NCSX

TO: M. ZARNSTORFF

FROM: H. W. KUGEL

SUBJECT: NCSX C-SITE OPERATION LIMITS

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1. Introduction

The effective annual D-D operation limits on NCSX using the PBX-M C-Site facility will be paced by maintenance requirements and by radiation restrictions. Based on previous embodiments of fusion experiments in this facility, it is expected that equipment reliability and maintenance schedules can be accommodated by routine annual shutdowns, and that the dominant pacing annual operations limit (for PBX-M-like neutron yields) will be radiation restrictions. These restrictions will determine the effective seconds of NBI D-D operation allowed per year, and consequently, the number of discharges of a given pulse length. This report discusses the expected NCSX C-Site operation limits due to radiation yields.

2. Neutron Source Rates, Yields, and Dose-equivalents

The NCSX facility will be designed to accommodate heat loads and peak neutron source rates expected for D-D operation at the power levels and pulse repetition rates allowed by the available auxiliary heating. Given possible NCSX constraints, auxiliary heating power levels used in this report are a nominal 5.5 MW of RF heating for 500 msec and 5.5 MW of Neutral Beam tangential injection for 500 msec. In addition, the NCSX systems and facility may be designed for heat loads and peak neutron source rates envisioned for 5 sec long-pulse D-D operations. This report considers 0.5 sec and 5 sec D-D pulse lengths, and the feasibility of a small number of 60 sec demonstration pulses.

2.1 NCSX Radiation Shielding

NCSX D-D operations in the PBX-M Test Cell should exhibit radiation field characteristics similar to those measured for PBX-M. Typical PBX-M Control Room neutron dose-equivalents were $< 2.1 \times 10^{-14}$ mrem per PBX-M DD-neutron, and gamma dose-equivalents were $< 1 \times 10^{-15}$ mrem per PBX-M DD-neutron. Assuming similar radiation conditions for the NCSX Control Room, and a Control Room radiation limit of 500 mrem per calendar-year as measured by stationary wall detectors (actual worker dose-equivalents will be less), then the total yield limit will be about $2.3 \times 10^{+16}$ NCSX DD-neutrons per calendar-year with the present shielding. The PBX-M Control Room dose-equivalent was attributed primarily to reflected neutrons entering the Control Room from above the shielding wall as the result of reflections from the upper walls and ceiling of the Test Cell. As an upgrade

option, it appears feasible to increase the shielding by a factor of at least 12, and thus permit a total yield limit of about 2.7 x 10^{+17} NCSX DD-neutrons per calendar-year.

2.2 NCSX Neutron Rates

As estimate of the NCSX radiation field can be obtained by considering NCSX operation in a high-β regime comparable to the PBX-M high-β case [1]. The PBX-M 6.8% high-β case at 1.1 T with 5.5 MW of NBI gave a TRANSP estimated D-D neutron rate of 3.2 x 10^{14} neutrons/sec. The thermonuclear contribution to this neutron rate (*i.e.*, neglecting the beam target contribution) was 6 x 10^{13} D-D neutrons /sec. These rates are used to estimate the number of RF and NBI heated discharges allowed per calendar year by an NCSX device with similar neutron rates.

2.3 NCSX Discharges Allowed Per Calendar Year BY Control Room Radiation Limit

Table 2.3.1 shows the estimated NCSX discharges per calendar year for various plasma discharge lengths at full parameters with the present shielding and with a feasible x12 upgrade in shielding.

