ON THE NEEDS AND STATUS OF CTR MATERIALS IRRADIATION FACILITIES, AN INTRODUCTION TO 14-MeV NEUTRON SOURCES*

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INTRODUCTION

In all likelihood, the next linear accelerator to be constructed in the U.S. will be very different, both in parameters and end use, from those built in the past. It will be a high-current, cw, deuteron linac with an energy of 30-40 MeV to be utilized as a neutron generator for radiation damage studies and development for future fusion reactor construction materials.

This paper reviews the requirement of neutron sources for radiation damage studies for fusion reactors, describes existing and planned facilities and serves as an introduction to several papers presented at this conference on proposed deuteron linac − neutron generators and other papers related to neutron sources.

RADIATION DAMAGE

A recent study[1] sponsored by the Atomic Industrial Forum states that..."The most severe problem associated with fusion reactors is seen to be that of the effects on reactor materials of 14-MeV neutrons and other high-energy particles generated in a D-T reactor -- Evaluation of materials to be used, in the so-called first wall ... is considered to be the pacing requirement in development of the planned Experimental Power Reactor." This statement is the result of the hard learned lesson gained from experience with fission reactors. Energetic fission neutrons have a strong influence on the mechanical properties and dimensional stability of reactor materials which arises in part from the formation of voids during long-term irradiation at elevated temperatures.

The following few figures give a brief indication of the problems one encounters when subjecting materials to neutron bombardment. In all cases these graphs refer to bulk radiation effects induced by fission (low-energy) neutrons. Figure 1[2] shows the loss of ductility in 304 stainless steel vs neutron fluence; notice the abrupt change after irradiation of 10^{22} n/cm^2. Figure 2[3] shows the effect of helium produced by neutron bombardment on the mechanical properties of a vanadium alloy vs temperature and Fig. 3[4] shows the effect on dimensional stability (swelling) vs neutron fluence for different aluminum alloys. This swelling, produced by the formation of voids within the material, is illustrated on Fig. 4.[5] Here we see the voids produced in Mo at 600°C (left) and in Nb at 800°C (right).

Fusion reactors, because of their high-energy neutron production, present a new challenge to the material scientist. Figure 5 compares the neutron flux vs energy for the EBRII-7 reactor and BENCHMARK which is a model fusion-reactor first wall neutron spectrum (Tokamak, burning DT). Notice the large spike of high-energy neutrons (~14 MeV) for BENCHMARK.

Although useful, the experience gained with fission reactor radiation damage is not adequate to supply engineering data to make choices of materials for fusion reactors. This experience does however indicate that fusion reactor materials will be subject to much worse conditions, in terms of bulk radiation damage, than those materials used in fission reactors. It is estimated that ~80% of the damage will be produced by those neutrons having an energy >10 MeV. It has become therefore imperative that a large experimental program be carried out to obtain 14-MeV neutron radiation damage data on existing materials and that new alloys be developed for this application. This program will require the irradiation of thousands of samples to fluences up to 10^{22} n/cm^2 under varied conditions to produce the engineering data necessary for a reactor design.[6]

The USERDA, DMFE (Division of Magnetic Fusion Energy) plan is to start the design of a first EPR (Experimental Power Reactor) in the mid-eighties. This sets a schedule for the need for radiation damage information at about that time.

Irradiation facilities to carry out this program are sorely needed, and U.S. laboratories have responded to that need with many proposals for such facilities. These are described in detail in the Proceedings of the International Conference on Radiation Test Facilities for the CTR Surface and Materials Program, held at Argonne in July 1975. I will briefly describe here only those facilities which are being built or considered for the immediate future.

NEUTRON SOURCE FACILITIES

Table I shows a composite summary of existing and planned neutron source facilities. The first of these (RTNS I, RTNS II and INS) are either existing (RTNS I) or have been authorized for construction. These three facilities utilize an energetic deuteron beam (triton beam for INS) at 300-400 kV to produce a DT reaction resulting in a pure 14-MeV, isotropic neutron source. In the three cases, the useful experimental volume is very small and the neutron flux is limited by thermal considerations.

At the other end of the table are two proposed plasma sources, one of which is a fusion reactor. At this time, these are outside the state-of-the art technology. As such they are not being considered for the near-term program.

A brief description of each facility follows:

RTNS's[7,8] (Rotating Target Neutron Source)

The RTNS built at LLL (Lawrence Livermore Laboratory) consists basically of a deuteron, duoplasmatron ion source, an electrostatic dc accelerator and a rotating tritium-containing target.

