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NUCLEAR DATA NEEDS FOR FMIT

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NUCLEAR DATA NEEDS FOR FMIT

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The Fusion Material Irradiation Testing Facility (FMIT) is designed to test samples in a high energy neutron environment so that data obtained in fission reactors can be extrapolated to that needed in fusion devices. Although most of the flux is centered around ~14 MeV, the neutron distribution will extend from thermal energies to 50 MeV.

Data needed in design include total, elastic, and removal cross sections for shielding, neutron yields for source calculations, and selected transmutation cross sections for dose determinations. Data needed for operation include transport and dosimetry cross sections for flux determinations, damage energy, transmutation, and gas production cross sections for damage analyses, and selected data for machine operation and maintenance. Detailed reaction lists are given.

[Nuclear Data Needs for FMIT]

Introduction

The Fusion Materials Irradiation Test (FMIT) facility[1] is a d + Li neutron source which will more rapidly expand the materials data base to fusion energies. This national facility is being designed by the Hanford Engineering Development Laboratory for the U.S. Department of Energy and should start operation in 1984. The d + Li reaction (E_d = 34 MeV, I_d = 0.1 A) will provide an intense source of neutrons ($\sim 4 * 10^{16}$ n/sec) peaking at about 14 MeV and ranging up to E_n=50 MeV.

Design Needs

The end of Title II design (i.e., the period of final design) is early 1981. Therefore the data needed for design must be obtained consistent with the design schedule.

Because of the intense deuteron beam, beam spill is of great concern. During operation the major shielding requirements will be from neutrons produced by deuteron interactions. The magnitude of this source can be appreciated by noting that a 0.01% beam spill will result in a 10μA current, a current which many experimentalists would desire to have in their research machines.

The major materials that the deuterons may strike are the accelerator (Cu or some coating such as Au), the high energy beam transport system (e.g. aluminum or stainless steel), and the lithium target. The neutron yield must be known as a function of neutron energy and emission angle. It must also be known as a function of deuteron energy for those materials in the accelerator structure.

After the machine is turned off, gamma radiation from delayed activity becomes predominate. These radioactive nuclides come not only from the deuterons striking the accelerator, the beam transport system, and the Li target (which will have Na, K and Ca impurities), but also from the neutrons produced by the deuteron interactions. Note that impurities, rather than the main material, may be the most important gamma source. The amount of delayed activity will have a major impact on choice of materials and placement of bending magnets, quadrupole focusing magnets, and shielding materials.

In order to determine shielding requirements, transport calculations will be needed. The most likely shielding materials are ordinary concrete, high density concrete, iron, and soil. For each, the neutron differential scattering cross sections as a function of incoming and outgoing energy and of outgoing angle are needed.

Other areas of concern are the production of prompt gamma radiation so that proper wall cooling and instrumentation can be designed. Besides moderating the neutrons, the shields will heat up, thus requiring accurate kerma factors. Finally estimates of damage parameters for the target must be made so that it has an adequate life expectancy.

Operational Needs

Whereas the needs for nuclear data for the design phase will be quickly over, the needs for data during operation will grow more stringent as experimenters learn more from their samples. The experimenters will want to know the flux and damage parameters seen by the samples.

Presently, the damage parameters which are thought to be most important are displacements, helium and hydrogen production, and transmutations. These quantities will have to be available for the materials the experimenters will use and for energies from 0-50 MeV, with the most precise results being needed around 15 MeV.

In order to calculate the displacements per atom, the recoil spectra of the atoms must be found. Using standard kinematic formulas this reduces to knowing the energy-angle differential cross sections for the various nuclear reactions possible, with elastic and inelastic scattering being the most important. Doran et al., have shown that the effect of secondary emission is unimportant. Gas production involves not only $(n,p\gamma)$ and $(n,\alpha\gamma)$ cross sections but also all other reactions which can produce hydrogen or helium with (n,np), (n,pn), and $(n,\alpha n)$ usually being the most important. Transmutation may be important for those materials where small amounts of impurities can cause significant property changes. Although not a damage parameter, the experimentalists will want to know the induced radioactivity of their sample so that post-irradiation experiments can be properly planned.

The experimenters will also want to know the

Table I. Possible Dosimetry Reactions.

$^{23}\text{Na}(n,2n)^{22}\text{Na}$
$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$

$^{54}\text{Fe}(n,\alpha)^{51}\text{Cr}$
$^{54}\text{Fe}(n,p)^{54}\text{Mn}$

$^{58}\text{Ni}(n,p)^{58}\text{Co}$
$^{60}\text{Ni}(n,p)^{60}\text{Co}$
$^{58}\text{Ni}(n,2n)^{57}\text{Ni}$
$^{58}\text{Ni}(n,3n)^{56}\text{Ni}$

$^{59}\text{Co}(n,p)^{59}\text{Fe}$
$^{59}\text{Co}(n,2n)^{58}\text{Co}$
$^{59}\text{Co}(n,3n)^{57}\text{Co}$
$^{59}\text{Co}(n,4n)^{56}\text{Co}$

