LA-UR -91-2747

LA-UR--91-2747

DE91 016039

TITLE RADIATION HARDENING OF DIAGNOSTICS

AUTHOR(S) Richard E. Siemon, CT-NSPO

SUBMITTED TO Diagnostics for Contemporary Fusion Experiments, Course & Workshop, Int'l School of Plasma Physics
Varenna, Italy
Aug. 27 thru Sept. 6, 1991

Radiation Hardening of Diagnostics

Richard E. Siemon
Los Alamos National Laboratory

Abstract

The world fusion program has advanced to the stage where it is appropriate to construct a number of devices for the purpose of burning DT fuel. In these next-generation experiments, the expected flux and fluence of 14 MeV neutrons and associated gamma rays (from surrounding structure) will pose a significant challenge to the operation and diagnostics of the fusion device. Radiation effects include structural damage to materials such as vacuum windows and seals, modifications to electrical properties such as electrical conductivity and dielectric strength, and impaired optical properties such as reduced transparency and luminescence of windows and fiber optics during irradiation. In preparation for construction and operation of these new facilities, the fusion diagnostics community needs to work with materials scientists to develop a better understanding of radiation effects, and to undertake a testing program aimed at developing workable solutions for this multi-faceted problem. A unique facility to help in this regard is the Los Alamos Spallation Radiation Effects Facility (LASREF), a neutron source located at the beam stop of the world's most powerful accelerator, the Los Alamos Meson Physics Facility (LAMPF). The LAMPF proton beam generates about 10^{16} neutrons per second because of "spallation" reactions when the protons collide with the copper nuclei in the beam stop. Other contemporary diagnostic work at Los Alamos includes development of methods to measure accurately the neutrons and alpha particles emitted by fusion reactions, and development of an intense diagnostic neutral beam.

Introduction - The problem of Radiation Hardening

Although the problem of radiation hardening in the vicinity of a DT burning experiment has been recognized for many years, rather little emphasis has been placed on this area of research and development while the world program has concentrated on the problem of plasma performance. With confidence growing that tokamak ignition experiments can be built, it is time to examine the effects of radiation damage in greater detail.

The following table lists some radiation parameters for the US BPX design and the ITER conceptual design. Because neutrons scatter from the surrounding structure, neutronics codes predict a broad spectrum of neutron energy near the first wall with an energy-integrated flux larger than the directed 14 MeV flux by a factor of 5 to 15 depending on what materials are used in the structure and blanket. The first wall environment will also include a substantial number of gamma rays that are emitted when materials are bombarded by 14 MeV neutrons.

Radiation Parameter			
Flux	**BPX**	**ITER**	
Wall Load (MW/m^2)	3	1	
14 MeV neutrons/$m^2 \cdot s$	1.3×10^{18}	4.4×10^{17}	
ϕ_n ($n/m^2 \cdot s$)	2×10^{19}	2×10^{18}	
ϕ_γ ($g/m^2 \cdot s$)	8×10^{18}	2×10^{18}	
In ceramics			
Rad's by neutrons	$\sim 2 \times 10^4$	$\sim 2 \times 10^3$	
Rad's by gamma	$\sim 2 \times 10^4$	$\sim 4 \times 10^3$	
Fluence	**BPX**	**ITER Physics Phase**	**ITER Tech. Phase**
$MW \cdot yr/m^2$	0.001	0.03	3
$\int \phi_n$ (n/m^2)	2×10^{23}	2×10^{24}	2×10^{26}
In ceramics			
dpa	~0.02	~0.2	~20
Rad	$\sim 6 \times 10^7$	$\sim 6 \times 10^9$	$\sim 6 \times 10^{11}$

Notes
1 Rad = 100 erg/gm absorbed
= .01 Gray
dpa = displacement per atom

Radiation Effects

In the context of a fusion reactor, the information available on radiation effects is limited and difficult to apply quantitatively in many cases. This is especially true for diagnostic speciality materials such as windows, insulators, reflectors, and fiber optics. One problem recently discussed [1] is that all available radiation sources differ in one or more possibly important aspects: neutron energy, ratio of neutrons to gammas, flux level, pulsed instead of steady state, etc. Nevertheless, the available data can be used as guidance for anticipating problems and in formulating the needed research.

Most of the documented radiation effects involve property changes with absorbed dose, often using the rough approximation that absorbed energy (measured in rads) from different radiation sources will have the about the same consequences. Among the known effects are swelling and loss of strength. For example, vacuum windows mounted with metal seals must be designed to allow for differential expansion, and an order of magnitude reduction in the modulus of rupture has been observed for ceramics at a fluence of 10^{24} neutrons/m^2. Many optical components lose their transparency when irradiated. Sapphire (Al_2O_3), for example, is known to have broad absorption bands in the visible spectrum [2]. Fiber optics turn very dark when irradiated --100 dB/km for 10^{16} n/m^2 [3]. By development efforts, such as deliberately doping with impurities or bleaching with intense light after irradiation, it may be possible to reduce the problem significantly.

