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A NEWLY DEVELOPED IRRADIATION FACILITY AT LAMPF*

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Abstract

LAMPF is a National Facility designed, built and operated for the USAEC by the Los Alamos Scientific Laboratory. It is a linear proton accelerator designed primarily as a meson factory, but includes a neutron radiation effects facility. This presentation describes how LAMPF has been developed as a neutron irradiation damage facility, and informs potential users about the facilities available for their experiments.

Introduction

The Clinton P. Anderson Meson Physics facility (referred to as LAMPF by its users and builders) is a National Facility designed, built and operated for the USAEC by the Los Alamos Scientific Laboratory. It is a linear proton accelerator designed primarily as an intense meson factory. A massive target must absorb completely the residual proton beam after it passes all the various experimental channels. This residual beam will be intense when the accelerator is operating at full designed power (1 mA at 800 MeV) and will generate considerable heat and radiation in the absorbing target. Atomic nuclei in this beam stop will have nucleons ejected by the intranuclear cascade process and will emit additional evaporation nucleons from the residual excited state. The yield of neutrons is known as a spallation evaporation source. The intranuclear cascade component of the spectrum is a high energy component. Some neutrons will have energies up to the incident proton energy (800 MeV) in the forward direction of the proton beam. This component is anisotropic not only in energy but also in intensity: it is more intense in the direction of the proton beam. On the other hand, the evaporation component is isotropic in intensity and in energy distribution.

The spallation-evaporation neutrons will be a useful by-product of LAMPF and will be available for neutron irradiation effects studies. This presentation describes the development of LAMPF as a neutron radiation damage facility. Procedures for interested experimentalists to become users are also described.

General Information

LAMPF will be available for use by any qualified member of the scientific community. Use of the facility is granted to experimenters on the basis of the scientific merit of the proposed research and on the experimenter's qualifications. Program support is not considered. Collaboration is encouraged. Restrictions on the participation of foreign scientists are minimized. Proposals for experiments submitted by foreign scientists which are found acceptable will be referred to the USAEC for approval prior to scheduling. Each non-LASL user will sign an appropriate AEC Guest Patent Agreement. Prior patent agreements between non-LASL users and their home installation are recognized. It is expected that perhaps 50% of the beam time will be allocated to non-LASL users.

A decision on the scientific merit of a proposed program is made by the Director of LAMPF. The Director is guided by an evaluation from the Program Advisory Committee (PAC). To initiate an experiment, a formal proposal is submitted to the Director of LAMPF. The proposal is then evaluated by PAC. PAC is made up primarily of nuclear scientists, but they request advice from experts in the radiation damage field whenever necessary. Prior to a final decision, a spokesman for the participants presents and defends, if necessary, the proposal before PAC.

*Work performed under the auspices of the United States Atomic Energy Commission.

Users do not pay a beam charge. Users will normally provide their own apparatus, travel and shipping expenses, salaries and their expenses. LASL will normally be reimbursed for major computing time, design, fabrication, testing, delivery, and operation and maintainence of specialized equipment. Charge rates, including direct expense and distributed overhead costs, will be those in effect at LASL at the time. Users will have access to a LAMPF equipment pool. A report entitled "LAMPF Users Handbook" (1) is available on request. It discusses the facilities and services available to users in detail including the computing facilities, on-line computers for experiment control and data acquisition, technical assistance by the LASL Staff, safety and installation of experiments.

To receive the LAMPF Users Handbook, send your request to the LAMPF Users Group Secretary, MP Division, P. O. Box 1663, Los Alamos, New Mexico 87544. A liaison office is set-up to aid users in matters ranging from local housing to directing a user to the proper administrative aid within the LAMPF Administration.

Radiation Effects Information

A radiation damage working group was formed in 1972. User groups provide a communication channel between the user and the LAMPF administration, as well as between specific projects and the administration. W. V. Green (LASL) is the Chairman (1972-1973) of the Radiation Damage Working Group, and E. G. Zukas (LASL) is the secretary. T. H. Blewitt (ANL) is the working group representative to the technical Advisory Panel (TAP). TAP is concerned with new developments at LAMPF. The list of those who have indicated an interest in belonging to the Radiation Damage Working Group include 87 non-LASL names. These are about equally divided between those on University Staff and those working at National Laboratories. Two meetings of the working group were held in 1972. Various aspects of LAMPF as a radiation damage facility were considered. Newsletters and meeting minutes supplemented the meetings.

The main interest of the present members of the working group is in neutron radiation effects. Perhaps 10% of the interest is in proton radiation effects, with a lesser interest in meson lattice-defect interactions.

The number of neutrons from a spallation evaporation source is determined by the beam current (1 mA for LAMPF) and the number of neutrons per incident proton. Figure 1 shows the neutron yield as a function of incident proton energy for various target materials. High atomic number targets, such as uranium or lead, have a high yield of neutrons per proton. Low atomic number targets have lower yields, but the neutron spectrum is harder. The flux at a neutron radiation damage station is determined by the neutron source strength, the geometry relating the source to the experiment, and the moderating materials surrounding the source and the experimental cavity. Two features of spallation-evaporation sources make them attractive for neutron radiation effects studies: 1) a reactor facility approaches a point experiment in an infinite source, the converse is true for spallation sources; and 2) the gamma heating is low relative to the neutron flux for spallation sources. The first point makes highly regulated experiments, such as creep tests, electrical resistivity measurements, superconductivity evaluations, etc., practical. There is space to accomodate the necessary electrical leads, cooling water, gas and vacuum lines. The second point makes both low and high temperature irradiations easier to achieve because excessive gamma heat isn't deposited in the samples, grips, cooling lines, and other equipment. High temperature creep experiments are already planned for LAMPF. Low temperature experiments are anticipated in the near future, but

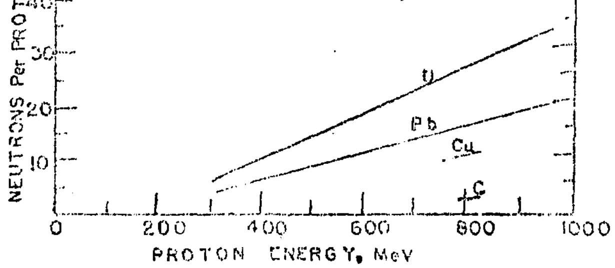

Fig. 1. Neutron yield versus proton energy for various target materials

the accomodations haven't been provided for as yet, mainly because the experimental programs have not been proposed to PAC.