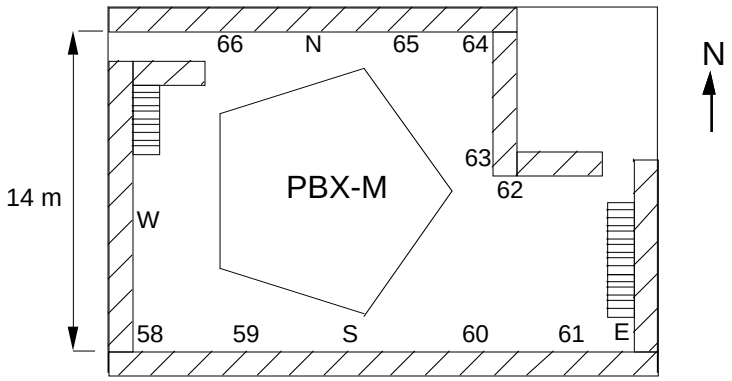
Table 2.3.1. The dose-equivalent per NCSX D-D neutron was assumed to be 2.1 x10^{-14} mrem per NCSX D-D neutron and the Control Room radiation limit 500 mrem per calendar-year.

Heating Operation With Present Shielding	Estimated D-D neutron rate (n/sec)	Total D-D neutrons per calendar year	Total D-D discharge seconds per calendar year*	Total D-D 0.5 sec discharges per calendar year*	Total D-D 5 sec discharges per calendar year*	Total D-D 60 sec demo discharges per calendar year*
RF-only (5.5 MW)	6 x10^{13}	2.38x10^{16}	396.8	793.7	79.4	6.6
RF + NBI (11 MW)	3.8x10^{14}	2.38 x10^{16}	62.6	125.2	12.5	1.0
Operation With x12 Shielding Upgrade						
RF-only (5.5 MW)	6 x10^{13}	2.86 x10^{17}	47,667	95,333	9,533	794
RF + NBI (11 MW)	3.8x10^{14}	2.86x10^{17}	752.6	1505	151	12.5

*Actual number of discharges could be much greater because not all discharges would be at full parameters.

3. NCSX D-D Operations and Measured PBX-M Dose-Equivalents in the Test Cell

Expected NCSX radiation levels in the Test Cell will be sufficiently low during D-D operations to allow placement of electronic equipment in the Test Cell for many years of D-D operation. Fig 3.1 is a partial schematic plan view of the PBX-M Test Cell showing the locations of preliminary mid-plane neutron and gamma radiation contour measurements performed during October 1993 using Vendor Film Badge Dosimeters.



PBX-M TEST CELL

Fig. 3.1

Table 3.1 gives the preliminary mid-plane neutron and gamma radiation contour measurements performed during October 1993 using Vendor Film Badge Dosimeters.

Table 3.1

Test Cell Mid-plane Location	Gamma Dose-Equivalent (mrem/DD-n)	Neutron Dose-Equivalent (mrem/DD-n)
W		1.0E-12
58	4.1E-14	2.9E-13
59	1.4E-13	9.8E-13
S		1.1E-12
60		1.3E-12
61	3.1E-14	6.0E-13
E		3.3E-13
62	3.1E-14	5.9E-13
63		4.4E-12
64	7.1E-14	7.6E-13
65	1.5E-13	3.8E-12
N		1.3E-12
66	3.1E-14	5.8E-13

The PBX-M Mid-plane radiation fields (Table 3.1) were dominated by the neutron field which was about 10x greater than the gamma field. The highest dose-equivalents per DD-neutron in the PBX-M Test Cell were measured opposite PBX-M windows. Table 3.2 gives typical dose-equivalents expected at radiation Streaming and Non Streaming locations on the NCSX Platform.