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RTNS I operates with a beam of ~15 mA accelerated to 400 keV. The beam on target reacts with the tritium to produce an isotropic neutron source of very limited volume at high flux. RTNS I operates at fluxes of 1-2x10^{12} n/cm^2/sec in a volume of ~1 cm^3. The achievable flux is limited by the thermal capacity and the life of the target. RTNS II which is scheduled to operate in 1978 will have greatly improved target cooling, operate with a 150 mA - 400 keV beam and is expected to produce fluxes of 2x10^{13} n/cm^2/sec in a volume of ~1 cm^3. It is hoped that the facility can be further upgraded in the future to produce 10^{14} n/cm^2/sec with a 400 mA deuteron beam.

INS[9] (Intense Neutron Source)

The INS to be built at LASL (Los Alamos Scientific Laboratory) and scheduled to operate in 1982 consists of the interaction of two beams: one of 1.1 A of 300 keV tritium ions and the other of a supersonic jet of deuterium gas. The tritium ions will be produced in multiple duoplasmatron ion sources arranged around a single plasma expansion cup. The beam will then be extracted and accelerated in a 300 kV electrostatic accelerator. Like the RTNS the neutrons will be produced via a DT reaction resulting in an isotropic source. The expected performance from this source is 1-2x10^{14} n/cm^2/sec in a volume of 2-3 cm^3.

d-Li Neutron Sources

The d-Li Neutron Source concept is very different from that of DT sources. In this case the neutrons are produced by the breakup of energetic deuterons incident upon a low Z material (lithium) target. The neutron energy spectrum peaks at about half the deuteron energy and its width is determined by secondary processes. To achieve this peak at about 14 MeV, one requires a 35 MeV deuteron linac. Figure 6 shows the difference between a d-Li primary neutron spectrum and that of a DT source. This difference has been a handicap to the desirability of such a facility. However, work carried out at BNL and other laboratories is demonstrating that the d-Li neutrons closely approximates the radiation damage effects of the 14-MeV neutrons.[10,11] Table II illustrates the point by comparing the radiation damage effect of various facilities in terms of dpa/sec (displacement per atom per sec) and helium production in ppm/sec and perhaps more importantly in terms of the ratio of the two, dpa/ppm He. This a priori handicap is however overshadowed by the advantages that the d-Li neutron source has over the DT sources, the main one being a large, accessible experimental volume (~1800 cm^3 for a 200 mA deuteron beam) at high flux (10^{14} n/cm^2/sec).

The d-Li Neutron Source consists of a high-current, cw deuteron linac and related flowing-liquid lithium target. It will be described in greater detail in several papers at this conference.

The concept developed by BNL resulted in a formal proposal for BANG (Brookhaven Accelerator-based Neutron Generator) in July 1975.[12,13] The enthusiasm for such a facility was so great that within 6 months thereafter three other proposals, going by such names as: INGRID,[14] CMIT[15] and High-Intensity Neutron Source,[16] were published competing for the identical facility. All this activity, of course, has resulted in getting the linac community quite interested since NAL and LBL got involved and have also produced some interesting papers for this conference.

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Table I Composite summary of parameters of neutron and plasma sources

	NEUTRON SOURCES				PLASMA SOURCES	
SOURCE TYPE	RTNS I	RTNS II	INS	BANG	DPF	FERF
REACTION	DT	DT	DT	D-Li	DT	DT
YIELD (n/sec)	2×10^{12}	4×10^{13}	8×10^{14}	2×10^{17}	—	—
GEOMETRY	4π	4π	4π	2π	4π PULSED	—
USEFUL FLUX (n/cm^2-sec)	1×10^{12}	2×10^{13}	$<10^{14}$	$>10^{14}$	$\sim 10^{13}$	$\sim 10^{14}$
CORRESP. VOL. (cm^3)	2-3	2-3	2-4	>1800	$>10^3$	$>10^4$
CORRESP. AREA (cm^2)	2-3	2-3	2-4	$<10^2$	$>10^3$	$>10^4$
EST. REQ. POWER (MW)	—	6.3	2	25	12	—
EST. COST (M$)	—	5	25	70	—	>400
EST. OPER. DATE	NOW	1978	1982	1983?	—	—

Table II Production rates of helium and lattice atomic displacements at various nuclear facilities

