Nuclear Data relevant to Accelerator Development

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1. Introduction

Accelerator utilization is in progress in progress over the world with the for intense neutron sources, basic research for nuclear transmutation and medical treatment and so on. For accelerator development, various nuclear data are required as the basis for the system optimization and shielding design.
In reply to the requirement, a special purpose file "JENDL High Energy (JENDL-HE) File" is under development in Japan [1][2]. The file includes nuclear data for neutron and proton cross sections for energies up to 3 GeV for the whole 132 nuclides shown in Table 1 [1][2].
This paper describes the status of JENDL-HE and also the importance of nuclear data in the accelerator application by taking the system design of BNCT (Boron Neutron Capture Therapy) as an example.
More details are found in Refs.[1],[2] and [3].

Table 1. List of nuclides included in JENDL-HE file

1st priority (39)	^{1}H, ^{12}C, ^{14}N, ^{16}O, ^{27}Al, ^{50,52,53,54}Cr, ^{54,56,57,58}Fe, ^{58,60,61,62,64}Ni, ^{63,65}Cu, ^{180,182,183,184,186}W, ^{196,198,199,200,201,202,204}Hg, ^{204,206,207,208}Pb, ^{209}Bi, ^{235,238}U
2^{nd} priority (43)	^{9}Be, ^{10,11}B, ^{24,25,26}Mg, ^{28,29,30}Si, ^{39,41}K, ^{40,42,43,44,46,48}Ca, ^{46,47,48,49,50}Ti, ^{51}V, ^{55}Mn, ^{59}Co, ^{90,91,92,94,96}Zr, ^{93}Nb, ^{92,94,95,96,97,98,100}Mo, ^{238,239,240,241,242}Pu
3rd priority (40)	^{2}H, ^{6,7}Li, ^{13}C, ^{19}F, ^{23}Na, ^{35,37}Cl, ^{35,38,40}Ar, ^{64,66,67,68,70}Zn, ^{69,71}Ga, ^{70,72,73,74,76}Ge, ^{75}As, ^{89}Y, ^{181}Ta, ^{197}Au, ^{232}Th, ^{233,234,236}U, ^{237}Np, ^{241,242,242m,243}Am, ^{243,244,245,246}Cm
4th priority (10)	^{15}N, ^{18}O, ^{74,76,77,78,80,82}Se, ^{113,115}In

2. JENDL-High energy file

To apply to accelerators, the data of JENDL-HE file are provided for charged-particle reactions, particularly proton reactions, as well as neutron-induced reactions to enable analysis of radiation transport and activation. The current version of the JENDL-HE file consists of neutron total cross sections, nucleon elastic scattering cross sections and angular distributions, non-elastic cross sections, production cross sections and double-differential cross sections of secondary light particles (n, p, d, t, ^{3}He, α) and γ-rays, isotope production cross sections, and fission cross sections in the ENDF6 format.
The evaluation of JENDL-HE is done on the basis of experimental data and theoretical calculation by taking account of the following specific features in high-energy nuclear reactions (E > 20 MeV):
1) Particle emissions show strongly forward-peaked continuum angular distributions because of dynamical processes, such as intra-nuclear cascade processes and pre-equilibrium processes.
2) Reaction residues are produced over wide ranges of mass and atomic numbers due to high multiplicity of neutrons and light ions.
3) The degree of freedom of pions and excited nucleons will influence the reaction for incident energies beyond the threshold energy of pion production (150-200 MeV).
Accordingly, the evaluations of JENDL-HE employ reaction models of statistical multi-step models for pre-equilibrium processes, microscopic simulation methods using molecular dynamics for hadronic reactions followed by statistical decays, and so on. A hybrid calculation code system with some available nuclear model codes and systematics have been constructed based codes, such as ECIS96, OPTMAN, GNASH, JQMD, JAM, TOTELA, FISCAL, and so on [1][2].
The main code for energies below 150 or 250 MeV, is GNASH based on statistical Hauser-Feshbach plus preequilibrium exciton models. In the energy range above 150 or 250 MeV, either JAM or QMD is employed for description of dynamical processes. Both the frameworks have been demonstrated to reproduce well the measurements of DDXs of nucleon, pion emission and fragment production cross sections for proton-induced reactions from 100 MeV up to 3 GeV.
All the DDX data are given as tabulated data in the laboratory system taking account of energy-angle correlation of particles.
Typical examples are shown below. In Fig.1, the results of DDXs for the (p,n) reaction are displayed in comparison with experimental data and LA-150 [3]. As shown in the figure, JENDL-HE reproduces the experimental data consistently both in the shape and magnitude. In Fig.2, the example of activation cross section of ^{nat}Mg is shown. Again, JENDL-HE reproduces reasonably well the cross sections and provides new evaluation in the region where no data exist.

