MICHIGAN MEMORIAL PHOENIX PROJECT

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THE UNIVERSITY OF MICHIGAN

A REACTOR CORE MODIFICATION TO ENHANCE BEAMS FOR THERMAL NEUTRON SPECTROMETERS

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I. Introduction

A common problem encountered in thermal neutron spectrometer experiments is that of maximizing the collimated thermal neutron flux and minimizing the detector background. The usual solution of this problem is to operate the reactor at the maximum practical power level, select the beam port that has the highest neutron flux, build the most efficient collimator practical, and use as much neutron shielding around the detector as space will allow. However, eliminating the fast neutron component in the beam is a means of reducing detector background independent of the reactor power level.

An arrangement for reducing the fast neutron flux has been incorporated in the design of the Brookhaven National Laboratory High Flux Beam Reactor.(1) The beam ports of the HFBR are placed tangentially to the reactor core face. As a result of the anisotropy of the fast neutrons in the reflector region, this geometry produces a beam with fewer fast neutrons than the usual radial geometry. The D_2O reflector sustains the thermal flux over the beam port source planes, so that the thermal neutron current is not reduced by the tangential configuration.

A similar method for reducing the fast neutron flux in the spectrometer beam ports of The University of Michigan's 2 MW light water pool reactor has been investigated experimentally. The experiment consisted of installing a heavy water tank adjacent to the reactor core in a position which effectively converted two beam ports from a radial geometry to a tangential arrangement having a D_2O source region. The results show that a significant improvement in the quality of thermal beams from light water moderated reactors can be achieved by such an installation. The heavy water tank is small, inexpensive, and practical to operate.

II. Modification Concept

Neutron spectroscopy constitutes a major fraction of the research programs at The University of Michigan Ford Nuclear Reactor (FNR). Consequently, considerable effort has been exerted to improve the reactor as a source of neutrons for spectrometer research. In a study on the prediction of exit thermal neutron current from reactor beam ports, (2) S. C. Cohen investigated variations in reflector materials and core-reflector configurations. The results indicated that a slab core configuration employing D_2O reflection for beam extraction was desirable. The slab core configuration enhances neutron leakage in the narrow dimension. The diffusion and slowing down properties of the D_2O make it a suitable medium to contain this high leakage current for beam extraction.

After reviewing the existing structural arrangement of the FNR it was decided that a simple and economical modification would be a slab of heavy water in the form of a tank placed on the existing fuel grid plate. It was observed that a D_2O slab 12 inches thick could be used to convert two of the existing beam ports into a tangential geometry similar to the BNL concept. The modification concept is shown in Figure 1. Ports "A" and "J", which have been effectively converted from radial to tangential beam ports, serve a triple axis diffraction spectrometer and a mechanical monochromator spectrometer respectively.

Calculations were performed for the proposed 12 inch D_2O tank using two-group, two-dimensional diffusion theory. The calculations employed region and group dependent bucklings for the vertical dimension. The change in thermal beam currents (0 to .625 ev) for "A" and "J" ports in tangential versus radial configuration was based on the predicted thermal fluxes at the beam port source planes. The calculations indicated that the thermal

