NEUTRON CROSS SECTION MEASUREMENTS AT ORELA

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ORELA (Oak Ridge Electron Linear Accelerator) has been for the last decade the most powerful and useful pulsed neutron time-of-flight facility in the world, particularly in the broad midrange of neutron energies (10 eV - 1 MeV). This position will be enhanced with the addition of a pulse narrowing "prebuncher", recently installed and now under test. Neutron capture, fission, scattering, and total cross sections are measured by members of the Physics and Engineering Physics Divisions of ORNL, and by numerous guests and visitors. Several fundamental and applied measurements will be described, with some emphasis on instrumentation used. The facility comprises the accelerator and its target(s), 10 evacuated neutron flight paths having 18 measurement stations at flight path distances 8.9 to 200 meters, and a complex 4-computer data acquisition system capable of handling some 17000 32-bit "events"/sec from a total of 12 data input ports. The system provides a total of 2.08×10^6 words of data storage on 3 fast disk units. In addition a dedicated PDP-10 timesharing system with a 250 megabyte disk system and 4 PDP-15 graphic display satellites permits on-site data reduction and analysis. More than 10 man-years of application software development supports the system, which is used directly by individual experimenters.

[Electron linac, pulsed neutron source, time-of-flight, neutron cross sections, data acquisition, computers, $^{238}U\sigma_{tot}$, majority logic, inelastic neutron scattering, gas scintillator, prebuncher]

Introduction

The Oak Ridge Electron Linear Accelerator (ORELA) is a powerful pulsed electron accelerator dedicated to the function of producing short intense bursts of neutrons over a wide range of energy. It was commissioned in 1969 and in the intervening decade has been used for an extremely large number of experiments utilizing the neutron time-of-flight technique. Principally, measurements have been made on neutron capture, fission, scattering and total cross sections for nuclides over the entire periodic table. Many other types of measurements have also been made, e.g., determinations of $\overline{\nu}$ and α for heavy elements, inelastic scattering experiments, etc. Until the present time, ORELA continues to be the most useful and most powerful pulsed neutron time-of-flight facility in the world, particularly in the broad midrange of neutron energies (10 eV - 1 MeV).

The staff consists of 19 persons associated with the Engineering Physics Division and 10 persons associated with the Physics Division of Oak Ridge National Laboratory. The Co-directors of the accelerator are J. A. Harvey (Physics) and R. W. Peelle (Engineering Physics). The Engineering Physics Division primarily supports applied measurements and the Physics Division primarily supports fundamental measurements at the accelerator. Both divisions continue to have numerous visitors and collaborators from other institutions and universities throughout the world. The staff is supported by 7 persons in accelerator operations and development, 16 craft and maintenance personnel, 1 computer software expert and 1 computer hardware expert.

Description of ORELA Facility

Figure 1 is a list of the characteristics of the electron accelerator and its neutron production rates. In general all of the specifications shown in Figure 1 have been met in actual practice for the largest part of the life of the facility. In recent months some difficulty has been encountered with electron gun fabrication problems. This has led to power restrictions associated with excessive grid emission ("dark current"). The grid pulse shaping network has also recently presented rise time problems for narrow pulse widths and we have suffered reductions in power because of this. Wide pulse power outputs as high as 60 J/pulse have been obtained over long periods of time for several important experiments in the past[1] and there is reason to expect that this power

ORELA SPECIFICATIONS

L-band, 1300 megacycles
10-140 MeV electrons
15 amp peak current (τ <24 nsec)
2-1000 nsec burst width
5-1000 pulses per second
50 kw electron beam (τ >24 nsec)
10^{11} neutrons/pulse (τ >24 nsec, Ta target)
10^{14} neutrons/sec (average, 50 kw)
4×10^{18} neutrons/sec (peak, 15 amps)

Fig. 1

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level will be again obtainable, once the gun problem has been resolved. Improvements in the grid pulse shaping network are also being pursued.

Figure 2 shows a layout of the facility. The facility comprises the accelerator and its targets, 10 evacuated neutron flight paths having 18 measurement

target changes and storage. With the aid of a mains-frequency beam sweeping system the tantalum target is capable of absorbing up to 75 kW, although 60 kW is the maximum power which has been actually used for extended periods.[1] As seen in Figure 2, the flight paths are for the most part symmetrically disposed on either side of the accelerator at ~15° intervals.