The Neutron Radiation Effects Facility

The experimental area of the neutron radiation damage facility is housed in a cavity directly below the beam stop, Figure 2. The beam stop is an 8" diam x 17.2" (20.3 cm x 43.7 cm) water-cooled copper cylinder capable of absorbing the proton beam at maximum operating power (1mA and 800 MeV). Experiments are inserted into the radiation cavity on the end of a 2" wide x 8" high x 26' long (5.1 cm x 20.3 cm x 7.93 m) stringer, Figure 3, driven from the target change pit through a shielded tunnel into the radiation cavity. Each stringer has the capability of carrying 15 pairs of mineral insulated wires for thermocouples, linear variable displacement transformers (LVDT's) strain gages (*and other measuring devices*), 21 air, gas or water passages, and 12 power leads. Provision is also made in each stringer for a small vac ion pump. The utility connector provides for five thermocouples, seven air, water or gas connections and four power leads. Each user of the LAMPF Radiation Effects Facility will be expected to provide his own stringer and furnace (or other experimental chamber). Presently, the cost of a stringer is between $3500 and $5000, depending upon the exact power and instrumentation requirements.

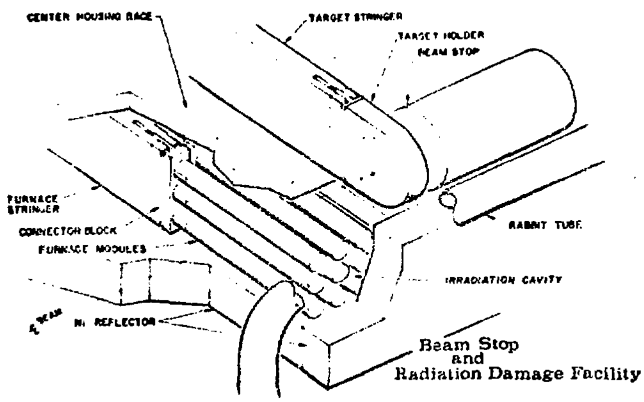

Fig. 2. The neutron radiation damage facility at LAMPF.

The furnace end of the stringer has a remote disconnect that enables plugging various types of modules into the stringer, Figure 4. A second remote plug at the rear connects the stringer to air, power, gas and instrumentation. Each stringer will handle three LASL-type furnaces. If individual requirements demand it, two or more stringers can be joined to accept a larger module or modules.

On completion of an experiment, the stringer is retracted and the furnace (target) remotely removed to the target change pit, Figure 3. The irradiation package is then placed in a transfer cart and removed from the pit for placement into a shipping cask. The irradiation package may then be transferred to one of the hot cells at LASL for removal of the test specimens. Additional tests can be done on the specimens at LASL, or the specimens may be packaged for shipping.

Presently, only one bottom loading transfer cask is available for tranferring material within LASL. Any specialized shipping or transfer casks would be supplied by the experimenter. For our radiation effects experiments, each furnace is a double containment system, Figure 5. The inner unit is a three-zone resistance heater furnace controlled from the specimen temperature through a cascade loop system, Figure 6. The control system is designed to enable the set point to be set manually, or it may be tied directly to a control computer for remote automatic set point.

The radiation effects specimens can be stressed in either of three modes; axial fatigue stress, axial creep stress or cyclic bending. All stresses are applied by pressurizing a bellows. The bellows assembly can be water cooled when necessary to eliminate thermal effects. In addition, the gas pressure is controlled by pneumatic controllers, Figure 7. Displacement will be measured either pneumatically or by using radiation-hardened linear variable displacement transformers (LVDT's). Pneumatic measurement of displacement in a severe radiation environment has been successfully made by Dutton (2), for example, at Whiteshell. This method is based on the measurement of the pressure differences between two chambers when an orifice is partially blocked by a tapered needle moving into the nozzle. This method has a sensitivity of about 25×10^{-6} in. LVDT's have been used successfully at LASL and also by Dr. T. Blewitt (3) at Argonne for measuring small strains during irradiation. Instead of using the usual constant voltage system, a constant current method is employed. This eliminates errors caused by electrical resistance changes.

At the present time, a 50-channel multiplexer, pneumatic controllers, a 200-channel Dymec Acquisition System, and several Brown recorders are available for use by the experimenter on a priority basis.

Dosimetry Requirements

Dosimetry considerations within the Radiation Damage Working Group have been formalized into a Dosimetry Committee which met twice in November, 1972. Multiple foil activation and spectrum unfolding is one method of neutron dosimetry which is actively being pursued. Two members of the Committee, Dr. N. D. Dudey of ANL and Dr. D. M. Parkin of BNL, are developing such dosimetry methods for the Brookhaven Linear Isotope Producer (BLIP) and their work is expected to be directly applicable to the LAMPF facility. Also, a program at Los Alamos Scientific Laboratory is simultaneously establishing a multiple foil activation and unfolding program for LAMPF based upon well established fission reactor methods, using the SAND-II unfolding code.

In addition to foil activation methods, we plan to do time-of-flight measurements. A time-of-flight (T-O-F) tube is installed at 135° from the proton-beam direction and can be used for neutron spectrum calibration from < 100 keV to ~100 MeV. Comparisons of multiple-foil unfolded spectra will also be made with the T-O-F tube for a 200-MeV proton beam incident on a beryllium target, in support of the BLIP program. In addition, serious consideration is being given to using a self-contained T-O-F spectrometer developed by Madey and Waterman. (5) Briefly, this spectrometer measures the time-of-flight for neutrons scattered at a known angle, using the time interval between pulses in two scintillators, the first scintillator being also the scatterer. Madey and Waterman have used this "two-fold coincidence spectrometer" to measure neutron spectra in the 1 to 500 MeV region, using 1- to 5-meter flight paths. Perhaps such a spectrometer could be used for routine neutron flux monitoring at the LAMPF Radiation Effects Facility, as well as for calibration of spectra unfolded from foil activations.

