Requests from Use Experience of ORIGEN Code
-Activity of the working group on evaluation of nuclide generation and depletion-

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A questionnaire survey was carried out through the committee members of the working group on evaluation of nuclide generation and depletion about the demand accuracy of the ORIGEN code which is used widely in various fields of design analysis and evaluation. WG committee asked each organization's ORIGEN user, and obtained the reply from various fields.

1. Introduction

In order to improve accuracy of nuclear data, requests of evaluation accuracy of the ORIGEN code have been discussed in the working group on evaluation of nuclide generation and depletion (WG)*. A questionnaire survey was carried out through the committee members of the WG about the demand accuracy of the ORIGEN code which is used widely in various fields of design analysis and evaluation. WG committee asked each organization's ORIGEN user, and obtained the reply. For this reason, it is thought that the opinion of each organization's business person in charge was able to be collected. The replies are obtained for following fields.

(1) Spent fuel cask (including spent fuel storage facilities)
(2) Re-processing facility
(3) Decommissioning, and waste treatment and disposal
(4) Plant decay heat analysis (accident analysis)
(5) Plant equipment design
(6) Burn-up credit

2. Result of the questionnaire (see Table 1)

(1) Spent fuel cask (including spent fuel storage facilities)

There are the following safety design criteria and the inspection standard concerning the demand accuracy of ORIGEN calculation about the spent fuel cask [2];

- The rate of the surface dose equivalent [< 2 mSv/h]

*: This paper is based on chapter 6 of the WG report: JAERI-Research 2004-025 [1]

- The rate of the dose equivalent at 1m distance [< 100 μSv/h]
- In any cases, criticality [< 0.95]

The restriction temperature of a spent fuel cladding is defined with the amount of accumulation creep of 1%. These restriction temperature are about 360 ^{0}C (PWR) and 380 ^{0}C (BWR) as initial temperature.
The questionnaire results of demand accuracy are:

- Gamma-ray source and a spectrum: 5%.
- Neutron source: 5% and 20% (there are two replies)
- Decay heat: 10% (a few ^{0}C in the surface of cask)

The surface dose equivalent of a cask is calculated with radiation source of ORIGEN calculation and transportation calculation code in which a spent fuel cask is modeled with one-dimensional or two-dimensional. Neutron effective multiplication factor (criticality) is usually calculated with the Monte Carlo calculation codes of MCNP [3], KENO [4], etc. Moreover, the restriction temperature of a spent fuel cladding is evaluated with thermal conductivity calculation of general finite element programs, such as ABAQUS [5], based on the decay heat value by ORIGEN-2 calculation.

There are some evaluation errors in transportation calculation, thermal conductivity calculation, etc. However margin in safety side evaluation model and assumptions are considered to be larger than these evaluation errors such as setting higher burn-up, shorter cooling period of spent fuel than anticipated values, and safety side modeling (quality of the material, geometry, etc.) of calculations.

In case of spent fuel transport cask of FBR, the accuracy of less than 10% is required in decay heat evaluation. This request of accuracy is coming from minimum temperature margin of 18 ^{0}C. The present calculation value is less than design conditions enough, and there are about 20 times margin at the surface, about 7 times at a 1m point from the cask surface.

Decay heat accuracy evaluation is necessary for 2~3 year in transportation of a LWR spent fuel, 10~50 years for spent fuel storage. Accuracy of 5% is assumed to the decay heat of an ORIGEN-2 calculation value. This is decided with the comparison result of the heat measured value and ORIGEN-2 calculation value. Mainly, Cs137 is decay heat source of spent fuel cooled for more than 10 years. From a viewpoint of neutron shielding, Cm242 (2~3 years) and Cm244 (> 4 years) are important, and 5% is required also for the prediction accuracy.

(2) Re-processing facility

ORIGEN-2 is used for radiation source evaluation of a re-processing facility. The calculation accuracy of ORIGEN-2 is not set up on radiation source, but 50% of a standard dose is used as a safety margin of a radiation shielding design. Therefore order of 10% accuracy in ORIGEN-2 can be accepted within this safety margin. Accuracy of decay heat evaluation should be within AESJ decay heat standard (1990) [6]. Moreover, for environmental radioactivity safety evaluation of FBR spent fuel Re-processing facility, inventories of ^{3}H, ^{14}C, ^{85}Kr, ^{129}I are important. Especially, the amount of ^{14}C needs about 10% of accuracy, which is generation by the reaction of ^{17}O and ^{14}N with fast neutron.

(3) Decommissioning, and waste treatment and disposal

ORIGEN-2 is used for evaluation of activation in whole PWR and contamination source for system equipments. In these evaluations, accuracy is estimated at about 50%, which is mainly error of neutron flux evaluation. However error of nuclear data is assumed to be less than about 5%. ORIGEN-2 is used with 1 group cross-sections from the JENDL3.2 and neutron fluxes which are evaluated in about 30 areas, such as a loop room, an operation floor and so on. Original library of ORIGEN-2 is used for a reactor core.

