1, ORNL/TM-2005/39, Version 5.1, Vols. I–III, November 2006.
[2] American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1-1979, American Nuclear Society, Lagrange Park, Illinois, 1979.
[3] ISO 10645:1992(E) "Nuclear Energy-Light Water Reactors Calculation of the Decay Heat Power in Nuclear Fuels" (1992).
[4] 86-03320-DM-001, "Shield Design Manual", AECL, June 1995.