Although gamma-ray flux levels are expected to be low based upon the results of Fullwood, et al.,(6) (e.g., one escaping photon per 12 escaping neutrons for a 15-cm diameter ^{238}U target), simple gamma-ray dose measurements will be made at the radiation damage experimental locations. Such measurements, using silver phosphate glass or other integral dosimeters, should provide reasonable estimates of gamma-ray heating to be expected in the metallurgical experiments. Most of the gamma rays considered by Fullwood, et al. arise from non-elastic neutron interactions with the target and surrounding media; additional capture gamma rays will originate in the predominantly steel and concrete shielding surrounding the radiation damage facility.

Dosimetry requirements at the LAMPF Radiation Damage Facility can be classed in two general categories; viz., irradiation cavity flux mapping and calibration-performed by LASL in implementing the facility, and monitoring of individual experiment exposures - performed by the experimenter with LASL support.

As soon as possible after sufficient beam current is available, mapping of the irradiation cavity fluxes by multiple foil activation will commence. The foils (actually foils and wires, referred to generically as foils) will be positioned on the three-dimensional aluminum grid to obtain reliable data on the spatial distribution of the neutron flux absolute intensity and spectrum. One perturbation which may be studied by 3-D foil activation maps is that due to the presence of the radiation damage test furnaces. Present plans call for using about 10 different types of foils in each packet, covering the energy range from 0 to 30 MeV. The 3-D grid will enable simultaneous neutron spectrum measurements at all the spatial grid points. Gamma-ray dosimeters will also be located at selected grid points. In unfolding the neutron flux spectrum, advantage will be taken of the ANL-BNL experience with BLIP dosimetry below 18 MeV as well as LASL experience with carbon and bismuth foils for neutron energies up to 30 MeV.

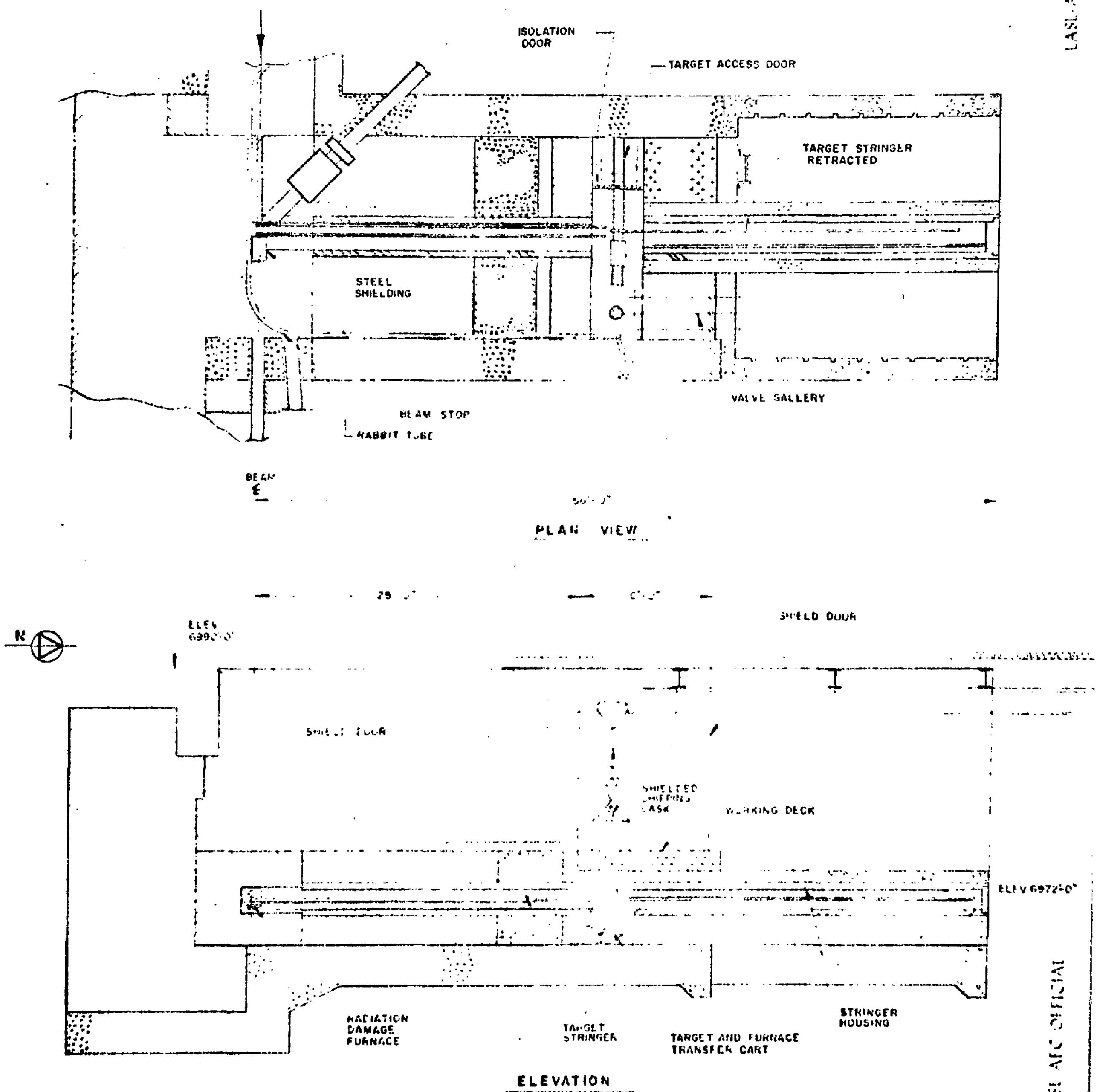

Fig. 3. Radiation Damage Facility Details.