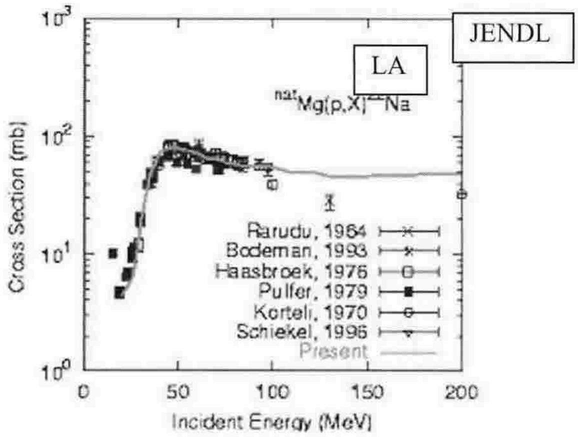

Fig.1 DDX of C(p,xn) reaction

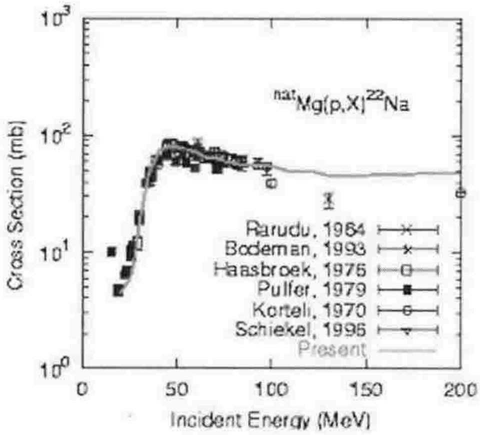

Fig.2; $^{nat}Mg(p,x)^{24}Na$ reaction cross section

The evaluation has been finished for 66 nuclides among the entire 132 nuclides, and the results have been tabulated in the ENDF6 format and released as the JENDL/HE-2004 file.

3. Importance ofnuclear data in nuclear system

Here, the effect of nuclear data is discussed concerning the case of the BNCT cancer treatment method. In BNCT, tumor cells are killed with particles formed in the $^{10}B(n,\alpha)^{7}Li$, $^{7}Li^{*}$ reactions using boron-containing pharmaceutical which concentrates selectively in tumor cells and a thermal or epithermal neutron beam. The method is used effectively owing to the selectivity of tumor cells. Now the treatment is done using neutron beams from reactors.

To improve the treatment effectiveness using optimized neutron spectrum and the accessibility,accelerator-based neutron sources are strongly required, but not realized yet mainly because of very high beam current required whenMeV beams are employed [4].

We have been doing design work of accelerator-based neutron source using MCNP-X code and La-150 [4]. The points in the design are

1) realization ofepi-thermal neutron flux ofrequiredfor the treatment , and

2) reduction of fast neutron components which damage normal cells.

Considering the requirement, we have selected the (p,n) spallation neutrons emitted from heavy nuclides and to backward angles as the primary source of neutrons around 50 MeV, and. iron and ALF/LiF mixture for moderators, and Pb reflector [4]. The schematic view is shown in Fig.3.

As the target element, Ta seems appropriate from the view point of heat property and chemical stability under cooling water environment. The neutron emission data, however, are not given in LA-150. We employed the data of W in LA150 because our experiment indicated that the data for Ta are almost the same with those of W. However, the data of LA-150 show systematic difference from the experimental data as shown in Fig.4. To see the influence of this difference, we carried out survey calculations, and found that this difference brings also difference in the moderated neutrons in the same order f magnitude. This result indicated the importance of the source neutron spectrum as well as the nuclear data of moderating materials.

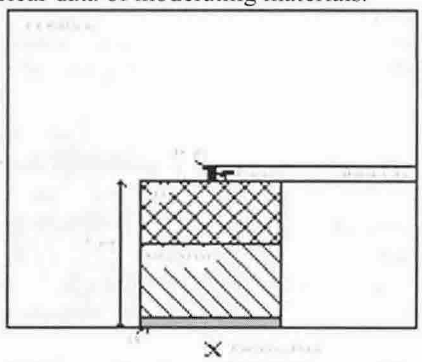

Fig.3 Schematic view of BNCT assembly

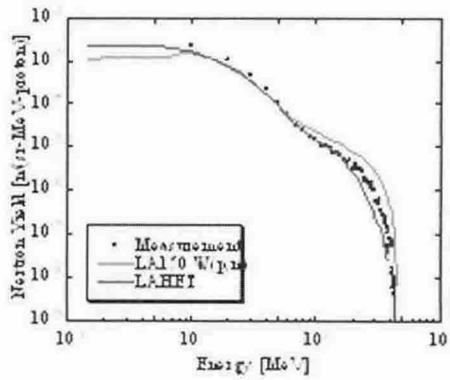

Fig.4 Difference in measured and calculated spectrum

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