BENCH MARK SPECTRA FOR HIGH-ENERGY NEUTRON DOSIMETRY

R.DIERCKX
Commission of the European Communities
JRC Ispra, 21020 Ispra, Italy

ABSTRACT

To monitor radiation damage experiments, activation detectors are commonly used. The precision of the results obtained by the multiple foil analysis is largely increased by the intercalibration in bench-mark spectra. This technique is already used in dosimetry measurements for fission reactors.

To produce neutron spectra similar to fusion reactor and high-energy high-intensity neutron sources (d-Li or spallation), accelerators can be used. Some possible solutions as p -Be and d-D_2O neutron sources, useful as bench-mark spectra are described.

1. INTRODUCTION

The monitoring of radiation damage experiments for fusion application requires special attention due to the high neutron-energy nature of the spectra to be measured. The first-wall spectrum of a fusion reactor has a peak at 14 MeV. The accelerator neutron sources used to simulate fusion irradiation environments, d-Li or spallation sources, have neutron spectra extending to about 40 MeV.
Experience from fission reactor dosimetry has shown that the use of Bench Mark spectra is not only useful but necessary to obtain reliable results and to keep the uncertainties below the 10% level [1,2].
Bench mark spectra useful for fusion oriented dosimetry can be realized at a cyclotron. With a beam current (protons or deuterons) of 65 μA it is possible to obtain a medium-intensity high-energy neutron source of about 5.10^{12} n/s.sr in the forward direction.

Such a source can be used for different research activities :

1. fusion dosimetry studies
2. cross-section testing up to 40 MeV

2. THE NEUTRON SOURCE [3-6]

Different targets and bombarding ions have to be used in function of the different experiments executed. All sources have about the same output, 5.10^{12} n/s.sr in the forward direction and 10^{13} n/s total neutron output for normal cyclotron operation conditions of 65 μA beam current. The source should be operated in two ways, a D-C mode and a pulsed mode. In the D-C mode of operations, the full cyclotron current is used and the maximum neutron output obtained. For the pulsed mode, a pulsed ion source will be used delivering a 1 ns pulse, necessary for time of flight experiments.

2.1. 19 MeV deuterons on a D_2O target

This source delivers a spectrum which is a good simulation of a first wall-neutron spectrum. It has a low energy part, peaking around 6 MeV and about 20% of the neutrons have energies greater than 12 MeV (fig.1). The difference between the spectrum and a first-wall neutron spectrum is that instead of having a peak at 14 MeV, the neutrons are equally distributed between 12 and 21 MeV.

Using 12 MeV deuterons as bombarding particles on a D_2O target, the spectrum of fig.2 is obtained. The maximum neutron energy is 15 MeV but the source intensity is about one thirth relative to the 19 MeV deuterons. By changing the deuteron energy different spectra are obtained.

2.2. 19 MeV deuterons on a Be target

This source has a broad peak around 6 MeV, with a half width of 10 MeV. This means that most neutrons lies between 2 MeV and 12 MeV (fig.1).