FURNACE MODULES

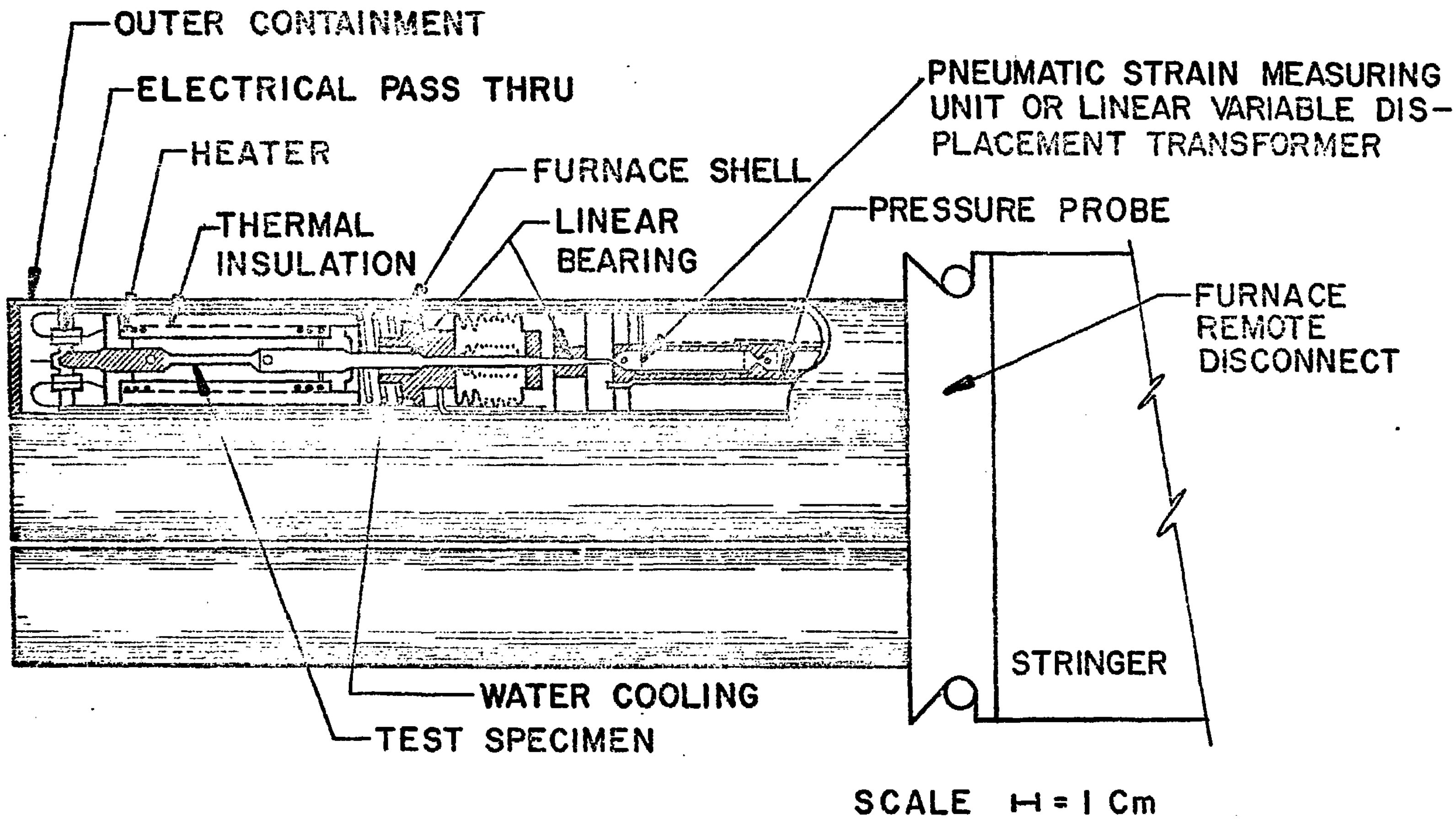

FIG. 4

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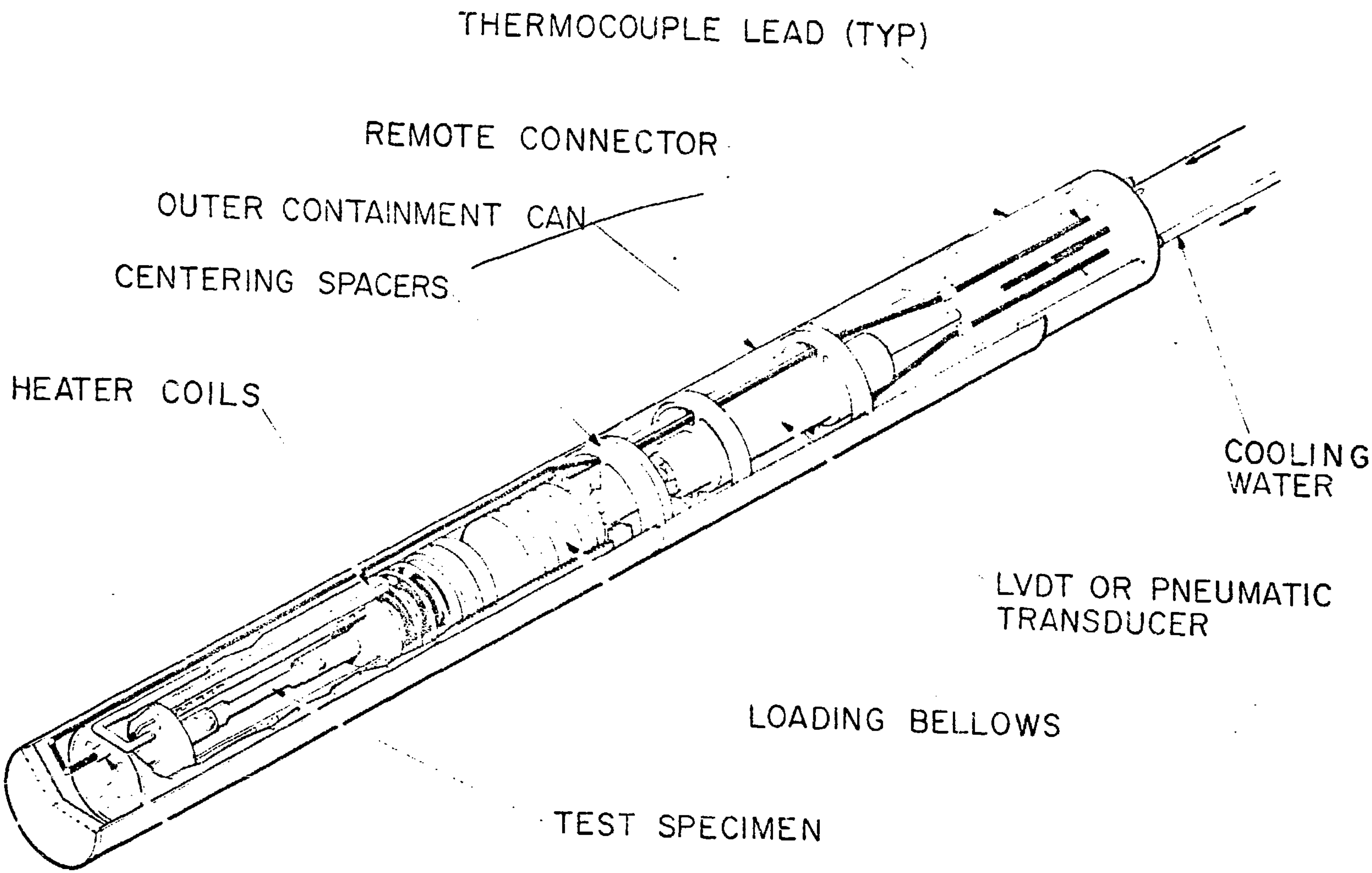
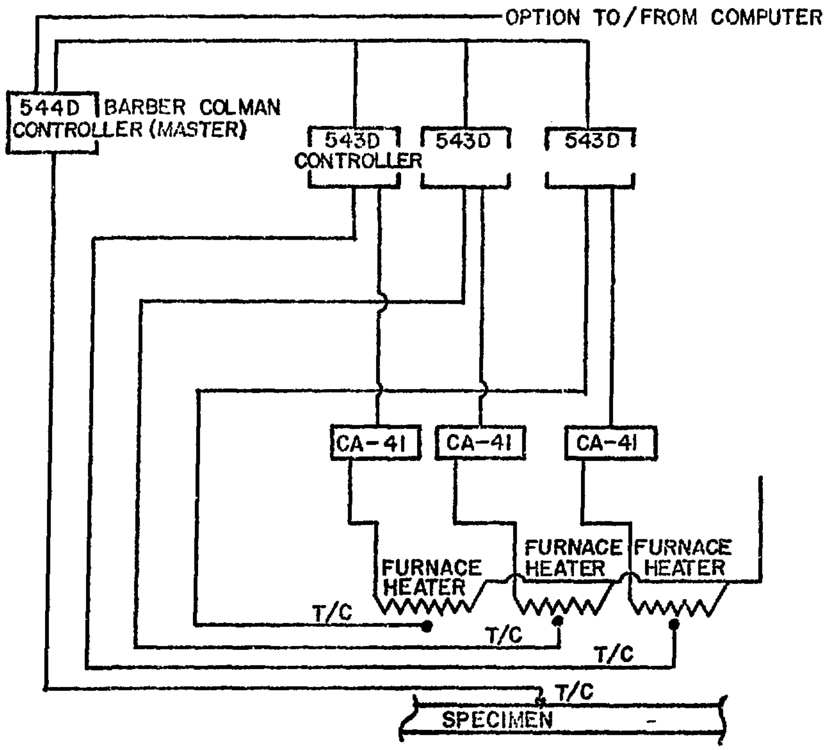
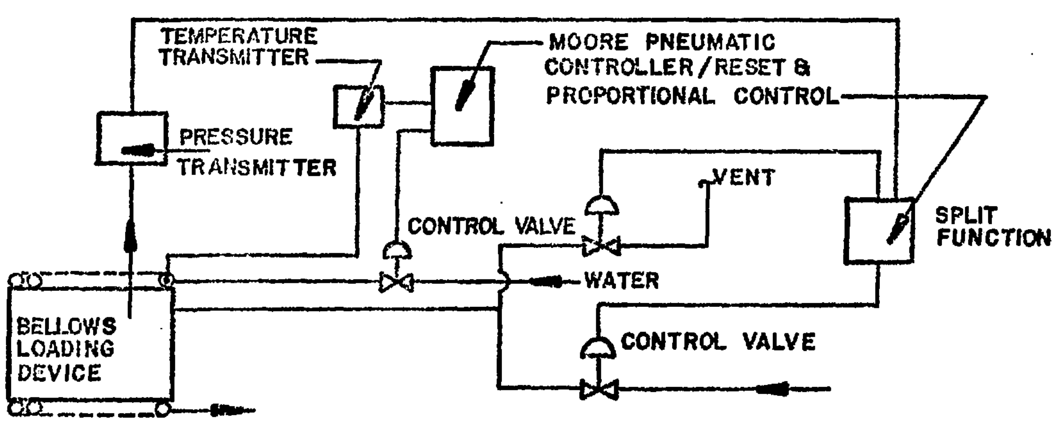


Fig. 5. Furnace Chamber



FURNACE CONTROL SCHEMATIC

FIG. 6



PNEUMATIC CONTROL SCHEMATIC

FIG. 7

A second category of dosimetry is that routinely used to monitor the radiation exposure of individual experiments. It is anticipated that a body of such data will be built up at the facility into a data bank available to all users. In line with this intent a standard package of about ten foils is being devised, to be provided to each user. This procedure should simplify intercomparisons and standardization of spectra, since all foils will be derived from the same lot of material. Sufficient quantities of those foils have been acquired for the use of all materials irradiation experiments anticipated in the near future, but each experimenter will be responsible for irradiating and counting his foils, as well as for data reduction and unfolding. However, it is anticipated that adequate handling and counting equipment will be available at LAMPF, along with computer facilities for data reduction and unfolding. This is the standard support provided by LAMPF as a national facility. Also, the SAND-II code is operational on LASL's CDC 6600 and CDC 7600 computers, so the analytical capability to unfold spectra will be available to the experimenter on site.

