Nuclear Data Needs for Advanced Reactors

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A wide spectrum of advanced reactor concepts are being envisaged around the world. The Generation IV reactors selected by International Forum in the early 2000's cover 6 new categories of advanced reactors. Apart from the Gen-VI reactors, introduction of Inert Matrix Fuel in order to burn plutonium effectively is extensively studied. These new reactor concepts and new materials used therein create new needs for nuclear data.

1. Introduction

In the course of time, scientific and technology fields which are in keen needs of the nuclear data are expanding from conventional reactor applications to astronomy, electronics, particle accelerators, ADS and so on. Accordingly the required data spread from the neutron data less than, for instance, 20MeV to much higher energy up to several GeV including the charged particle and the photon reaction data. In this report, however, we confine the survey within the advanced fission-reactor applications. When we consider about the future advanced reactors, it seems appropriate to cite, first of all, the Generation IV reactors, which are expected to be deployed in 2030's. They are ; 1) Supercritical Water-cooled Reactor (SCWR), 2) Sodium-cooled Fast Reactor (SFR), 3) Lead-cooled Fast Reactor (LFR), 4) Gas-cooled Fast Reactor (GFR), 5) Very High Temperature Reactor (VHTR), and Molten Salt Reactor (MSR). In order to discuss the nuclear data needs for analysis and design of these reactors, Workshop on Nuclear Data Needs for Generation-IV System was held on 5 ~ 7 April 2005 in Antwerp [1]. Discussion there can be summarized from two view-points, namely, the quality and the variety of nuclear data. As for the quality, most speakers stressed the urgent necessity for the covariance matrices. As for the variety, the needs come from the non-conventional materials introduced into the core of the Gen-IV reactors. On the other hand, the concepts of the Inert Matrix Fuels under study worl-wide can be realized by introducing exotic materials, in the sense of neutronics, into their cores. In this paper we preview the nuclear data which become necessary in feasibility study and design of those advanced fission reactors.

In advance of the Antwerp Workshop, another workshop on Gen-IV nuclear data was also held in the US domestically. The conclusions and the recommendations from this US/CSEWG Workshop were summarized by Taiwo and Khalil [2] at the begining of Antwerp Workshop.

II. Covariance Data

Aliberti *et al.* [3] made a sensitivity analysis and evaluated the present uncertainty in various reactor characteristics ranging from k_{eff} to decay heat. They used two independent sets of covariance matrices. One is an ANL "home made" covariance set and another is a set available from the NEA Data Bank, which are the selection from JENDL3.3, IRDF-2002 ENDF/B-V, -VI and JEFF3. The systems they studied are SFR, LFR, GER, VHTR and, in addition, EFR (European Fast Reactor). Roughly speaking, the inclusion of the off-diagonal elements of the covariance matrices increases the estimated uncertainty by 60 ~ 70% though only the energy-energy correlations are taken into account. Hagura *et al.,* concluded that 10 ~ 30% increase in the uncertainty comes from the inclusion of the energy correlation in their error analysis of the actinide decay heat from spent LWR fuels [4].

Apart from the off-diagonal elements, it should be kept in mind that the standard deviation, the square roots of the diagonal elements of the covariance matrix, varies drastically from set to set. Taking fission as an example, SD differs by factor of more than ten in 10 ~ 100 eV for ^{241}Pu, and 50 ~ 100 % for ^{241}Am less than 100 keV. It is clear from these examples that consistent and reasonable uncertainty for each nuclide should be given prior to the off-diagonal elements. The importance of covariance data, however, does never diminish as many authors discuss in Ref. [1].