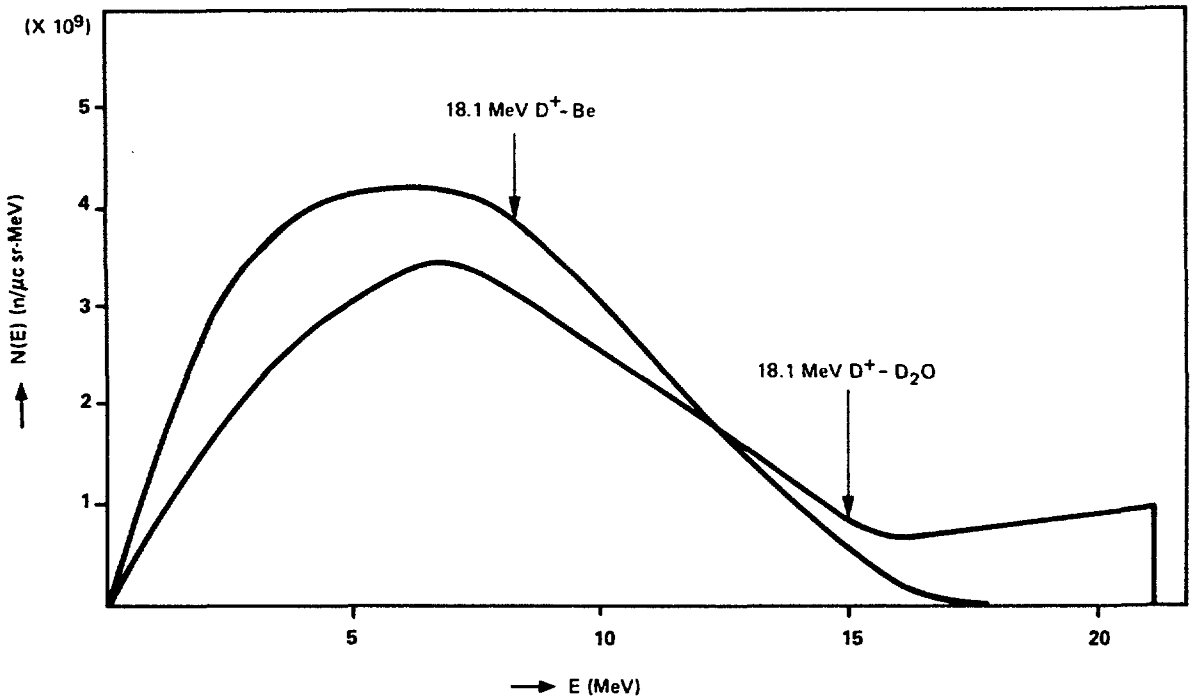

Fig. 1. 0° neutron spectra from 18.1 MeV deuterons on beryllium and D_2O

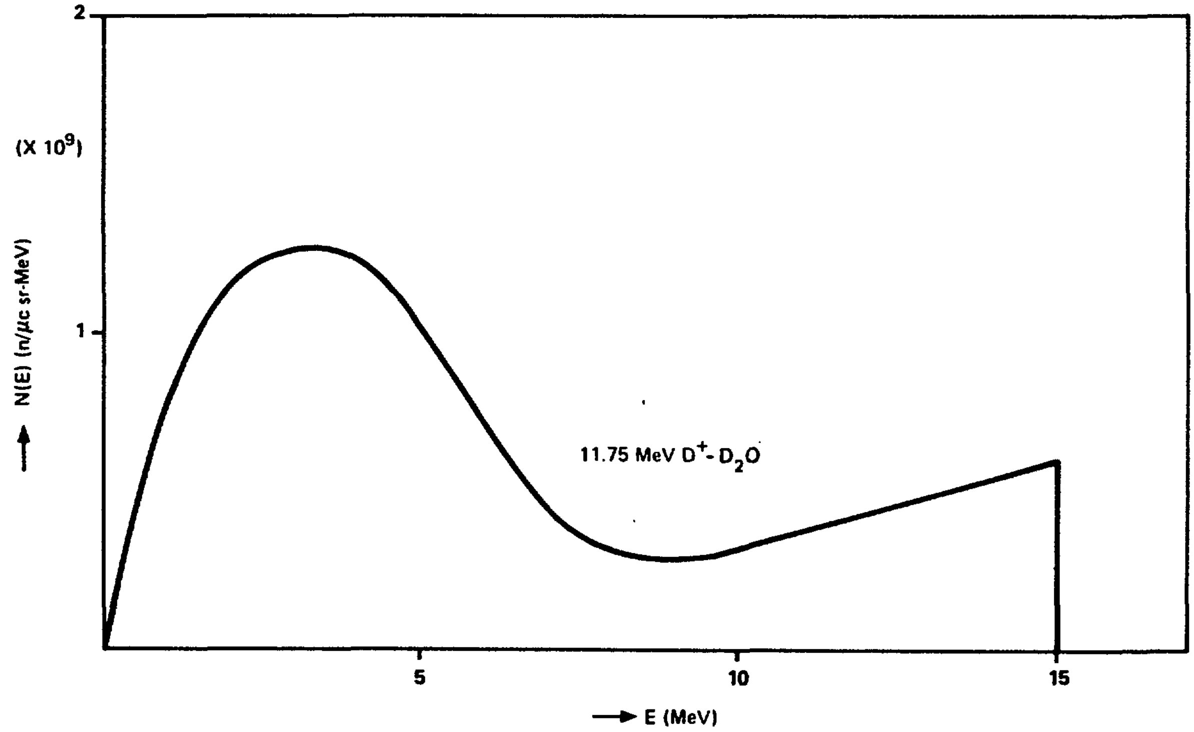

Fig. 2. 0° neutron spectrum from 11.75 MeV deuterons on D_2O

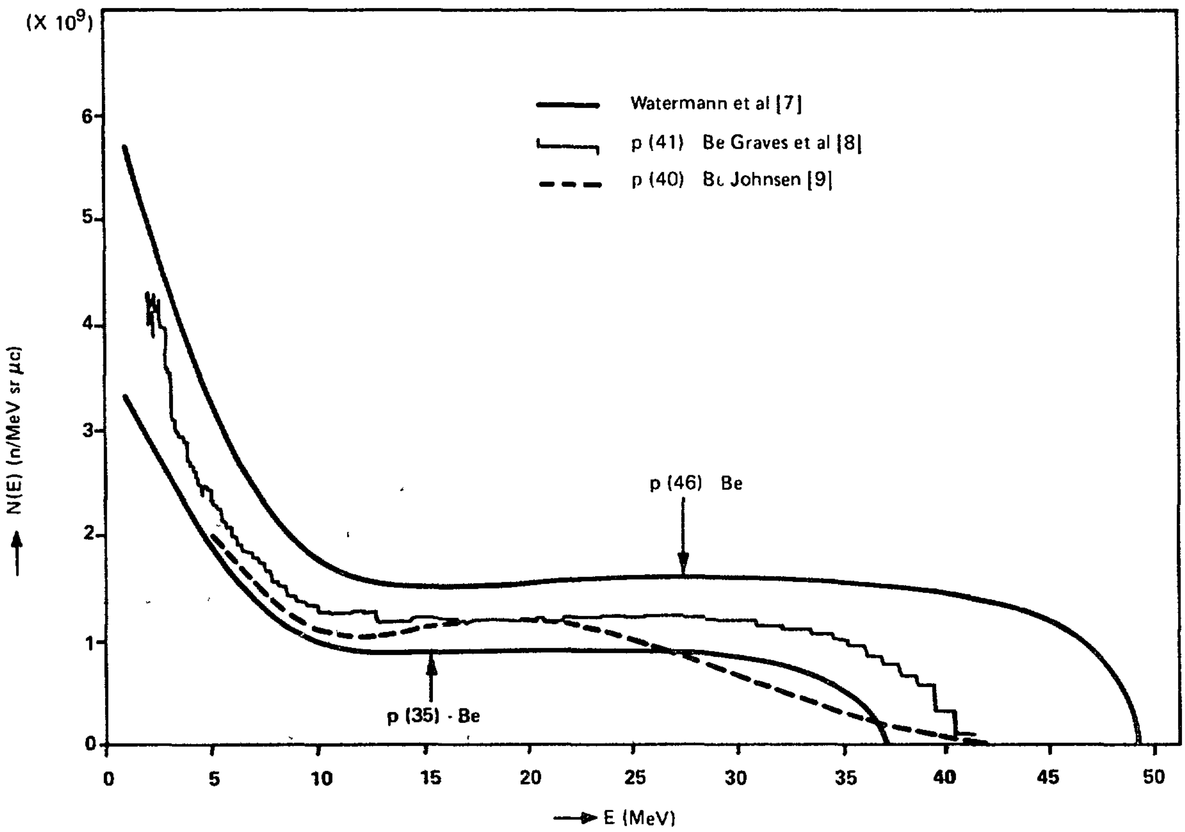

Fig. 3. 0° neutron spectra from protons on beryllium

2.3. 20 to 40 MeV protons on Be /7,8,9/

The maximum neutron energy is equal to the bombarding proton energy, and the neutron spectrum is quite flat from a few MeV up to the maximum neutron energy with a rise at small neutron energies. Thus bombarding with 40 MeV protons, neutrons up to 40 MeV are produced (fig.3).