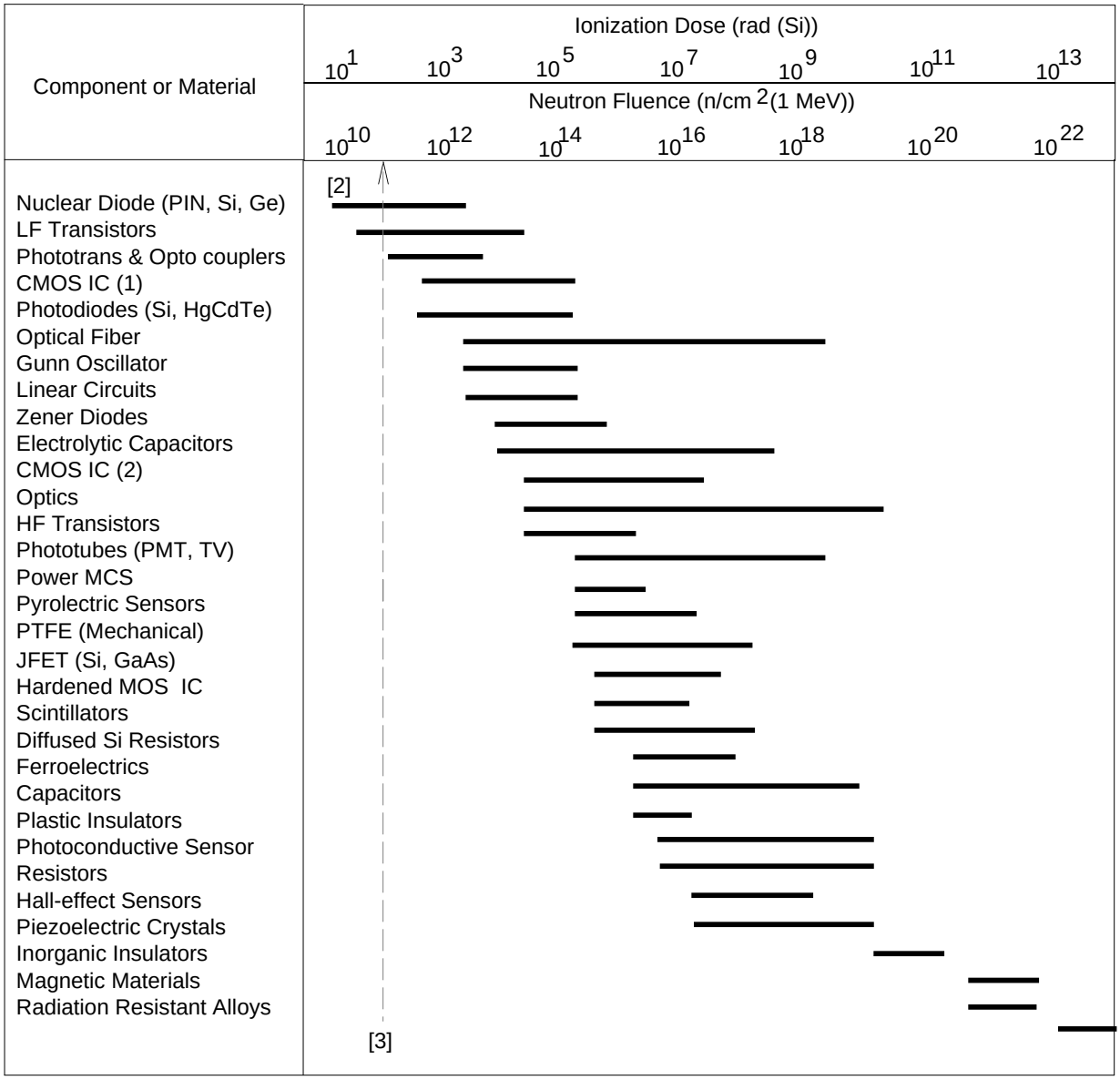
Table 3.2.

Location	n-Dose-Equivalent per PBX-M DD-n (mrem/DD-n)	n-Dose-Equivalent for 2.7×10^{17} DD-n per calendar year	Fluence @ 5m for 2.7×10^{17} DD-n per calendar year (possible upgrade)
Average for PBX-M Non-Streaming Locations	5.9×10^{-13}	159 rem	if all n @ 1 MeV 8.6×10^{10} n/cm^2
Average for PBX-M Streaming Locations	2.2×10^{-12}	594 rem	if all n @ 1 MeV 3.2×10^{11} n/cm^2

Comparison of the results shown in Table 3.2 with Table 4.1 which shows the radiation tolerance of components for fusion diagnostics indicates that neutron radiation levels in the NCSX Test Cell will be low enough to allow placement of electronic equipment in the Test Cell for many years of D-D operation.