III. Gen-IV Reactors

As any fully exotic materials are not introduced in the Generation-IV reactors from the neutronic point of view, the data needs may not change drastically from the case of conventional reactors. Although the significant accumulation of minor actinides (MA) will result from the increase of extended burnup in advanced reactors, MA data do not always play any decisive role with some exceptions according to the analysis made in Ref.[3]. On the other hand the data for Pu-isotopes become more and more important. For example, the dominant path leading to MA nuclides runs through the neutron capture in ^{240}Pu and therefore the uncertainty of the ^{240}Pu(n, γ) cross section must be diminished. The standard deviation in JENDL-3.3 for this reaction is less than 2 %, except the energy range from 10 to 20 eV where the SD reaches 10%. This might be too small when we consider the fact that even the ^{235}U resonance capture is now to be revisited as one of the activities of WPEC[5]. In reality Rimpault stressed the present inconsistency in ^{240}Pu(n, γ) between JEF2.2 and new evaluation, and further its large impact on the CAPRA PuN core design [6].

Importance of the nuclear data for non-conventional materials were stressed in the GEN-IV nuclear data workshop [1] as well as the enhanced importance of the Pu-isotopes. These new materials are lead and bismuth in LFR, silicon and zirconium in GFR, Th and ^{233}U in MSR and so on. Especially the inelastic scattering cross section for Pb attracted attention in the Antwerp Workshop.

III. Actinide Burner and Inert Matrix Fuel

In order to manage the surplus of the world inventory of plutonium, the inert matrix fuel (IMF) is studied world wide [7]. In addition to this, U-free fuels are also envisaged in transmuting the minor actinides [8]. Table I taken from Ref. [7] shows the candidates of IMF materials. As seen here, magnesium, aluminum, zirconium, yttrium are among the well-suited elements for IMF and the nuclear data for these elements will be required along with the progress of the IMF study.

IV. Concluding remarks

Nuclear data needs do not change fundamentally by placing advanced reactors in the scope, although non-conventional materials such as lead or silicon will be introduced to the core. We have already the nuclear data for most of these materials in the major data libraries. Much more reliability, however, will surely be required for these materials along with the development of the design study. On the other hand, the persistent needs for qualified nuclear data for actinides, especially Pu isotopes, will surely continue because the highly extended burnup is anticipated in the advanced reactors.

Table I Example of Inert Matrix Fuel Materials (taken from ref. 7)

Inert Matrix Type	Inert Matrix Formula
Elements	C, Mg, Al, Si, Cr, V, Zr, Mo, W
Inter-metals	AlSi, AlZr, ZrSi
Alloys	stainless steel, zirconium allys
Carbides	$^{11}B_4C$, SiC, TiC, ZrC
Nitride	AlN, TiN, ZrN, CeN
Binary oxides	MgO, Y_2O_3, ZrO_2, CeO_2
Ternary oxisides	$MgAl_2O_4$, $Y_3Al_5O_{12}$, $ZrSiO_4$
Oxide solid solutions	$Y_yZr_{1-y}O_{2-y/2}$, $Mg_{(1-x)}Al_{(2+x)}O_{(4-x)}$

Referenes

[1] P. Rullhusen (ed.) "*Nuclear Data Needs For Generation IV Nuclear Energy Systems*." Proceedings of the International Workshop, (2006) World Scientific Publishing

[2] T.A.Taiwo and H.S.Khalil, *ibid*., pp.8~17

[3] G. Aliberti, G.Palmiotti, M.Salvatores, T.K.Kim, T.A.Taiwo, I.Kodeli, E.Sartori, J.C.Bosq, and J.Tommasi, *ibid*., pp.81~100

[4] N.Hagura, T.Yoshida, M.Nakagawa, Int. Conf. on Nucl. Data for Science and Technol., Nice (2007)

[5] WPEC SubGroup 29, http://www.nea.fr/html/science/wpec/index.html

[6] G.Rimpault, Proc. International Workshop on Nuclear Data Needs For Generation IV Nuclear Energy Systems, (2006) pp.18~31

[7] C.Degueldre, H.Akie, P.Boczar, N.Chauvin, M.Meyer, V.Troyanov, Global 2003, pp.1967~1973

[8] D.Haas, A.Fernandez, J.Somers, Proc. International Workshop on Nuclear Data Needs For Generation IV Nuclear Energy Systems, (2006) pp.64~69