For diagnostics applications the in-situ behavior (response during irradiation) is also important. Fewer observations have been made because of the greater difficulties inherent to in-situ irradiation experiments. In alumina it has been reported that DC conductivity changes by six orders of magnitude for a flux of 5 x 10^3 rad/second [4]. In "radiation hardened" signal cables made with ceramic insulators, electrical breakdown is observed during irradiation, and the effect increases with fluence [5].

LASREF - A Neutron Source for Fusion Testing

The Los Alamos Spallation Radiation Effects Facility (LASREF) is a neutron source [6] located at the beam stop of the world's most powerful accelerator, the Los Alamos Meson Physics Facility (LAMPF). The 800-MeV, 0.8-mA LAMPF proton beam generates about 10^{16} neutrons per second because of "spallation" reactions when the protons collide with the copper nuclei in the beam stop.

The neutron energy spectrum for the spallation neutrons has a high energy tail [7] that is not present in a fusion device as shown in Figs. 1 and 2. Also shown is the spectrum of the fission Fast Flux Test Facility, which has essentially no neutrons at 14 MeV.

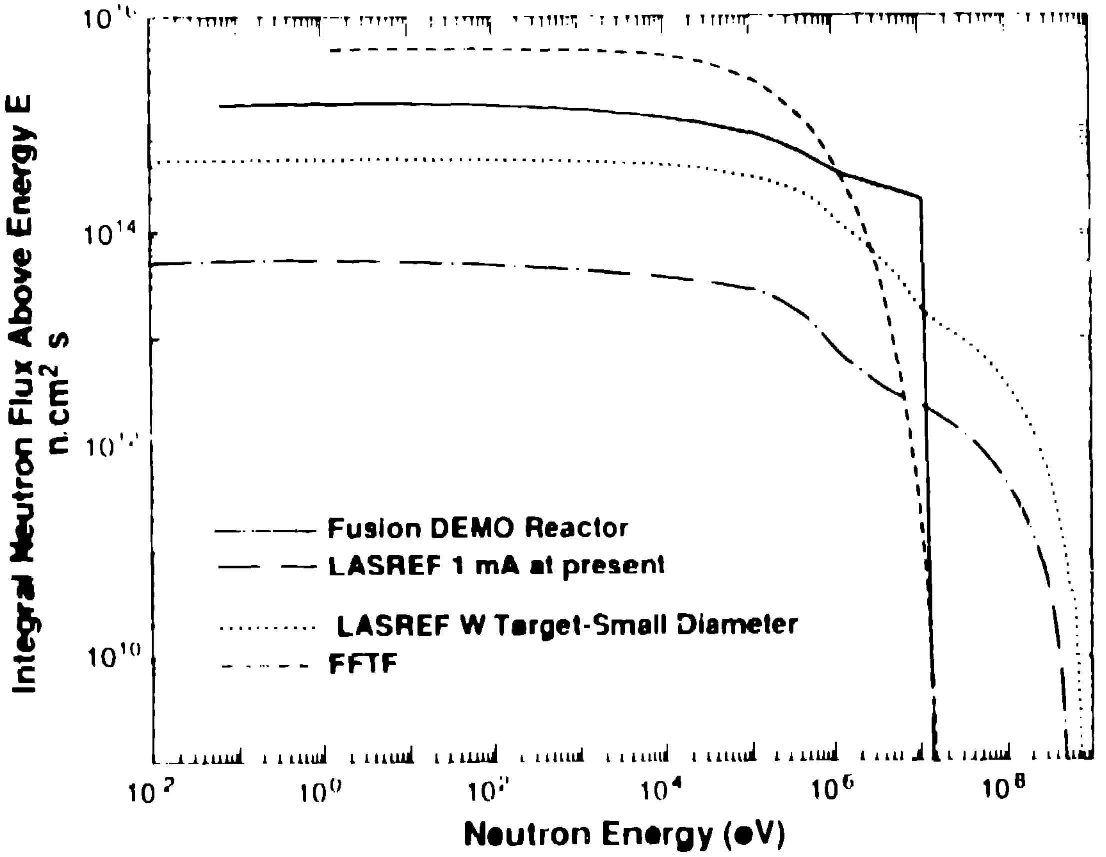

Fig 1 Integrated neutron flux above a given neutron energy (eV) compared for fusion, LASREF, and the fission Fast Flux Test Facility (FFTF)

The more energetic neutrons in a fusion source compared to fission has the important effect in materials of causing more helium to be produced by transmutations. The high-energy component of the neutron spectrum in LASREF generates close to the same ratio of helium production to displacements per atom that is expected in fusion reactors [8]. However, additional unwanted transmutations may also occur at LASREF because of the high energy tail, and this effect must be considered on a case by case basis.