Neutron Spectra Calculations

In anticipation of the LAMPF beam stop use as an irradiation facility, predictive calculations of neutron spectra have been performed. (7) The present beam stop material (copper) as well as other potential materials were considered. Calculations were made for neutron flux spectra in the experimental cavity, and ratios of helium production to displacements per atom were determined for niobium, a candidate CTR structural material. One-dimensional transport calculations were performed for various angles with respect to the incident proton beam axis to show the large variations possible in the high-energy component ($E > 10$ MeV) of the flux. Summarized below are a brief description of these calculations and some results, taken from Ref. 7. For more details, see that paper.

The present beam stop is a 10-cm radius copper cylinder designed to stop a proton beam approximately 7.5 cm in radius impinging on its end. Prior to final design of this stop, calculations using Monte Carlo codes (8,9) were performed for proton and neutron transport in a simplified model of a 15-cm radius copper stop. Neutron flux values from this calculation are shown in Figure 8. along with results of other calculations to be described below. The Monte Carlo fluxes are averaged over a 10-cm annulus adjacent to the front 15 cm of the beam stop. All fluxes shown in Figure 8 have been arbitrarily normalized to fit the same abscissa so only neutron flux spectra, not intensities, can be deduced from these curves. Because of neutron scattering, and thus moderation with the stop, the spectrum shown for copper in Figure 8 is somewhat softer than would be the case for a 10-cm radius copper stop. The EBR-II s ctrum is shown solely for comparative purposes.

Survey calculations of low-Z materials as potential beam stops were performed with the DTF-IV discrete-ordinates, one-dimensional transport code (10) so they provide only relative flux spectra. Beryllium, graphite and aluminum were the substitute materials chosen, primarily on the basis of their neutron emission spectra and on fabricability, ease of cooling and expense. Sources of intranuclear cascade and evaporation neutrons for these calculations were chosen from available published reports, (11, 12) and so some approximations had to be made. Figure 9 shows one set of data; in this case for 400-MeV protons incident on carbon. Note the strong correlation of high energy neutrons and forward angles. Table I reproduced from Ref. 7, lists the beam stop materials considered, along with the closest approximation for the neutron source. Examination of Table I shows the sharp increase in the high energy neutron flux ($E>10$ MeV) at the more forward angles, as well as a significant softening of the spectrum by larger beam stop radii (i.e., by increased moderation as in the case of the 10-cm radius beryllium stop compared to one of 7.5-cm radius). Also shown in Table I are the He production rate in ppm to dpa ratios in niobium compared to values expected for typical fusion and fast fission reactors. Not inferable from the table and figures, however, are the flux intensities. Time-averaged neutron fluxes of 10^{13} to 10^{14} n cm^{-2} sec^{-1} are expected for the copper stop. Due to lower evaporation-neutron yields, these fluxes will be about a factor of 3 lower for low-Z materials such as graphite.

TABLE I.

PARAMETRIC STUDY OF LOW-Z BEAM STOPS

(Reproduced From Ref.4)

Material	Neutron Source Proton Energy, Target	Radius (cm)	Angular Interval[1]	% of Total Neutron Flux[2] ≥10 MeV	10-50 MeV	10-25 MeV	He ppm/dpa[3]
Be	400 MeV, Carbon	7.5	0°-30°	12.4	3.1 (25)	2.3 (19)	1.3
Be	400 MeV, Carbon	7.5	30°-60°	8.6	3.5 (41)	2.6 (30)	1.0
Be	400 MeV, Carbon	7.5	60°-90°	4.8	3.5 (73)	2.8 (58)	0.7
Be	400 MeV, Carbon	7.5	90°-180°	2.9	2.8 (97)	2.6 (90)	0.5
Be	400 MeV, Carbon	10.0	0°-30°	9.1	2.2 (24)	1.6 (18)	1.2
Be	400 MeV, Carbon	10.0	30°-60°	5.5	2.1 (38)	1.6 (29)	0.9
Be	400 MeV, Carbon	10.0	90°-180°	1.6	1.5 (94)	1.4 (88)	0.4
Be	750 MeV, Oxygen	7.5	18.20°-25.85°	6.7	4.0 (60)	3.6 (54)	0.9
Be	750 MeV, Oxygen	7.5	85.27°-95.73°	4.4	3.9 (89)	3.8 (86)	0.6
Be	750 MeV, Oxygen	7.5	113.58°-126.90°	3.9	3.9 (100)	3.8 (97)	0.6
C	400 MeV, Carbon	7.5	0°-30°	15.6	4.1(26)	3.2 (21)	1.4
C	400 MeV, Carbon	7.5	30°-60°	12.1	5.1(42)	4.0 (33)	1.0
C	400 MeV, Carbon	7.5	60°-90°	8.3	6.2 (75)	4.9 (59)	0.9
C	400 MeV, Carbon	7.5	90°-180°	5.2	5.0 (96)	4.7 (90)	0.6
C	750 MeV, Oxygen	7.5	18.20°-25.85°	10.4	6.5 (62)	5.9 (57)	1.0
C	750 MeV, Oxygen	7.5	85.27°-95.73°	8.1	7.1 (88)	6.9 (85)	0.8
C	750 MeV, Oxygen	7.5	113.58°-126.90°	7.4	7.1 (96)	6.9 (93)	0.8
Al	750 MeV, Aluminum	7.5	18.20°-25.85°	9.0	5.4 (60)	4.9 (54)	0.9
Al	750 MeV, Aluminum	7.5	85.27°-95.73°	5.9	5.7 (97)	5.5 (91)	0.7
Al	750 MeV, Aluminum	7.5	113.58°-126.90°	5.9	5.7 (97)	5.6 (93)	0.7