Facility	Flux n cm^{-2} sec^{-1}	dpa/sec $\times 10^7$	He app m/sec $\times 10^7$	dpa/He
HFIR	6×10^{14}	1.49	0.06	24.8
EBRII-7	4×10^{14}	1.24	0.024	51.7
LAMPF	2×10^{13}	0.124	0.08	1.55
BENCH (CTR)	2×10^{14}	2.11	4.0	0.53
"14 MeV" (RTNS)	2×10^{12}	0.061	0.18	0.34
Li(d,n) (34.06 MeV)	1×10^{14}	2.81	6.95	0.40
Li(d,n) (28.94 MeV)	1×10^{14}	2.57	6.00	0.43

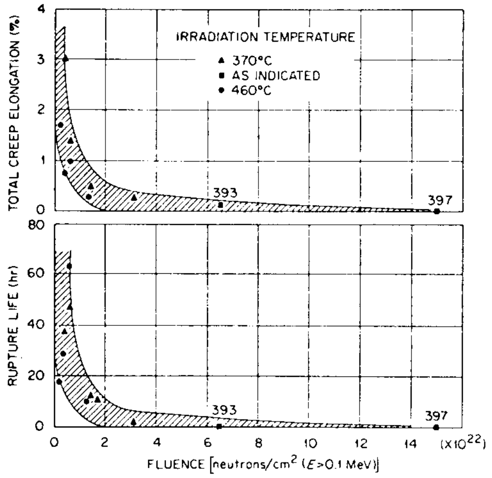

Fig. 1 Creep elongation and rupture life as a function of fast neutron fluence for annealed type 304 stainless steel tested at 550°C and 35000 psi.

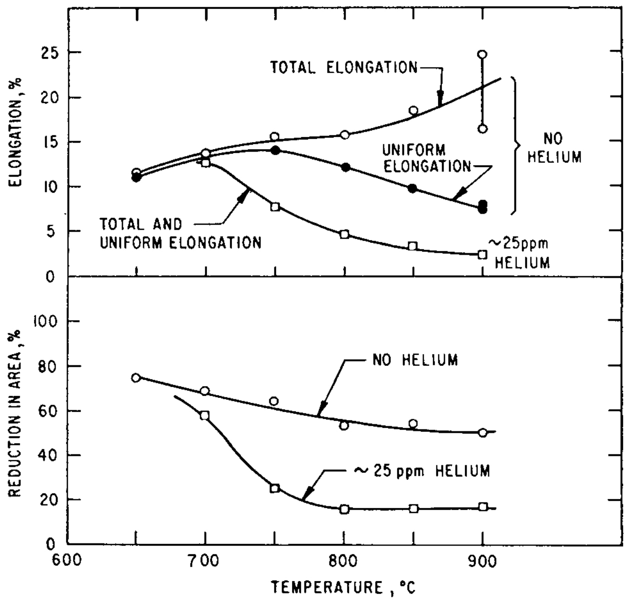

Fig. 2 Effect of the presence of helium on the tensile ductibility of V-15 wt % Cr-5.

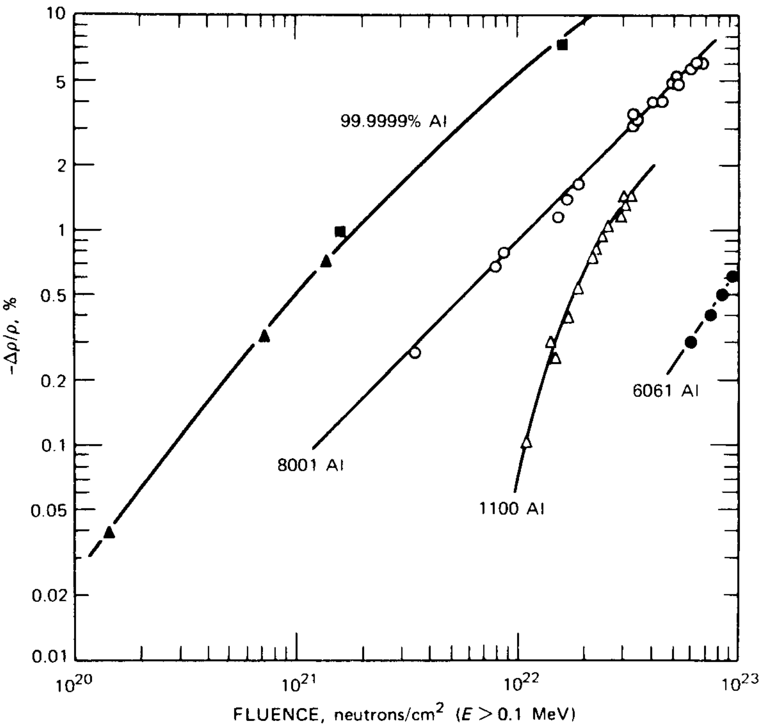

Fig. 3 Material swelling as a function of fast neutron fluence for various aluminum alloys.