$^{93}\text{Nb}(n,2n)^{92}\text{Nb}$
$^{90}\text{Zr}(n,2n)^{89}\text{Zr}$
$^{90}\text{Zr}(n,3n)^{88}\text{Zr}$
$^{90}\text{Zr}(n,p)^{90m}\text{Y}$

$^{89}\text{Y}(n,2n)^{88}\text{Y}$
$^{89}\text{Y}(n,3n)^{87}\text{Y}$

$^{107}\text{Ag}(n,2n)^{106m}\text{Ag}$
$^{107}\text{Ag}(n,3n)^{105}\text{Ag}$

$^{169}\text{Tm}(n,2n)^{168}\text{Tm}$
$^{169}\text{Tm}(n,3n)^{167}\text{Tm}$
$^{169}\text{Tm}(n,4n)^{166}\text{Tm}$

$^{197}\text{Au}(n,2n)^{168}\text{Tm}$
$^{197}\text{Au}(n,3n)^{195}\text{Au}$
$^{197}\text{Au}(n,4n)^{194}\text{Au}$
$^{197}\text{Au}(n,5n)^{193}\text{Au}$

$^{238}\text{U}(n,2n)^{237}\text{U}$

energy dependent flux at their sample positions. Among the ways available are passive and calculational dosimetry. The materials that will be used as dosimetry foils, helium accumulation monitors, and solid state track recorders are not yet precisely known. A likely set of foil material is shown in Table I. It will be important to know their responses not only in the peak response region, but also in the wings. Unfortunately, data above 15 MeV is lacking for many of these reactions. For calculational dosimetry to be accurate, both the d + Li source spectrum and the neutron transport cross sections must be known. Presently[2] the source spectrum is known to ∿15% for $E_n > 2$ MeV. The transport cross sections are fairly poorly known for E>15 MeV, and these cross sections must be known for each of the materials in the samples. Fortunately, the same data needed for displacement calculations are needed here.

It is likely that even after construction has started, fine-tuning of the design will occur, especially in those areas where initially there were large uncertainties. More concern will also be evidenced in the selection and design of diagnostic instrumentation.

General Notes

Not only are the cross sections needed, but also their uncertainties. In fact it is highly desirable to have a full covariance matrix for the data. This is extremely important for design purposes, since the facility must be conservedly designed, so often nominal values + 2σ are used. During operation, unfolding and uncertainty analyses will require covariance information.

Much of the needed data will come from nuclear model calculations. Such calculations require computer codes capable of multi-particle emission and pre-equilibrium treatment. However, such calculations must be anchored and verified by experimental data. For some uses, only experiment will provide data of sufficient accuracy.

Some of the needed base is already in place. ENDF/B-V,[3] the standard nuclear data library in the U.S., extends to E_n = 20 MeV. However the data above 8 MeV is usually of lower quality than the data below 8 MeV, while the data above E_n = 15 MeV is poorly known. Shielding libraries for accelerators by Alsmiller[4] and Wilson [5] are based mainly on nuclear model calculations and extend past 50 MeV. There is also scattered experimental data[6] but the major efforts have been initiated by the FMIT project. The d + Li neutron spectra for E_d = 35 MeV have been measured[7] with measurements for deuteron and neutron activation and for wall heating in progress.

Summary

Much nuclear data will be needed for successful operation of the FMIT facility. Some of the needs (mainly those in design) must quickly be satisfied, while others will be long term. Some of the long term needs await on the sample choices of the experimenters.

Fortunately, there is much overlap in the data needs, not only within the FMIT project but also between FMIT and proposed fusion devices. Table II provides a listing of the FMIT most important needs and their time tables.

References

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3. The Evaluated Nuclear Data Library (ENDF/B) is maintained at the National Nuclear Data Center, Brookhaven National Laboratory.

4. R. G. Alsmiller, Jr. and J. Barish, "NCDATA - Nuclear Collision Data for Nucleon - Nucleus Collisions in the Energy Range 25 to 400 MeV" ORNL-4220, Oak Ridge National Laboratory (1968).

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TABLE II

Nuclear Data	Design Needs (by 6/80)			Operational Needs	
	Neutron Sources	Gamma Sources	Shielding	Damage Parameters	Dosimetry
$\frac{d\sigma}{d\Omega dE_n}$ (d + accelerator, Li target)	X	X	X		X
$\frac{d\sigma}{d\Omega dE_n}$ (n + shielding)	X	X	X		
$\frac{d\sigma}{d\Omega dE_n}$ (n + samples)				X	X
σ_{act} (d + accelerator, Li target)		X			
σ_{act} (n + samples, accelerator)		X		X	X
σ_{gas} (n + samples)				X	X
$\sigma_{transmutation}$ (n + samples)				X	X

Accelerator materials include Cu, coatings on Cu (e.g. Au), beam pipe (e.g. Al, Fe C or Ta scrappers), and focusing devices (e.g. Cu, Fe).

Sample materials will be limited only by the experimenters' imagination, but certainly will include steels, refractory materials, Cu, Al insulators.

Shielding materials include concrete (Si, O, Ca, C), soil, and iron.