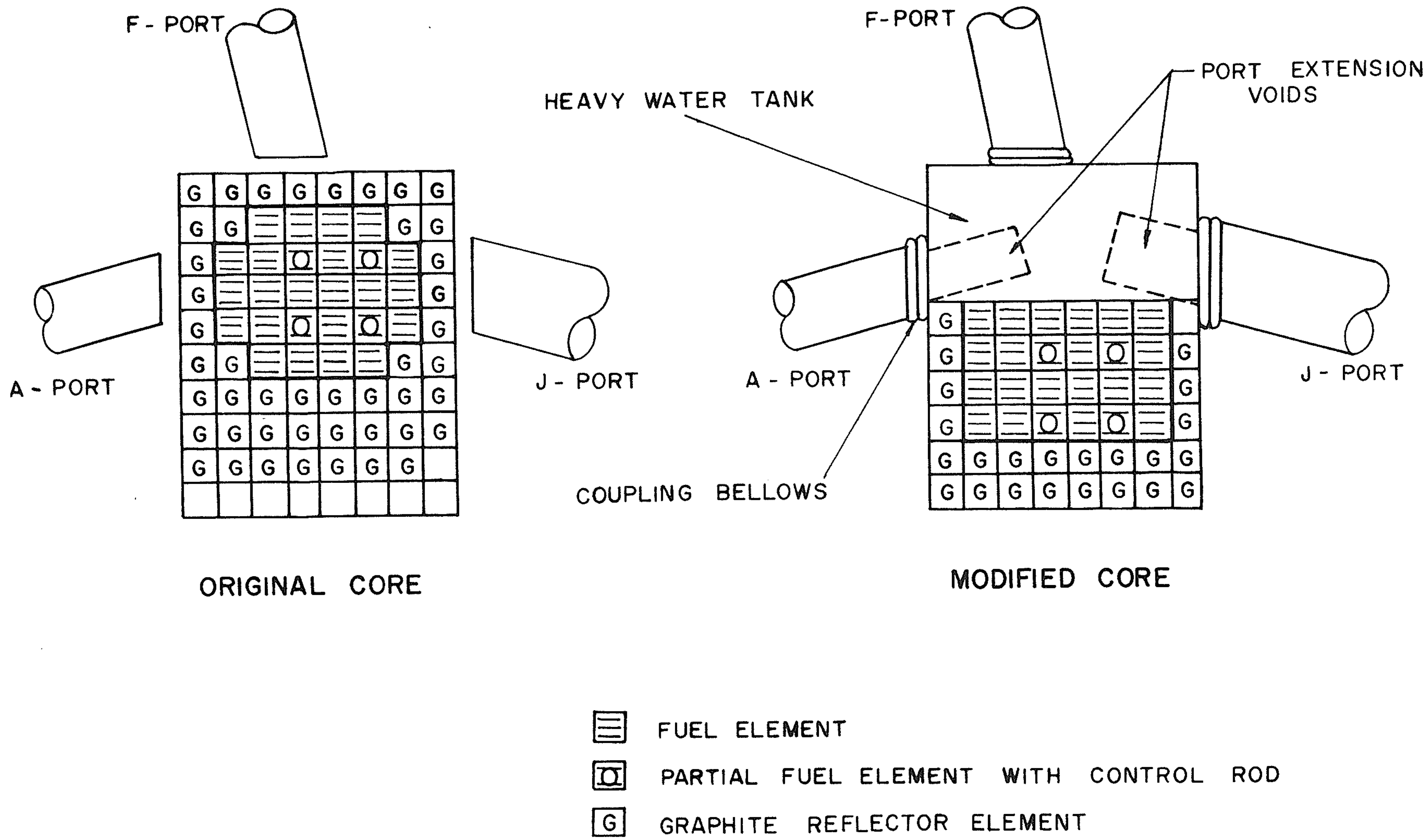

FIGURE 1: REFLECTOR MODIFICATION CONCEPT

beam port current would be increased a factor of 3 by the D_2O tank. The integrated fast currents above .625 ev were calculated by hand using the integral Boltzmann equation. A 20 per cent reduction in the total fast current above .625 ev was predicted. A one dimensional transport theory code was used to calculate the very fast flux. Cross sections for this calculation were generated from four energy group diffusion parameters. The source for the transport code was taken from the two-group diffusion theory calculation. These calculations showed that the integrated fast beam flux above .821 Mev would be down by a factor of 11.

III. Design Considerations

The calculations for the unperturbed medium show that the maximum thermal flux on the extrapolated axes of the tangential beam ports occurs approximately 3 inches from the intercept of the axes. Therefore, a greater thermal current could be realized by extending the existing collimators into the center region of the tank. The port extension voids shown in Figure 1 are aluminum cans approximating the projected collimator dimensions. Since the FNR core is suspended from a movable bridge, it is not desirable to rigidly attach the beam ports to the end of the port extension voids. A collapsible metal bellows was selected as a means of coupling the port extension voids with the beam ports. This arrangement effectively extends the collimators into the central region of the heavy water tank.

The tank was designed with five vertical holes to provide for sample irradiations in the D_2O reflector. The location and sizes for these facilities are shown in Figure 2.