(4) Plant decay heat analysis (accident analysis)

The accuracy demand of decay heat is 20% for form reactor shut down to 30 days. Since U-239 (β), Np-239 (β), Pu-238 (α), Cm-242 (α), Cm-244 (α), and Am-241 (β) are main heat sources, the inventories of these nuclides should be predicts within 20% of accuracy.

(5) Plant equipment design

In evaluation of decay heat system and a SFP cooling system, decay heat of actinides accuracy is 20%. Therefore 20% of prediction accuracy of main actinides inventories is required. Decay heat of FP is evaluated with AESJ decay heat standard.

(6) Burn-up credit: To introduce burn-up credit, the accuracy of less than 3% δk (possibly within 1% δk) is expected.

3. Evaluation of the demand accuracy of ORIGEN-2

Requirements of ORIGEN2 accuracy are 5~10% in general, it became 0.5% of demand accuracy. WG discussed this number. For example, spent fuel decay heat of a highest burn-up of 55 MWd/kg and an average burn-up of 48 MWd/kg differs more than 10%. Cooling time will also decreases decay heat by 5~10% in one year. Requirements of ORIGEN2 accuracy is same order of these uncertainty of evaluation. For this reason, it is interpreted as that requirement of ORIGEN2 accuracy of 5~10% is coming from design margin of various facilities. And since concepts of design margin are different in each field/facilities, requirements of ORIGEN2 accuracy differ in each field/facilities.

It should be noticed that present replies of the questionnaire include two types of answer based on present reasonable design margin and desirable design margin request for future.

The amount prediction accuracy of generation of Cm242 and Cm244 is important, and Cs137 is important from a thermal viewpoint. As for the amount of generation of these nuclides, about 5 - 10% of accuracy is demanded. About actinides decay heat, the accuracy of a main chain nuclide is demanded in 20% of accuracy. Demand accuracy of ORIGEN-2 can be reflected to nuclear core data through the verification work of PIE data (Fig. 1).

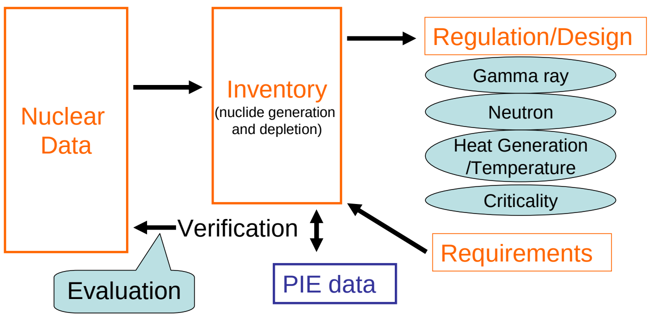

Fig. 1 Flow of Evaluation

The paper of Ando and Ohkawach [7] concludes that main U, Pu nuclides have enough (about 5%) accuracy, but TRUs are not so good. There is not enough accuracy of ORIGEN calculation in the present condition for having satisfied the demand accuracy of a questionnaire. However, the request of the industrial world which became clear as a result of the questionnaire is accepted with sincerity, and it is thought important to be reflected in future activity.

4. Conclusion

Questionnaire surveys were carried out about the demand accuracy of the ORIGEN code and obtained various fields of Requirements of ORIGEN2 accuracy. The questionnaire result had the reply relevant to a spent fuel cask, a storage facilities, a re-processing plant, a burn-up monitor, the criticality monitor, decommissioning ,waste processing and disposal, decay heat evaluation, the equipment design, a burn-up credit and others. These demand accuracy show request to cross-section area evaluation. For example, the following measures are required.

- Continue the verification work of the evaluation accuracy of nuclide composition in the analysis of experiment data, such as nuclide composition.
- Presume accuracy errors of ORIGEN calculation and consider relation with demand accuracy from sensitivity analysis and covariance data.
- Extract nuclide and nuclear reaction which need improvement of evaluation accuracy and covariance data, etc.

