Development of Dynamic Environmental Effect Calculation Model

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1. Introduction

The spent fuel (SF) accumulation has become a major issue for sustainable operation of nuclear power plants. If a once-through (OT) fuel cycle is selected, the SF will be disposed into the repository. Otherwise, in case of fast reactor (FR) or reuse cycle, the SF will be reprocessed and the high level waste (HLW) will be disposed. The short-term, long-term decay heat, and radioactivity are considered as main environmental parameters of the SF and HLW. In this study, the dynamic calculation models for radioactivity, short-term decay heat, and long-term heat load of the SF are developed and incorporated into the DANESS [1] code.

2. Dynamic Modeling

2.1 Short-term Decay Heat Model

When the isotopic concentration is calculated, then the radioactivity, instant decay heat, and long-term heat load can be calculated.

The short-term or instant decay heat can be calculated by:

SDH(Iso) = DHF(Iso) * IC(Fuels, Iso) ---------- (1)

where, IC(Fuels,Iso): Isotope concentration
SDH(Iso): short-term decay heat [w]
DHF(Iso): decay heat factor of isotope [w/g]

Also, the radioactivity is calculated by:

ACT(Iso) = SACT(Iso) * IC(Fuels, Iso) ---------- (2)

where, ACT(Iso): activity of isotope [Ci]
SACT(Iso): specific activity of isotope [Ci/g]

2.2 Long-term Heat Load Model

The long-term heat is calculated through the integration of the decay heat between 100 yrs and 1500 yrs after disposal [2].

The heat load factors are calculated by the following equation:

LTH[Iso] = HLF[Iso]*ID[Iso] ---------- (3)

where LTH[Iso]: Heat load [W-yr]
HLF[Iso]: Integrated heat load factor [W-yr/g]
ID[Iso]: Isotope disposing [g]

The *HLF* can be calculated by

$HLF(Iso) = DH_m(Iso)*DHF_m(Iso)+DH_d(Iso)*DHF_d(Iso)$ -- (4)

where $DH_m(Iso)$:decay heat of mother isotope[W/g],
$DHF_m(Iso)$:decay heat factor of mother isotope[yr]
$DH_d(Iso)$:decay heat of daughter isotope[W/g],
$DHF_d(Iso)$:decay heat factor of daughter isotope[yr]

The $DHF_m(Iso)$ and $DHF_d(Iso)$ can be calculated by

$$DHF_m = \frac{1}{\lambda_m}\left[e^{-\frac{t_1}{\lambda_m}} - e^{-\frac{t_2}{\lambda_m}}\right] \quad (5)$$

$$DHF_d = \frac{\lambda_m}{\lambda_d - \lambda_m}[DHF_m - DHF_d] \quad (6)$$

where λ_m=decay constant of mother isotope [1/yr]
λ_d=decay constant of daughter isotope [1/yr]
t_1=starting time of integration [yr]
t_2=termination time of integration [yr].

3. Analysis of Once-Through Cycle

The OT cycle was modeled by the "National Energy Basic Plan" [3]. In the OT cycle, the SF is cooled at reactor storage pool for 10 years, and then it is stored for 50 years in the interim storage. As shown in Fig. 1 the total SF inventory continuously increases with time and becomes ~186500 t 2150. The SF in storage pool remains almost constant value of 14000 t, while the amount of SF in the interim storage increases and will be ~101000 t. From 2060, the SF will be disposed into the repository and it will become ~72000 t in 2150.

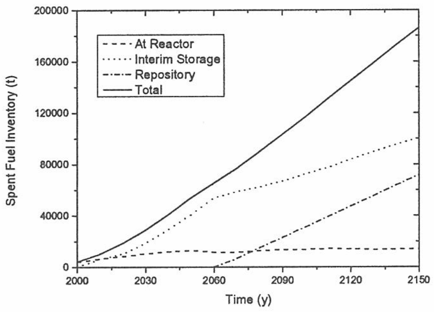

Fig. 1. Spent Fuel Inventory in Facility

The short-term decay heat (STDH) and radioactivity are calculated with the reference year of 2100. Fig. 2 shows short-term decay heat of Cs-137 and Sr-90 isotopes. The initial STDH are 2.27×10^6 W and 1.84×10^6 W, respectively, and they decrease to ~1/10 of initial values after 100 yrs.

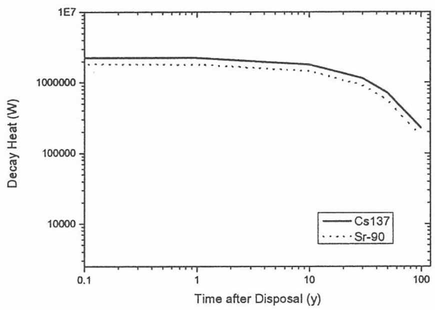

Fig. 2. Short-term Decay Heat of Fission Products

As shown in Fig. 3, the radioactivity of LLFP maintains constant value of 1.46×10^4 Ci and 4.51×10^5 Ci, respectively, during 100 yrs. The radioactivity of Cs-137, Sr-90, and Kr-85 decrease to ~1/600, ~1/10, and ~1/10 of initial value, respectively.

The LTH of Am isotope with cooling time is shown in Fig. 4. The LTH of Am-241 after 100 yrs disposal will be 1700 MW-y which is the highest value among the LTH of the actinides. The LTH of Pu-241 is ~1/2 of Am-241.

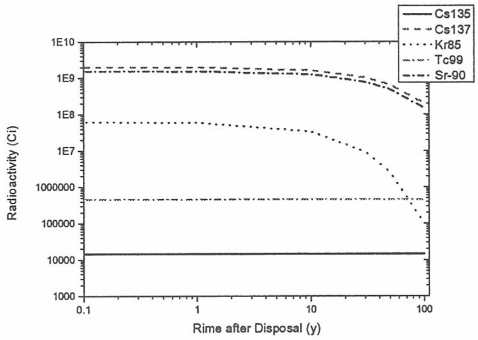

Fig. 3. Radioactivity of Fission Products

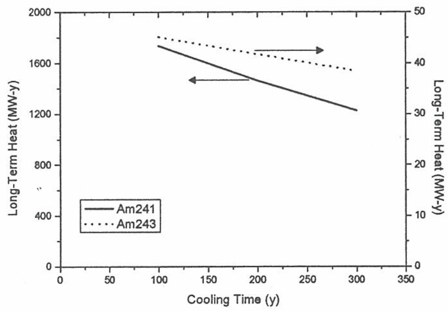

Fig. 4. Long-term Heat Load of Am Isotopes

4. Summary

The dynamic environmental effect evaluation model for spent nuclear fuel has been developed through short-term decay heat model, short-term radioactivity model, and long-term heat load model. From the analysis results, it is known that the newly developed method can be easily applied to evaluate the environmental effect of the spent fuel.

5. References

[1] L. V. D. Durpel et al., "DANESS- Dynamic Analysis of Nuclear Energy System Strategies," Global 2003, New Orleans, November 16-20, (2003).

[2] R. Wigeland et al., "Repository Impact of LWR MOX and Fast Reactor Recycling Options," Global 2003, New Orleans, November 16-20, (2003).

[3] "National Energy Basic," Ministry of Knowledge and Economy, (2008).