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ASOURCE: Source Term Analysis Tool for Advanced Fuel Cycle

Dong-Keun Cho*, DongHak Kook, Jongwon Choi, Heui-Joo Choi, JongTae Jeong
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon, Republic of Korea 305-353
**Corresponding author: dkcho@kaeri.re.kr*

1. Introduction

In 2007, the *3rd Comprehensive Nuclear Energy Promotion Plan*, passed at the 254th meeting of the Atomic Energy Commission, was announced as an R&D action plan for the development of an advanced fuel cycle adopting a sodium-cooled fast reactor (SFR) in connection with a pyroprocess for a sustainable stable energy supply and a reduction in the amount of spent fuel (SF). It is expected that this fuel cycle can greatly reduce the SF inventory through a recycling process in which transuranics (TRU) and long-lived nuclides are burned in the SFR and cesium and strontium are disposed of after sufficient interim storage.

For the success of the R&D plan, there are several issues related to the source term analysis. These are related with the following: (a) generation of inflow and outflow source terms of mixed SF in each process for the design of the pyroprocess facility, (b) source terms of mixed radwaste in a canister for the design of storage and disposal systems, (c) overall inventory estimation for TRU and long-lived nuclides for the design of the SFR, and (d) best estimate source terms for the practical design of the interim storage facility of SFs.

A source term evaluation for a SF or radwaste with a single irradiation profile can be easily accomplished with the conventional computation tool. However, source term assessment for a batch of SFs or a mixture of radwastes generated from SFs with different irradiation profiles—a task that is essential to support the aforementioned activities—is not possible with the conventional tool. Therefore, hybrid computing program for source term analysis to support the advanced fuel cycle was developed.

2. Explanation on Developed Tool

2.1 Functional Module

It was not possible to develop an entire program due to lack of manpower and engineering time. Therefore, ORIGEN-S [1] in SCALE code package was chosen as a depletion and decay chain solver. And, a hybrid method that adopts many functional modules to accommodate a flexible user-defined job was proposed.

Screening: The major function of this module is to provide information needed for the depletion and decay calculation by searching a SF database. The database includes physical characteristics such as assembly design, an array, ^{235}U enrichment, uranium loading, and information on structural materials. It also has irradiation characteristics such as the loading date, discharge burnup, discharge date, and the residence period of a fuel in a core, and storage characteristics such as the cooling time at a storage facility. These data are recorded for each fuel assembly identification (ID).

DeplDec: The role of this module is to irradiate and decay SF for specified irradiation and cooling time considering appropriate physics parameters. The main function of this module is to supply parameters such as the specific power, effective full power day, the number of cycles, initial loading of uranium, and index designating cross-section library, which are needed for ORIGEN-S to solve Eq. (1).

$$\frac{dN_i}{dt} = \sum_j \delta_{ij}\lambda_j N_j + \sum_k f_{ik}\sigma_k\phi N_k - (\lambda_i + \sigma_i\phi)N_i \qquad (1)$$

where σ_i = the absorption cross section of nuclide *i*,
δ_{ij} = the fraction of radioactive decay from nuclide *j* to *i*,
f_{ik} = the fraction of neutron absorption by nuclide *k* and transmuted to isotope *i*; other terms have conventional meanings.

After obtaining the parameters, this module provides input for ORIGEN-S, runs ORIGEN-S, and calculates source terms as a function of time. Because this module has a pre-generated cross-section library for each fuel design for a domestic fuel, it makes ORIGEN-S choose the appropriate library by giving an indicator nominating the specific fuel design.

MetalRun: The function of this module is to performa irradiation and decay calculation for structural component of SF. The neutron flux for the activation calculation of the each component is obtained by multiplying the flux scaling factor by the average neutron flux of the fuel.

DecRes: The function of this module is to carry out decay only calculation for SF or radwaste through a restart calculation with pre-calculated isotopic composition. It makes input for ORIGEN-S to restart the decay calculation. It supplies information to obtain the composition for the restart calculation and additional decay period, runs ORIGEN-S, and calculates source terms as a function of decay time.