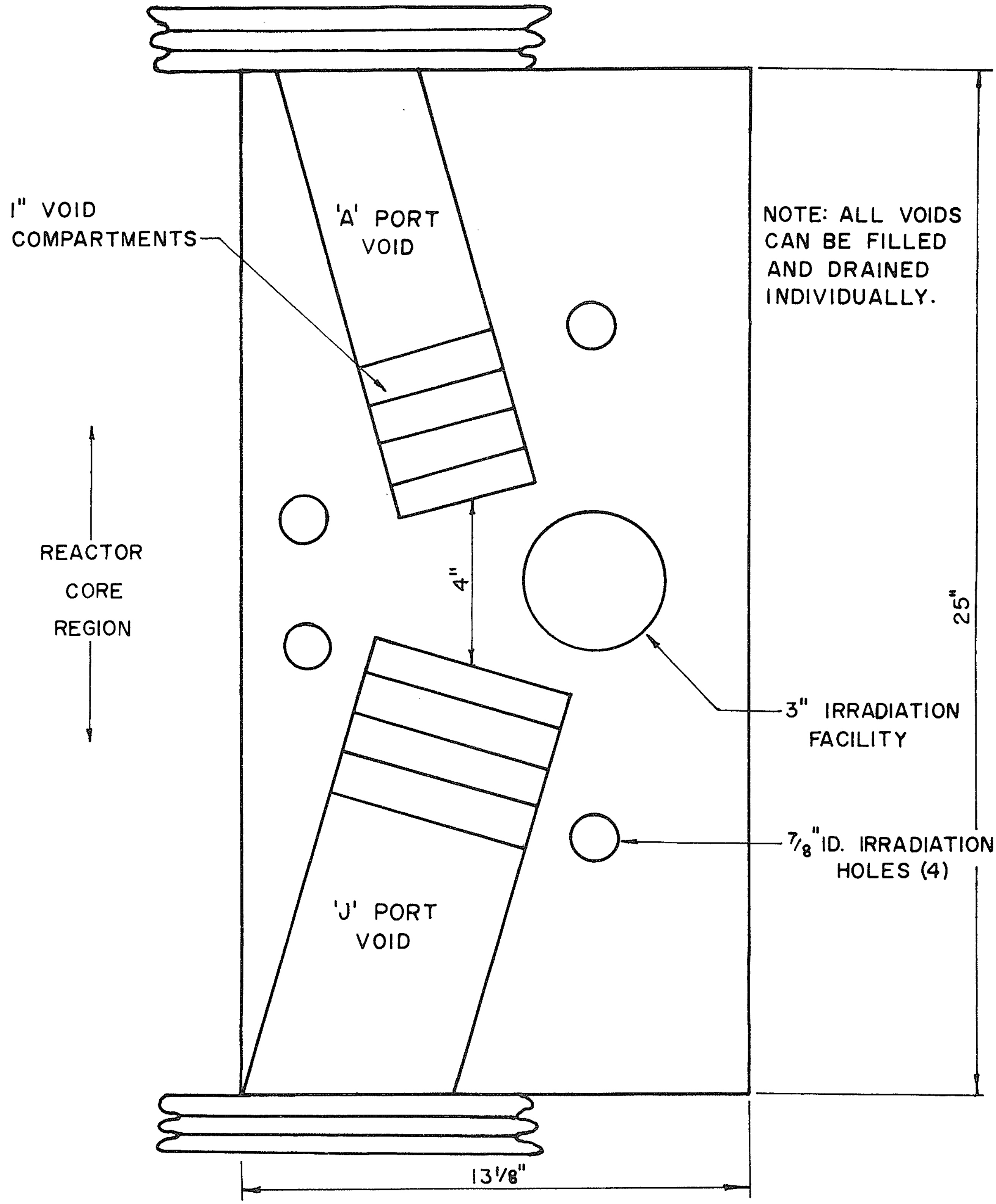

FIGURE 2: CROSS SECTIONAL VIEW OF EXPERIMENAL TANK

An important factor in the design considerations was that of reactor safety. A hazards evaluation of the modification concept was performed.[3] The hazards analysis concluded that the reactor could be operated safely at 2 megawatts with the D_2O reflector tank provided that 1) the tank be constructed of aluminum to make it compatible with the aluminum clad fuel elements, 2) the tank be provided with a vent to release hydrogen produced from radiolytic decomposition of the D_2O, 3) the reactor be substantially subcritical while manipulating the D_2O filled tank, and 4) the tritium inventory in the D_2O tank be maintained at less than 50 curies. Calculations indicated that any leakage of D_2O into the fuel region would add negative reactivity due to spectrum hardening.