4. NCSX Radiation Tolerance

Table 4. RADIATION TOLERANCE OF COMPONENTS FOR FUSION DIAGNOSTICS [1]



NOTES:
[1] J. F. Baur, et. al., "Radiation Hardening of Diagnostics for Fusion Reactors", General Atomics Report No. GA-A16614 UC-20, December 1981.
[2] Solid bar begins at dose and fluence at which the most sensitive components show significant degradation. Solid bar ends at dose and fluence at which least sensitive components show significant degradation. Dominant damage mechanisms are either bulk damage or ionization.
[3] Neutron fluence for a yield of 2.7x10+17 NCSX DD neutrons per year @5 m, and dose if all incident neutrons are scattered down in energy to 1 MeV.

5. NCSX PPPL Property Line Design Objective

As in the case of the PBX-M Mid-plane, the PBX-M Roof radiation fields were dominated by the neutron field which was about 10x greater than the gamma field. Fig. 5.1 shows preliminary neutron and gamma radiation contour measurements performed during October 1993 using Vendor Film Badges on the roof over PBX-M, 12 m above mid-plane, along East-West line, 2 m North of the PBX-M center.

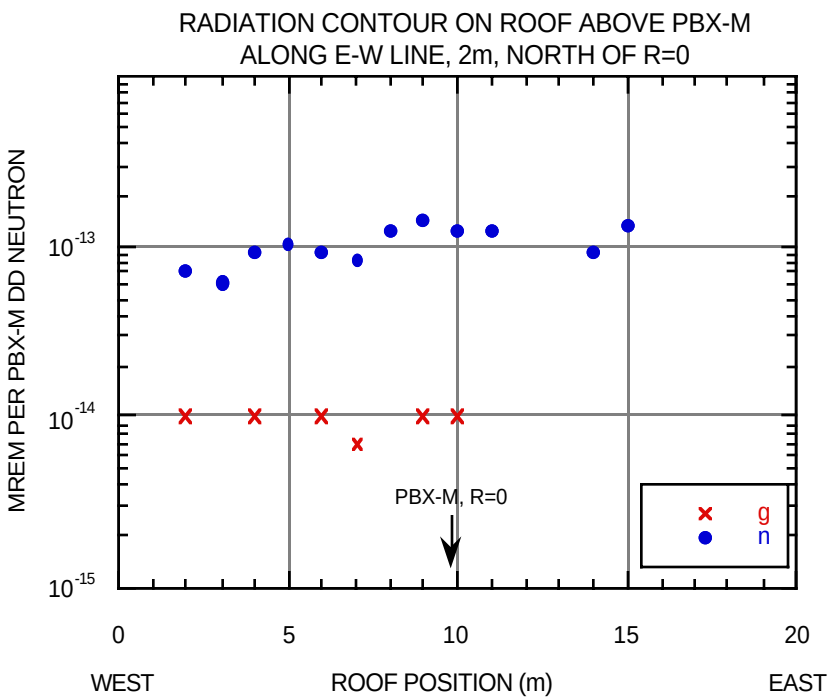


Fig. 5.1

These measured dose-equivalents are attributed to direct radiation transmission and radiation reflected from the upper walls of the Test Cell. This escaping radiation field contributes to the dose-equivalent at the nearest PPPL Property Lines.