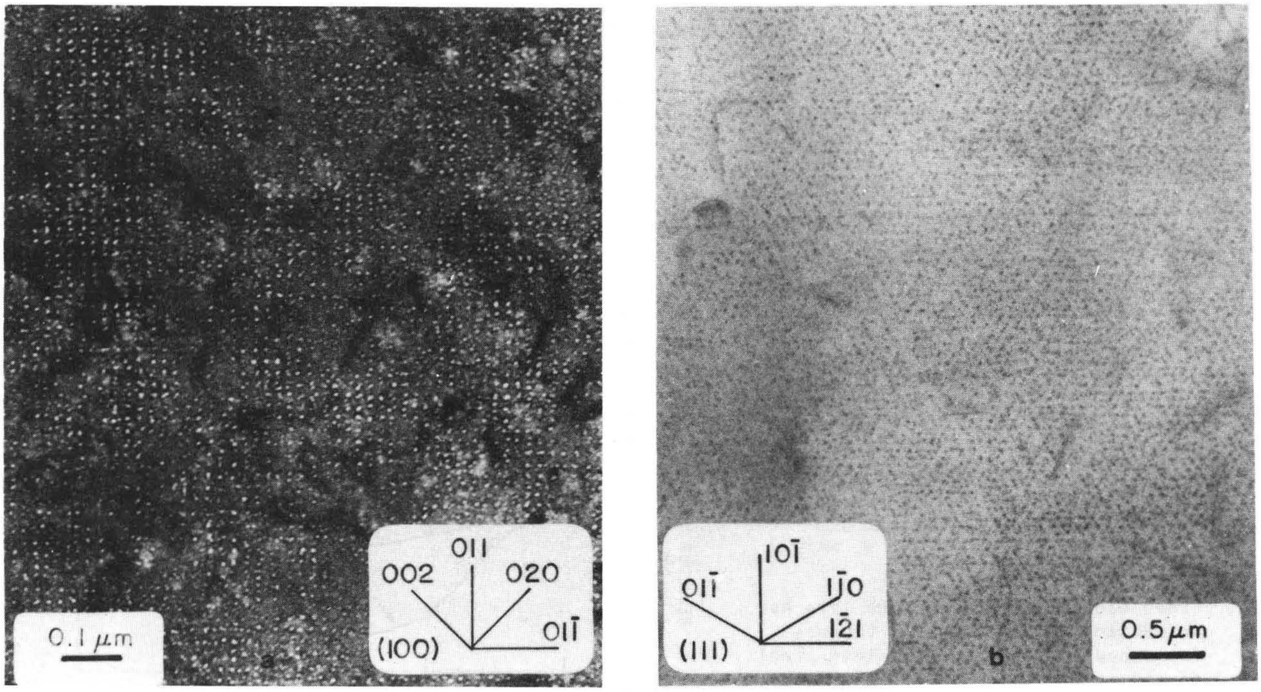

Fig. 4 Microphotograph of voids formed by neutron bombardment in molybdenum at 600°C (left) and in niobium at 800° (right).