IV. Preliminary Measurements

The perturbation of the thermal flux in the D_2O medium by the port extension voids made the calculations based on the unperturbed medium unreliable for predicting the spacing between the void cans. Rather than attempting to calculate the optimum spacing, a preliminary experiment was planned to measure the effects of the spacing between the cans on the beam port current. The test tank was constructed with void cans having compartmented sections which could be filled and drained with the tank in the operating position. A view of the test void can design is shown in Figure 2. The preliminary experiment also provided a means for testing the tank installation procedure and the bellows coupling technique.

After completing the tank installation the core was loaded using the critical experiment procedure. The experiment consisted of operating the reactor at low power and monitoring the beam port flux as a function of void can spacing over the range of

4 inches to 12 inches. The results show that the thermal beam intensity is changed by only a few per cent when the void can spacing is varied over this range. An optimum spacing of 8 inches was selected for the final design. The effect of light water in the 7/8 inch and 3 inch irradiation holes was also measured and proved to have little effect on the collimated beam intensity. A reactivity worth measurement of the D_2O tank was made by replacing the heavy water tank with standard graphite reflector elements. It was observed that a 3 inch row of graphite had a reactivity worth approximately equal to the worth of the 12 inch thick heavy water reflector.

In preparation for the final measurements the standard graphite-reflector core was loaded, and a routine vanadium scattering experiment was performed on each of the neutron spectrometers at an accurately calibrated reactor power level. In addition to the scattering measurements, a proton recoil fast neutron telescope [4] was used to measure the fast neutron leakage spectrum in the collimated beam at "J" port. Following completion of the reference measurements the modified D_2O tank was installed for the final experiment.

V. Final Experimental Results

The standard vanadium scattering experiment was repeated with the reactor operating at full power. The experiment consisted of measuring the monochromatic flux incident on the vanadium target, the scattered flux from the vanadium target at some reference angle and the detector background signal. All measurements were taken with an accurately calibrated power level.

The triple axis diffraction spectrometer measured a thermal flux increase of 1.8 compared to the original core. The background was reduced by a factor of approximately 6. The overall signal-to-background improvement with the D_2O reflector was therefore approximately 11. The mechanical monochromator operating at "J" port also realized a thermal flux increase of 1.8. However, the detector background for this machine was reduced by a factor of 3.2. The signal-to-background increase realized by the mechanical monochromator was 5.8. A summary of the results is shown in Table 1.

TABLE 1 - SUMMARY OF IMPORTANT RESULTS

PARAMETER MEASURED	RATIO OF D_2O MEASUREMENTS TO ORIGINAL CONFIGURATION MEASUREMENTS		
	TRIPLE AXIS SPECTROMETER	MECHANICAL MONOCHROMATOR	NEUTRON DIFFRACTOMETER
Thermal Beam Intensity	1.8	1.8	1.25
Detector Background	0.16	0.31	—
Signal-To-Background	11.2	5.8	—

The fast neutron spectrum measurements were repeated with the proton recoil telescope in the collimated beam at "J" port. The data are shown in Figure 3. The large drop in absolute amplitude and the increasing attenuation with neutron energy are clearly evident. This result may be quite consistent with the background attenuation of 6 seen at the crystal spectrometer.

The importance of the coupling bellows was observed during an experiment in which the bellows pressure was gradually reduced while monitoring the thermal flux in the collimated neutron beam. The results are shown for each of the three ports in Figure 4. It is estimated that the pressure reduction required for 50 per cent attenuation of the thermal beam results in approximately 1/4 inch of light water between the beam port and the heavy water tank. To assure no change of beam intensity during operation, the bellows were provided with a pressure monitor and alarm system so the experimenter can be alerted in the event the bellows pressure drops significantly. Beam measurements taken at "F" port with and without the bellows in position indicated that the thermal neutron flux attenuation in a 1 1/2 inch light water gap between the tank and the beam port is approximately 2.5. Operation of a diffraction spectrometer at "F" port, which was not provided with a void can extension, showed a 25% increase in the thermal intensity over the conventional graphite reflected core.