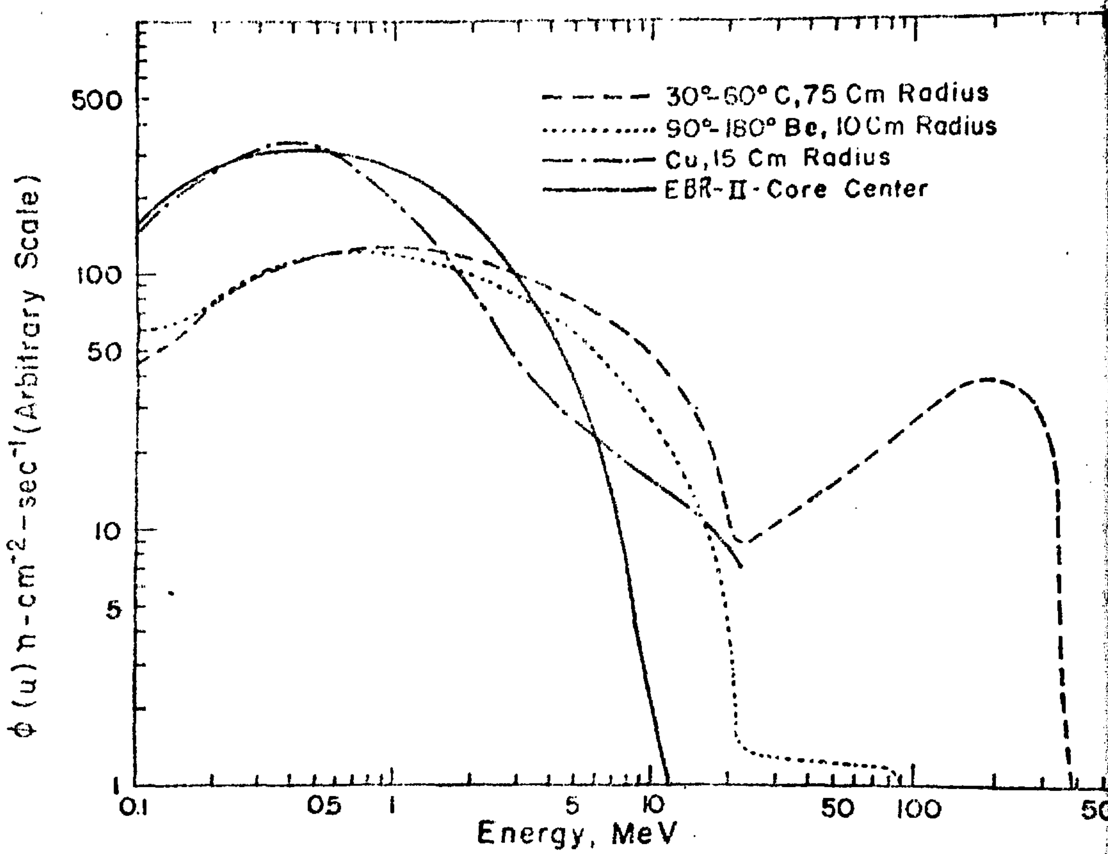
[1] Laboratory system.

[2] Numbers in parentheses are percentages of fraction above 10 MeV.

[3] Ratios given are for a niobium sample ~ 5 cm out from the surface of the beam stop, as in a radiation damage furnace. Values for a θ-pinch CTR are 1.6 and below; value for EBR-II core center is 0.02.

Figure 8.

Neutron flux spectra (n-cm^{-2} -sec^{-1} per unit lethargy) for EBR-II core center, Cu beam stop, and two selected angular intervals for Be or C beam stops. Note that flux intensities are not indicated because of arbitrary scales. (reproduced from Ref. 4)



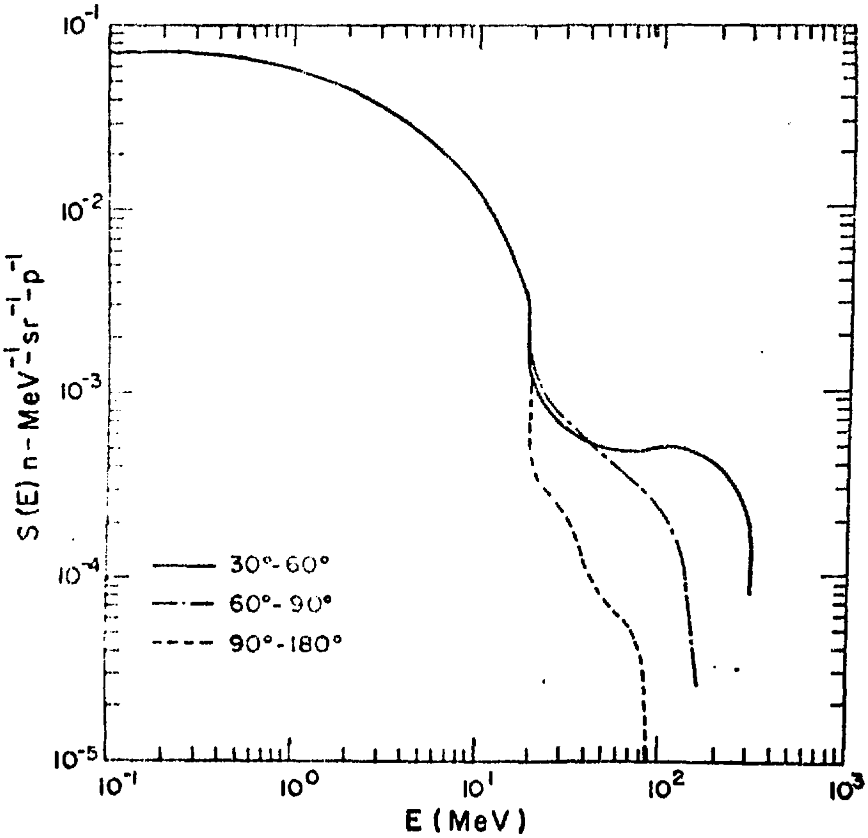


Fig. 9. Composite Neutron source spectrum from 400-MeV protons incident on Carbon (reproduced from Ref. 4).