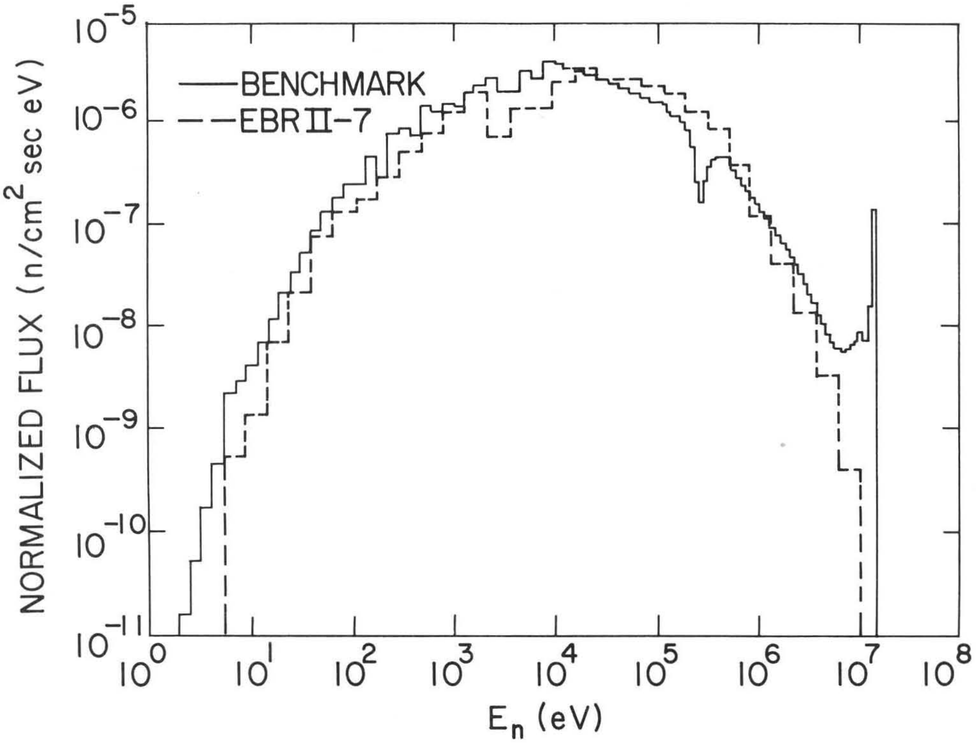

Fig. 5 Comparison of neutron energy spectra of calculated "first-wall" Tokamak Model (BENCHMARK) to that of fast flux fission reactor (EBRII-7).

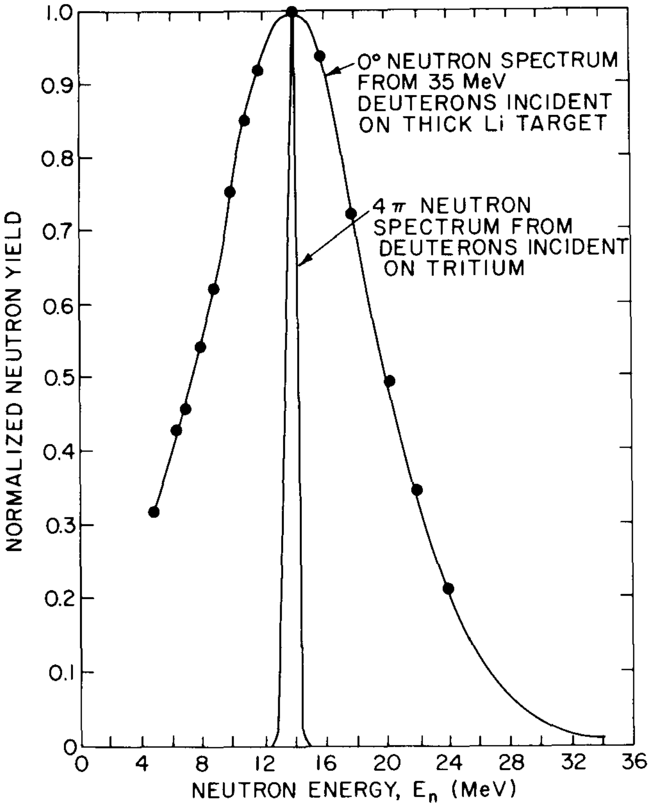

Fig. 6 Comparison of neutron energy spectra between a 14-MeV DT neutron source and 35 MeV D-beam on a lithium target.

DISCUSSION

M. Allen, SLAC: At the beginning you mentioned unpleasant things happening at fluxes above 10^{22} n per cm^2 yet you are talking about 10^{14} per cm^2 which is 8 orders of magnitude less.

Grand: The 10^{14} is the flux (neutrons/cm^2/sec) while the 10^{22} is the fluence or integrated flux (neutrons/cm^2).

A. Lone, CRNL: We have measured the neutron yields from Li(d,n) reactions and find a lot of low energy (E_n < 2 MeV) neutrons. These measurements were done at 14, 18 and 23 MeV. Does this create problems in using this kind of source as compared with the 14 MeV sources?

Grand: Nobody is looking at neutrons of energies less than a couple of MeV. For the bulk radiation damage problems nobody seems to be worried about the low energy neutrons.