The PPPL Radiological design objective, consistent with Regulatory Limits, has been to limit the dose-equivalent at the nearest PPPL Property Lines from all radiation sources and pathways to 10 mrem per calendar year. This design objective can be met by NCSX with the existing shielding

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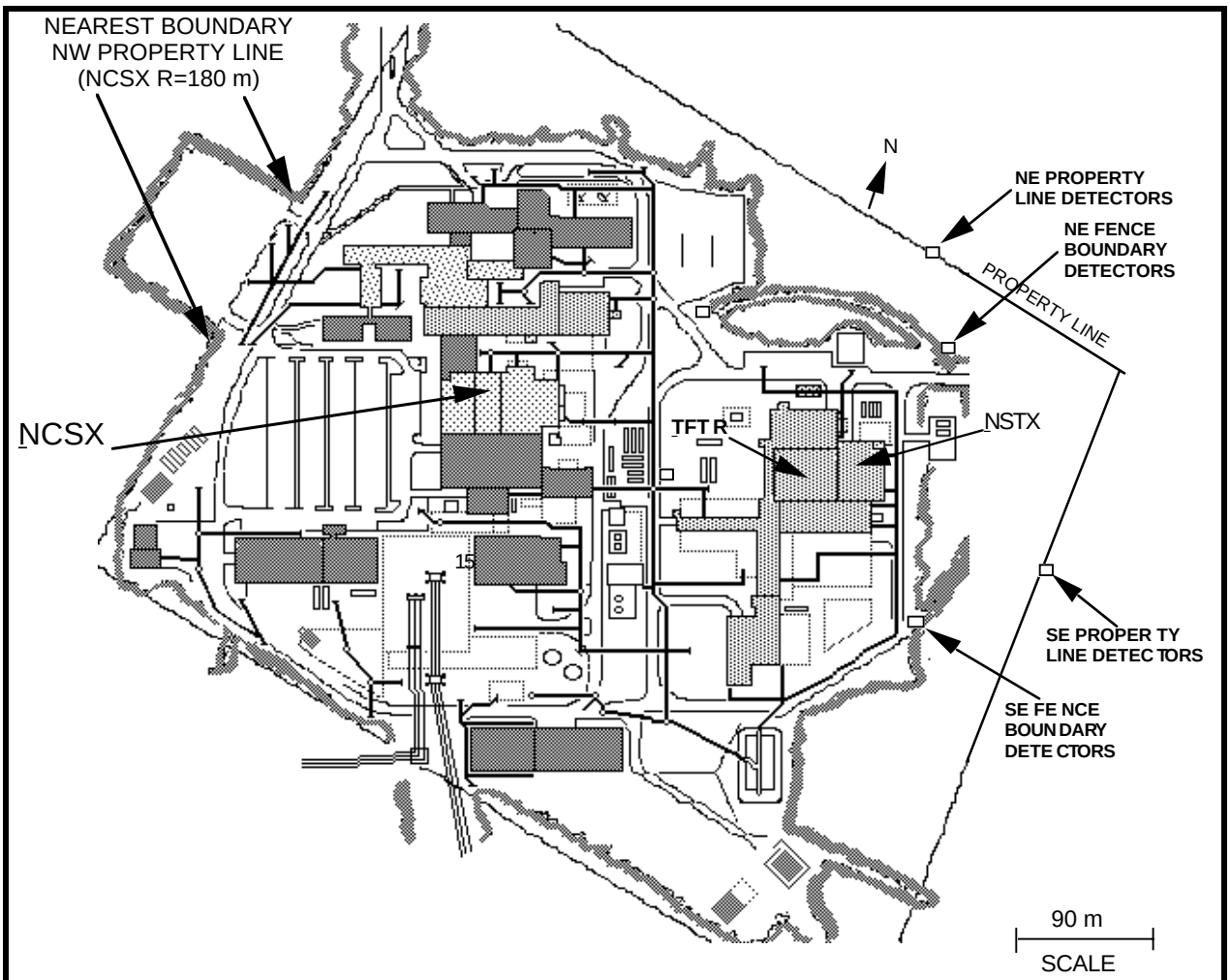
Fig. 5.2 shows a schematic plan view of the PPPL Site, the location of NCSX, and the nearest NW Property Lines at a major radius of about 180 m. The radiation field at this distance is expected to be predominantly due to D-D neutrons reflected from upper Test Cell structures and the sky (skyshine) as was found for TFTR. [2,3]