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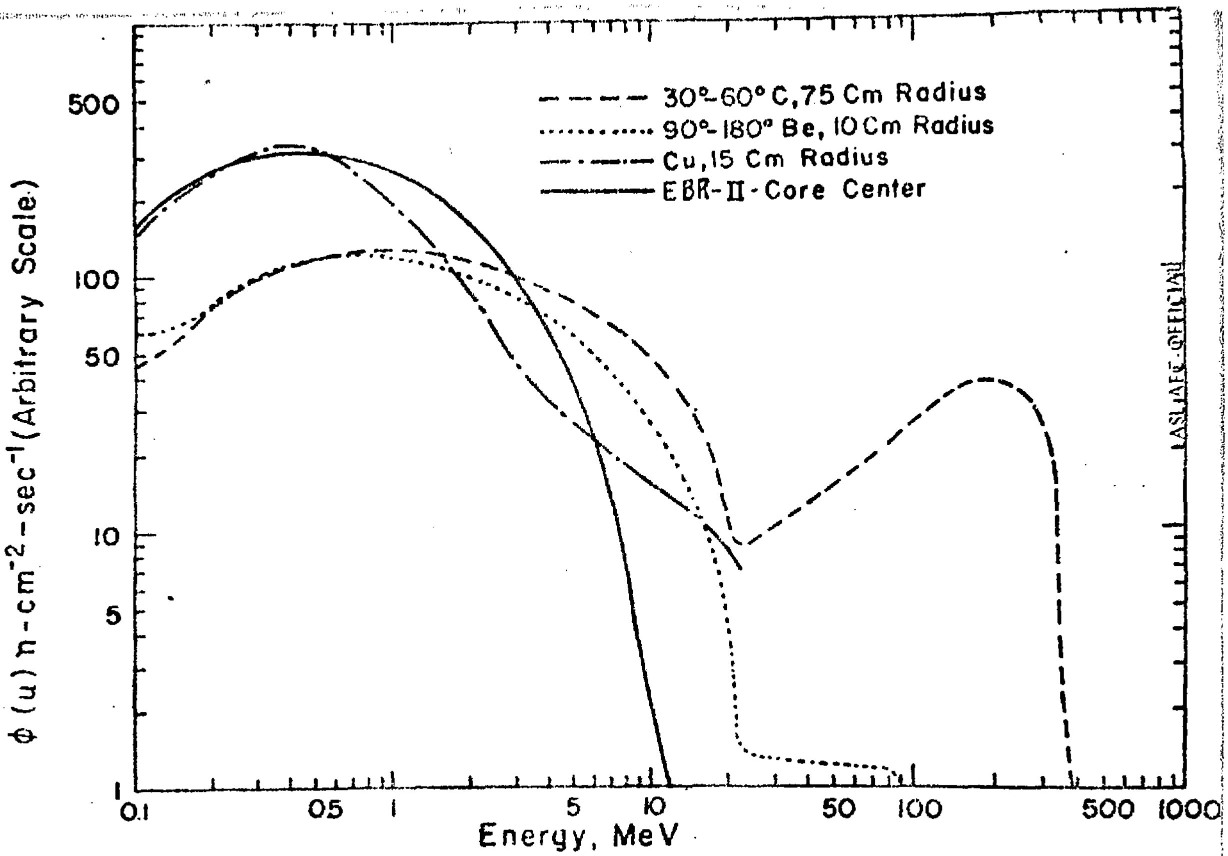

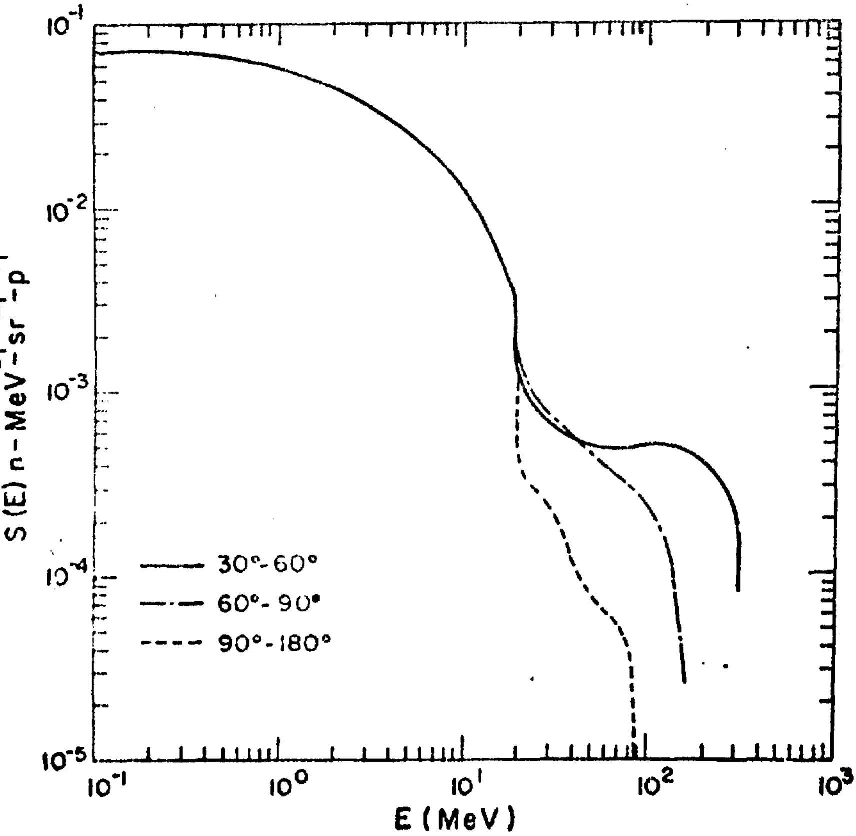

9. Composite Neutron source spectrum from 400-MeV protons incident on Carbon. (reproduced from Ref. 4).

At this time, detailed three-dimensional Monte Carlo neutron transport calculations are being set up, representing the actual geometry of the stop, furnaces and irradiation cavity as realistically as feasible. These are expected to be correlated with the neutron flux spectra and intensities unfolded from the foil activation maps. Also, these calculations should give reasonable estimates of the neutron flux intensities to be expected at various experimental locations.

Currently in the speculative stage are considerations of enhancing flux levels, perhaps by an order of magnitude or so, by focusing the proton beam to a few millimeters and impinging it on a molten metal target such as sodium or, for more intense but softer neutron spectra, lead-bismuth.

Acknowledgement

The authors gratefully acknowledge the contributions of Dr. James A. Horak (University of New Mexico) for consultation on the foil-activation dosimetry planning, and to Mr. Max A. Sherman , a summer graduate student, for working on many of the neutron flux spectra calculations.

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