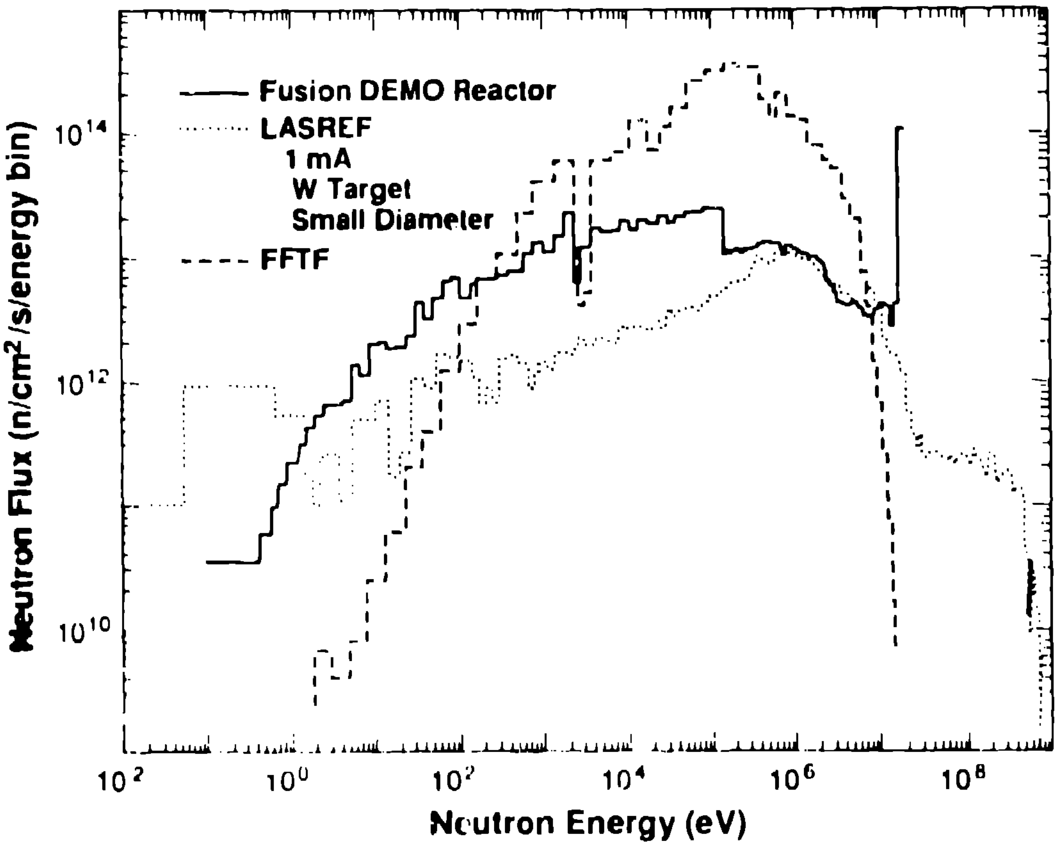

Fig. 2 Flux in energy bins (logarithmic increment as indicated) compared for fusion, LASREF upgrade, and FFTF.

When in operation (about 2500 hours per year), the LAMPF accelerator runs continuously and generates a time-averaged flux of about 5×10^{17} n/m^2-s. An upgrade to LASREF is under consideration (W target curves in Figs. 1 and 2) that would increase the flux by about a factor of 10. Operation is mainly in the summer months for the convenience of users.

The time-dependent flux consists of 0.5-ms pulses every 8.5 ms, which means the instantaneous flux is somewhat larger than that expected in next-generation fusion experiments. In-situ studies of flux-dependent properties such as electrical conductivity or induced luminescence are thus appropriate. In-situ studies are also facilitated by a large and readily accessible volume for doing experiments (10 x 20 x 40 cm^3).

Other Diagnostic Work at Los Alamos

In the past year a new effort to advance the state of the art in fusion product diagnostics has been instigated. Fusion products include neutrons and various energetic charged particles with orbits that escape from the plasma. At present collaborations with TFTR and Alcator C-Mod are underway aimed primarily at improvements in methods of calibration. New detection methods are being studied in preparation for the DT burning phase of TFTR (planned for FY93).

A second activity is the development of a high-intensity neutral beam source for doing charge exchange recombination spectroscopy. Conventional neutral beams are not sufficiently intense to overcome background noise from plasma Bremsstrahlung in a large plasma such as ITER. A new source is being developed and tested. The concept is based on developments in the past few years for high-voltage diodes used to accelerate intense ion beams. Magnetic fields are used to hold electrons in the accelerator gap,which allows surpassing the Child-Langmuir Law by two orders of magnitude.

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