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Table 1 (1/2) Result of the questionnaire about "the demand accuracy of ORIGEN calculation"

Items	Demand accuracy	Notes and comments
Spent fuel cask (metal cask for transportation) <Reply 1>	- Gamma ray source and a spectrum: 5% - Neutron source: 5%	Cask type: BWR 69 assemblies (PWR/BWR:UO_2 &MOX)
Same as above <Reply 2>	- Decay heat : 10% (a few ^{0}C in the surface of cask), - Gamma ray source and a spectrum: 5% (5% of surface dose), - Neutron source : 20% (20% of surface dose)	Cask type: MU The amount of gamma ray source and a spectrum influence gamma ray shielding evaluation by 100%.
FBR spent fuel cask (metal cask for transportation)	- Decay heat: a design value is about 6 times of the calculation value evaluated to the safety side. (The calculation value of 91 ^{0}C in fuel cladding, design value of 650 ^{0}C) however, temperature evaluation margin is about 30% at a fin tip. - Gamma ray source and a spectrum: (contribution of 0.4~0.9MeV is important at about 80%) - Neutron source: Cm242 is important (about 85% of the whole)	Object: Joyo Fuel Type: fuel basket for reactor core fuel (8 assemblies), and blanket fuel (11 assemblies). The present calculation value is less than design conditions enough, and there are about 20 times margin at the surface, about 10 times at a 1m point from the cask surface.
Spent fuel pool (including a spent fuel acceptance pool)	- Decay heat: 5% (BWR-UO_2 45 GWd/t), 10% (BWR/PWR:MOX), - Gamma ray source and spectrum: 10% - Neutron source: no problem since it is shielded enough.	Type of spent fuel: BWR-UO_2 45GWd/t, BWR/PWR-MOX
Spent fuel storage facility	- Gamma ray source and a spectrum: 5% (since it is based on a cask surface dose, it is the same as that of a cask. spectrum is important) - Neutron source: 5%	Type of storage facility: A metal cask, BWR
Re-processing facility	- Decay heat: decay heat evaluation curve is enough. - Safety margin of 1.2 is used in a RETF design, multiplying the calculation value of ORIGEN2. - Amount of generation of ^{3}H and ^{14}C, ^{85}Kr, and ^{129}I.in FBR: about 10%	
Burn-up monitor <Reply 1>	- Gamma ray source and a spectrum: 1% (for the important nuclide Cs 137: 0.5%), - Neutron source: 3% (the detection method: FC, demand accuracy: 1%)	Gamma ray source influences the amount of evaluations directly. The accuracy of neutron detection influences a burn-up monitor by about 1/3 in UO^2 and about 1/2 in MOX.
Same as above <Reply 2>	- The important nuclide of neutron measurement : Cm244, (alpha, n) and spontaneous fission data. - Gamma ray measurement :P r-144, Mn-54, Rh-106, Co-60, Eu-154, Cs-134, and Cs-137 (nuclear fission yield is also important in addition to cross-section data)	Considering the generation process of Cm244, the neutron capture cross section of Am243 is important.

Table 1 (2/2) Result of the questionnaire about "the demand accuracy of ORIGEN calculation"

Items	Demand accuracy	Notes and comments
Criticality monitor	- Neutron source: 5%	
Radioactivity concentration of decommissioning <Reply 1>	- Nuclides to be evaluated: about 57 nuclides. - Co-60: about 5% for dose evaluation for the public and worker.	For all of decommissioning plant, such as a Tokai gas plant and BWR/PWR, ORIGEN2 is utilized for inventory evaluation, radiation dose evaluation of worker, de-contamination, mechanical cutting, and radioactive waste processing, etc.
Same as above <Reply 2>	- Nuclides to be evaluated and demand accuracy: Co-60, Cs-134, Eu-154, Eu155, about 10% of accuracy. - For radiation dose evaluation: Co-60 and Cs-134 (10%),. - For waste amount evaluation: Co-60, and H3 (10%). - Gamma ray source and spectrum: 10% (for inner strictures of PRV)	Evaluation of Co-60 influences radiation dose evaluation accuracy by 100%.
Waste treatment and disposal	- For the safety evaluation of under-the-ground disposal of L1 waste generated from BWR. (although it changes with wastes for examination.). Examples: H-3, C-14, Cl-36, Ca-41, Fe- 55, Co-60, Ni-59, Ni-63, Se-79, Sr- 90, Zr-93, Nb-94, Mo-93, Tc-99, Sn-121m, I-129, Cs-137, Hf-182, Np-237, Pu-238, Pu-239, Pu- 240, Am-241, Cm-242, Cm-243, Cm-244, etc. (containing a long half-life nuclide) - I-129, TRU(for public in-take): 5% of evaluation accuracy - C-14: 5% for public in-take (high beta/gamma waste) - Cl-36: 5% for public in-take (high beta/gamma waste)	The ORIGEN code is utilized for activation evaluation of low level radioactive waste (L1 waste etc.) Evaluation accuracy influences scale of disposal facility (I-129 TRU influences by 90%).
Burn-up credit	- Since critical safe evaluation will be performed by spent fuel composition, the amount of U235, the total amount and composition of Pu, become important. - Evaluation accuracy: 3% δk in reactivity. (nuclide composition is also requested. Same for MOX fuel)	