3. RESEARCH ACTIVITIES

3.1. Fusion-dosimetry studies

Neutron dosimetry for Radiation-damage irradiation is of primordial necessity. These irradiations have to be monitored with enough precision to predict mechanical properties of the materials used for fusion-reactor design and construction. Only with a good neutron monitoring, it is possible to extrapolate and predict end-of-life of these materials under irradiation.

Therefore it is necessary to develop the neutron dosimetry for fusion and high-intensity high-energy neutron sources (such as the d-Li source, and spallation sources).

The neutron dosimetry is done with activation foils and the measured activities are analysed with unfolding techniques. For energies greater than 20 MeV only calculated cross-sections exist and these have to be tested (see next Section). Further unfolding techniques give reliable results when intercalibrated in calibration spectra or Bench-Mark spectra.

The research programme to develop the dosimetry for fusion and high-energy neutrons sources looks as follows :

- setting up of Bench-Mark spectra
- measuring these spectra with time of flight (TOF) and other techniques
- calibrating the foils in these TOF spectra
- testing of the methods in other spectra

3.2. Cross-section testing

It will take a long time before the first fusion reactor will work, and radiation damage experiments can be done in a real fusion environment. In the mean time the materials will be irradiated in the high-energy neutron sources such as d-Li and spallation sources. These sources have a significant part of the neutron spectrum up to 30-40 MeV. Cross sections are measured up to 20 MeV and some transmission measurements at higher energies.

Above 20 MeV, most used cross-sections are calculated, and need experimental verification. Differential measurements are difficult and very time consuming, such that only a few key cross-sections are and will be measured differentially. The other needed cross-sections have to be tested by integral experiments.

Both techniques, differential cross-section measurements and integral cross-section testing is possible at the proposed neutron sources.

A recommendation in this sense is put forward by the IAEA Advisory Committee "Nuclear data for radiation damage assessment and related safety aspects" held at Vienna in 1981 [10]. Some of the recommendations are :

1. Integral cross section measurements for dosimetry reactions in well-known neutron fields should be considered during the evaluation of neutron cross sections. These data should then be included in the data files.
2. It is recommended to supplement the future International Reactor Radiation Damage File, for Fe, Cr and Ni up to 40 MeV, and to include the data for Al up to 40 MeV with the first priority. The data for graphite, O, Ti, V, Mn, Cu, Zr, Mo, W up to 40 MeV and for Nb, Sn up to 20 MeV should be included in the file with second priority.
3. Few experimental data above 20 MeV exist. More experimental data are wanted, but in their absence one has to recur to theoretical calculations. Theoretical calculations of H and He production cross-sections show that at higher incident energies the contributions of reactions of the type (n,pp) and $(n,p\alpha)$ cannot be neglected for target nuclei with small neutron excess. Evaluations of needed changes in the energy dependence of the damage function should be considered in future theoretical and experimental research.
4. For the calculations of gas production and solid transmutation accurate excitation functions would be necessary from thereshold up to about 30 MeV for (n,γ); (n,xn); (n,tot.H) and (n,tot He)

mostly between 9 and 15 MeV. The list of important materials (e.g. Li, C, N, O, Al, Si, Ti, V, Cr, Mn, Fe, Ni, Cu, Zr, Nb, Mo, Pb) can be found in the IAEA biennial publication WRENDA.

5. It is further recommended that the Nuclear Data Section encourage measurements of total cross-sections up to 40 MeV for the above mentioned reactions.
   Such measurements are extremely useful for parametrization of nuclear model calculations.

4. EXPERIMENTAL LAY-OUT (fig.4)

A possible lay out of such a Bench Mark facility is given in fig.4. As reference the Ispra cyclotron is taken. The neutron source is located in a target-cell, constructed outside the actual cyclotron building. The ion beam will pass the existing cyclotron wall through an existing penetration, pass a 90° bending magnet and is lead into the target cell of 2 x 2 x 2 m^3. The target cell is shielded heavely (about 2 m of iron in the forward direction) and has beam holes to extract the neutron beam for TOF measurements either from the source itself either from a mock-up placed inside the target cell. Through the sliding door mock-ups for integral measurements can be brought into the target cell.
Around the target cell, an experimental hall is foreseen, in which a collimator, detector and electronics are placed. The experimental hall measures about 11 x 21 m^2.