ReproRun: The role of this module is to separate radwastes generated from the pyroprocess by running ORIGEN-S, considering the removal ratio of nuclide *i* for each unit process specified in the user-interface. It has flexibility to address alteration of the number of unit processes and material flows to flexibly accommodate technology development. It can estimate residual source terms of each unit process needed for the design of the facility and source terms of radwastes discharged from each process.

Batch: This module was introduced to calculate mixture composition when many kinds of SFs are processed or combined at the same time *t*. The mixture composition of nuclides is calculated through multiplication of the processing fraction by the mass of the nuclide, as shown in Eq. (3).

$$N_i = \sum_j \omega^j N_i^j \qquad (3)$$

where ω^j and N_i^j represent the mixing ratio of the SF *j* and the mass of nuclide *i* originated from the SF *j*, respectively.

2.2 Analysis Sequence

Developed program named ASOURCE has three analysis sequences such as *Fuel Waste Characterization Sequence*, *Metal Waste Characterization Sequence*, and *Grand Source Term Characterization Sequence*. Each sequence has formulated scheme, however, it has also wide flexibility to accommodate a variety of problem.

It needs to be explained on the basis of example. Figure 1 shows example of *Fuel Waste Characterization Sequence*.

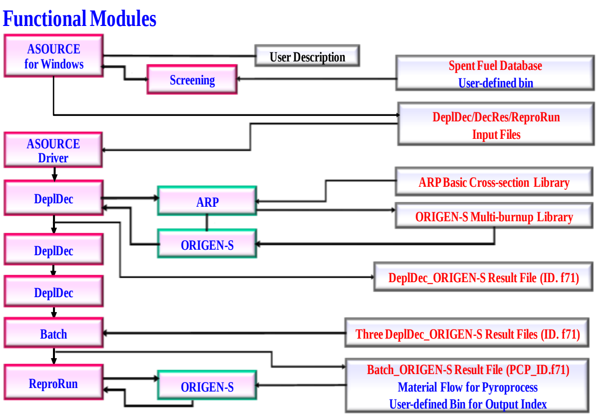

Fig. 1. Example of *Fuel Waste Characterization Sequence*

The concept and structure of the *Fuel Waste Characterization Sequence* is as follow; If a user describes information through *ASOURCE Window* to define fuel waste characterization problem, *Screening* module extracts data needed to make input for each module such as *DeplDec*, *Batch*, and *ReproRun*, modules. After completion of ASOURCE input, ASORUCE deriver is activated to run each functional module sequentially. Firstly, *DeplDec* module is initiated to estimate isotopic compositions at the beginning of pyroprocess. This module has the capability to deplete and decay single fuel assembly. Therefore, if three fuel assemblies need to be analyzed, this module should be activated three times. Initial composition of fuel, indicator of cross section library, and irradiation and decay profile of the spent fuel are main input data for this module. This module uses ORIGEN-S in the depletion calculation with problem-dependent cross section library. After entire depletion and decay calculation for user-defined SFs, *Batch* is run to calculate mixed composition, considering user-defined mixing ratio. Finally, *Reprorun* is initiated to calculate source terms of each waste stream considering user-defined material balance, with the isotopic composition of mixed fuel that is output of *Batch* module.

The other two sequences has same concept and formulated scheme, however, those have also wide flexibility to accommodate a variety of problem.

3. Superiority of ASOURCE to Other Codes

While the conventional codes is optimized to estimate source terms of SF with single irradiation and decay profile, ASOURCE has the capability to perform a source term assessment of a bath of SFs taking into account respective physical, irradiation, and aging characteristics of each spent fuel.

Through several pseudo problems such as pyroprocessing problem, axially heterogeneous burnup problem, domestic TRU inventory estimation problem, and average decay heat estimation problem for batch of SFs, it was confirmed that the ASOURCE can satisfy source term assessment essential to achieve an advanced fuel cycle by utilizing several functional modules sequentially.

The ASOURCE was also verified against ORIGEN-ARP for completeness.

4. Conclusions

When overall source term representing a variety of spent fuels or radwastes with different irradiation and decay profile is estimated, there are some restrictions in conventional analysis tools. A hybrid computing program that employs several functional modules was developed to support source term analysis in R&D action plan on an advanced fuel cycle. It is expected that it will be very useful to perform a variety of source term analysis to achieve the R&D action plan.

ACKNOWLEDGEMENTS

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