VI. Operational History

The operational performance of the heavy water tank since its final installation on March 1, 1965, has been totally satisfactory. Preliminary tritium production rate measurements indicate that the D_2O will have to be changed or diluted after about every 18 months to keep the total inventory below 50 curies. There has been no

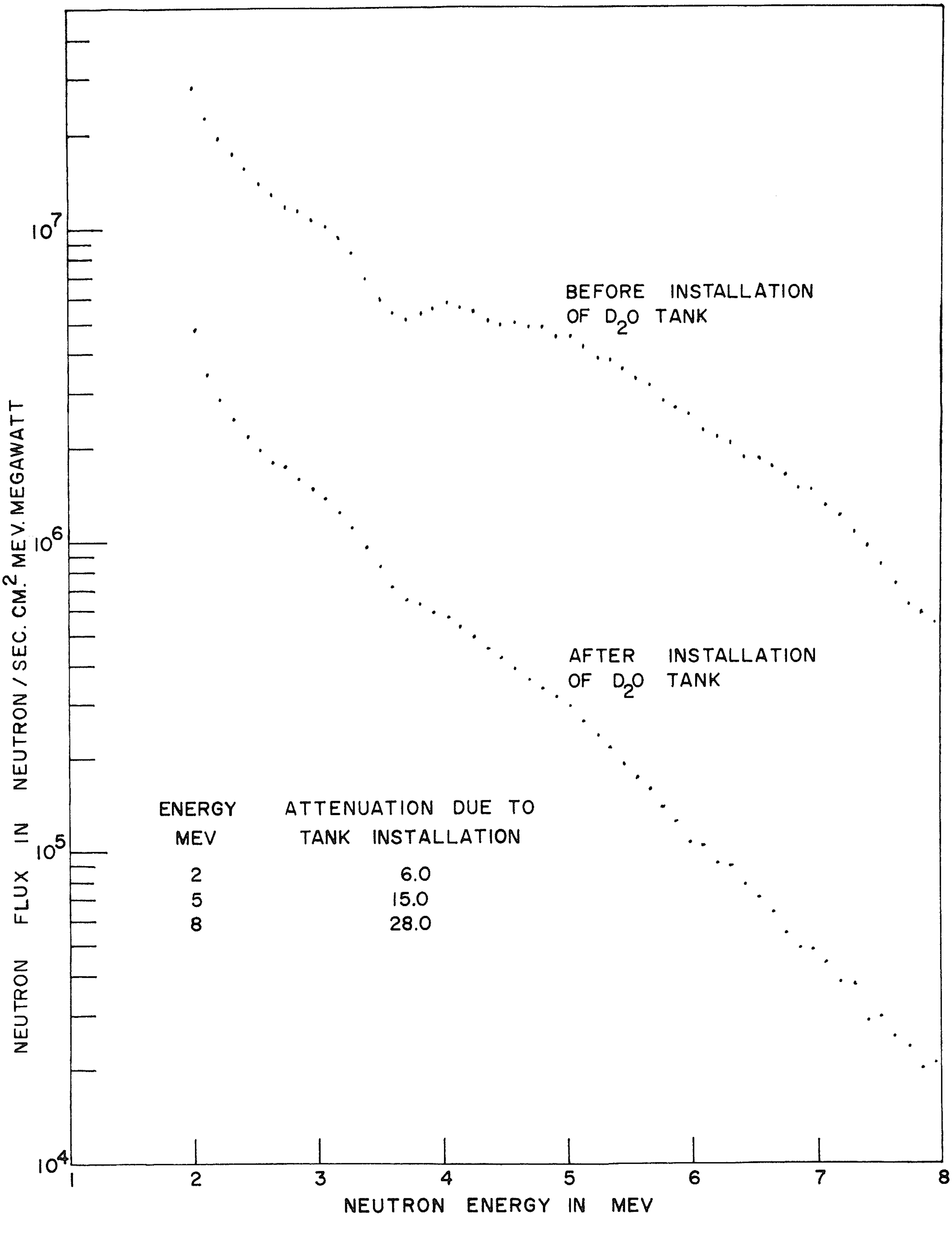

FIGURE 3: NEUTRON SPECTRA OF COLLIMATED BEAM FROM TANGENTIALLY CONVERTED PORT

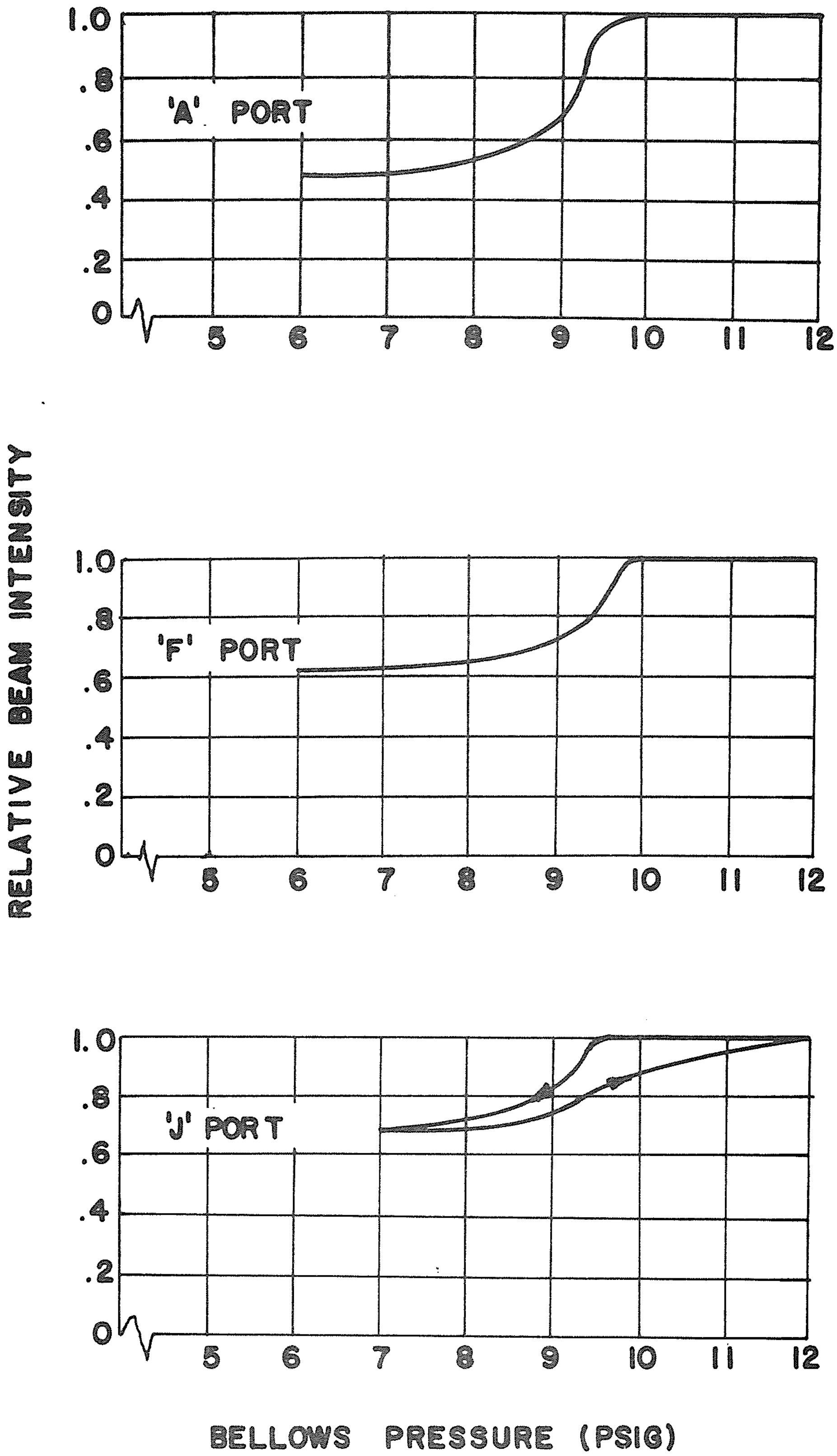

FIGURE 4: DEPENDENCE OF BEAM INTENSITY ON BELLOWS PRESSURE

indication of significant radiolytic decomposition or evaporation of the D_2O. A detailed discussion of the operational aspects of the tank will be presented at the Operations Division Meeting of the American Nuclear Society on July 28, 1965.

VII. Conclusions

Light water moderated research reactors can be substantially improved as sources for thermal neutron spectrometer experiments by providing low absorption moderating materials for extracting beams tangentially from the core face. The improvement by a factor of 1.8 in the intensity of the thermal neutron beams realized at the FNR by replacing the conventional graphite-light water reflector region with a heavy water region is equivalent to increasing the reactor power level to 3.6 MW. The importance of the reduction in the detector background, however, is clearly dependent on the signal-to-background ratio for each experiment. A figure of merit for the overall signal-to-background increase may be stated in terms of an equivalent reactor power level. This equivalent power level is defined as the power required with the original configuration to duplicate in the same counting time the statistics obtained with the D_2O tank. For that class of experiments having a signal-to-background ratio of 1.0 using the original core, the increase of 6.0 in the signal-to-background by the D_2O tank is statistically equivalent to operating at 8.0 MW with the old core.

References

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