PPPL SITE PLAN SHOWING NCSX
C-SITE TEST CELL LOCATION
RELATIVE TO NEAREST PROPERTY LINES

Fig. 5.2

At the same major radius distance of 180 m, the TFTR D-D neutron dose-equivalent in the NE direction, was a factor of about 200 lower than immediately outside the TFTR Test Cell North shield wall.[1,2] Using this factor as a preliminary estimate for the NCSX far radiation field characteristics, it is appears that for a Control Room calendar year dose-equivalent of 500 mrem, the dose-equivalent from NCSX D-D neutrons at the nearest NW Property Lines will be of order 2 mrem, which is well within the design objective. Practical constraints on operations, as well as ALARA considerations will reduce the annual Control Room to below 400 mrem and Property Line dose-equivalents to below 1 mrem.

6. Upgrade of the NCSX Test Cell Radiation Shielding

PBX-M is the third embodiment of a tokamak in the PBX-M Test Cell (preceded by PDX, and PBX). In 1979, a conceptual design was carried out for the installation of about x12 additional radiation shielding in the PDX Test Cell to accommodate long pulse 5 sec deuterium Neutral Beam operation. A thorough analysis of the PDX shielding requirements was carried out by EG &G Idaho [4], and additional engineering design and cost studies were performed by PPPL. Table 6.1 shows the resulting cost estimate for the PDX radiation shield upgrade. Using the DOE Escalation Rate for 1979-1998 gives a total radiation shield upgrade cost of $3060.6 K in 1998. Although advances in commercially available radiation shielding materials might result in simplifications to the PDX design, this design is a useful preliminary indicator for an upgrade of the radiation shielding for NCSX long pulse operation.

Table 6.1. Cost Estimate for installation of the proposed 1979 upgrade of the PDX Radiation Shield.

Element	$K (1979)	$K (1998)*
Shield Ceiling Structure	100.9	220.1
Roof Tanks	327.2	713.6
Wall Extension	143.3	312.5
Doors, Hatches, and 4" wall Shields	451.5	984.7
Safety and Auxiliary Systems	117.3	255.8
Instrumentation and Interlocks	20.4	44.5
Area Preparation	9.8	21.4
Management (EDIA)	49.9	108.8
Sub-Total 15% Contingency	1220.3 183.0	2661.4 399.2
TOTAL	1403.3	3060.6

* Using DOE Escalation Rate of x2.181 for 1979-1998.

Increasing the shielding by 100x would allow more long-pulse discharges per year. In principle thicker walls could be accommodated, however, the primary contributions to the Control Room dose-equivalents are *reflections over the wall* from the ceiling, the upper regions, and the sky. Shielding the entire Test Cell might require a formidable edifice to support the wall and thick ceiling structures, and hence, might be easiest to install prior to machine installation, rather than during an upgrade period. Placing only a low shield ceiling over the machine, as in the case of the PDX 12x shielding upgrade, would reduce the amount of Test Cell volume to be shielded. This Cost estimates for increasing the shielding by 100x are not available at this time.

References

1. N. Sauthoff, *et al.*, " PBX-M Research progress: Approach to Second Stability", in Plasma Physics and Controlled Nuclear Fusion Research, IAEA 1990, V1, p 709, (IAEA-CN-53/E-II-4.

2. H. W. Kugel, *et al.*, "TFTR Radiation Contour and Shielding Efficiency Measurements During D-D Operations", Fus. Technol., **26**, 963 (1994).

3. H. W. Kugel, *et al.*, "Measurements of Tokamak Fusion Test Reactor D-T Radiation Shielding Efficiency", Fus. Eng. and Design, **28**, 534 (1995).

4. R. A. Grimesey, *et al.*, "Preliminary Studies for the PDX Tokamak Radiation Shield Design," EG&G Idaho Report (April 1979).