This lay-out permits the measurement of the neutron output of the source and of the scattered neutrons in the mock-up from 0° to 180°.

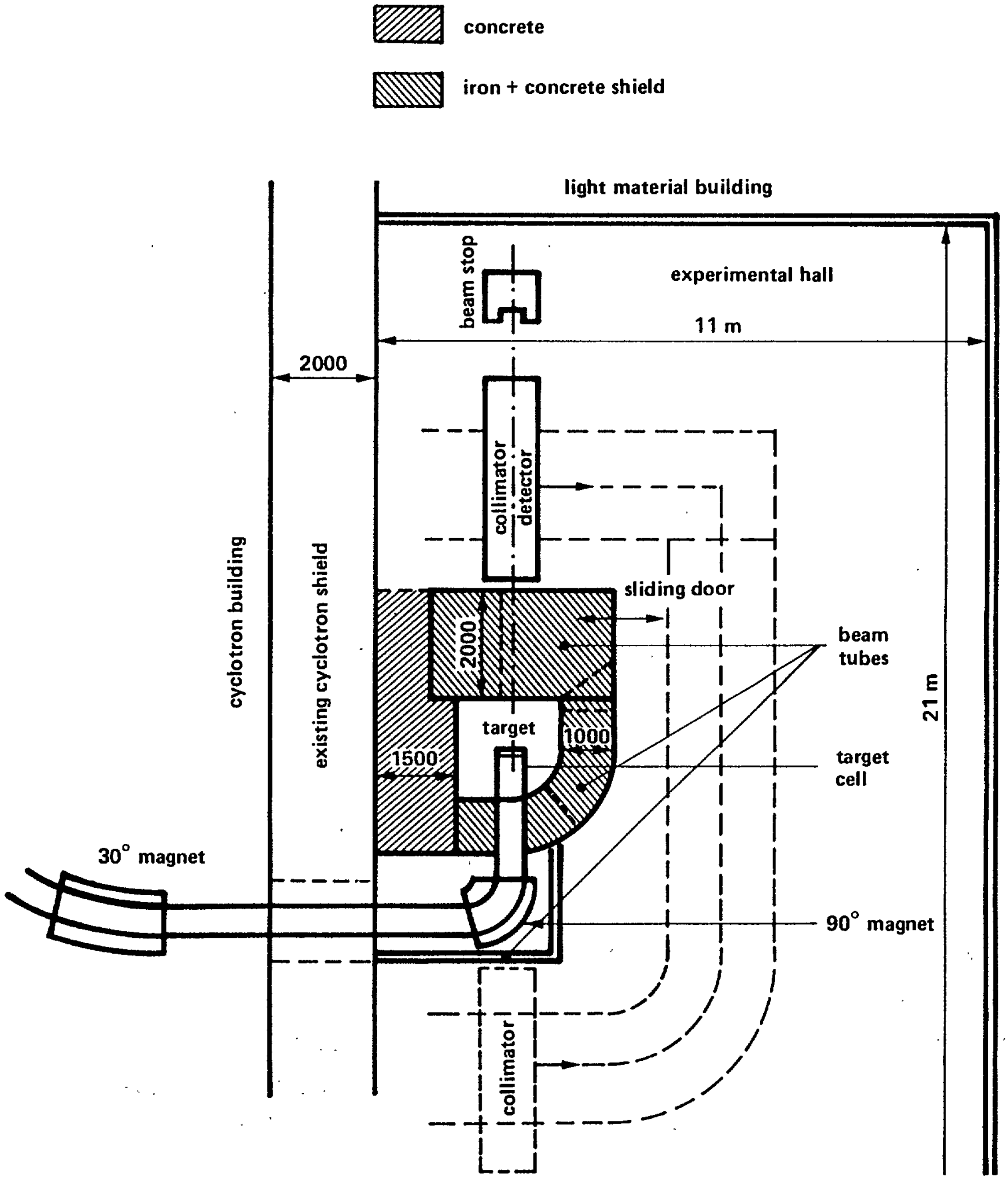

Fig. 4. Lay-out of target cell and experimental hall

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