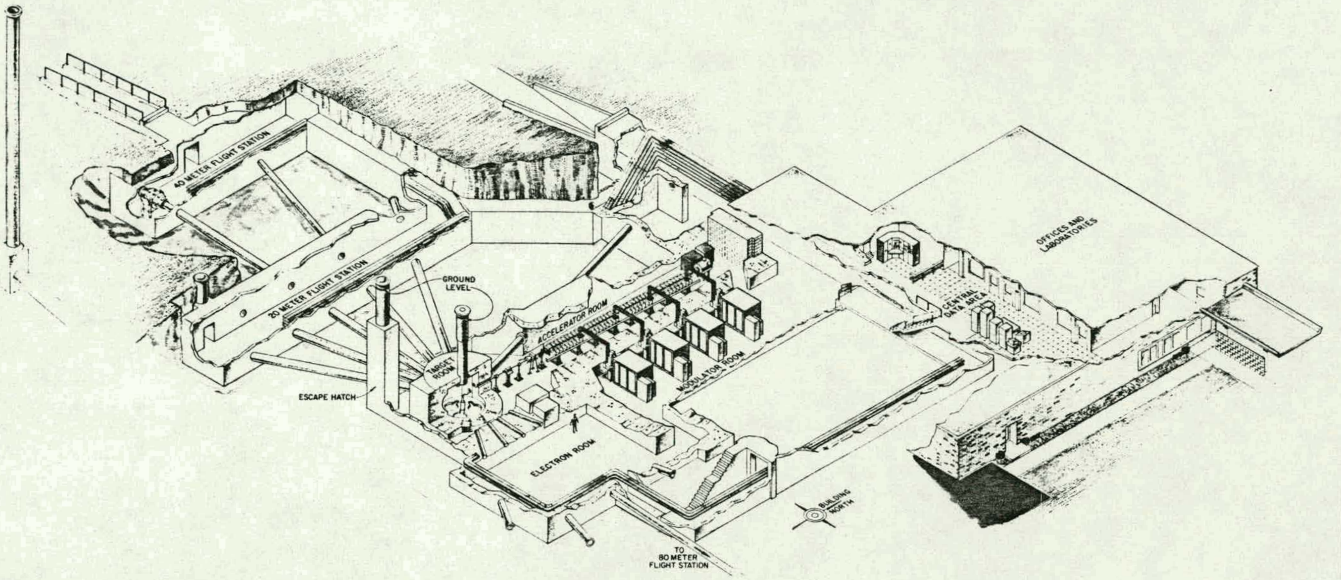


Fig. 2. ORELA

stations at flight path distances of 8.9-200 meters and a complex 4-computer data acquisition system. Two types of targets are used. The most commonly used target is a tantalum metal, water cooled target which is shown in Figure 3. An alternate target for high

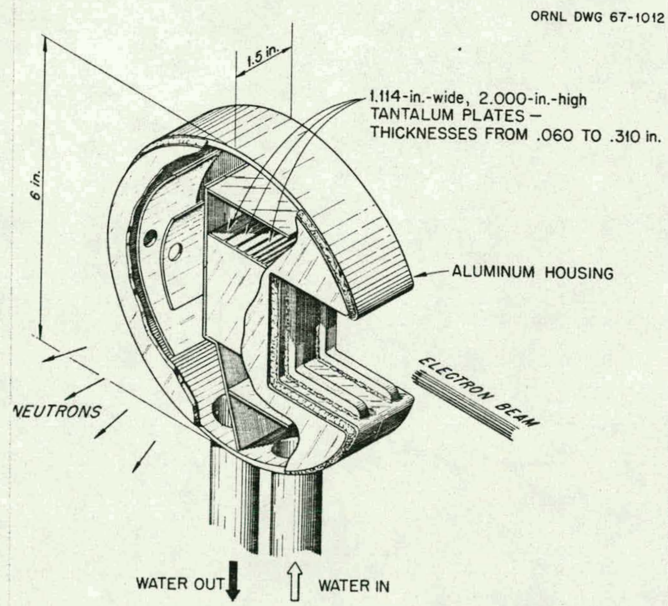


Fig. 3. ORELA target. The housing material has been changed to Beryllium.

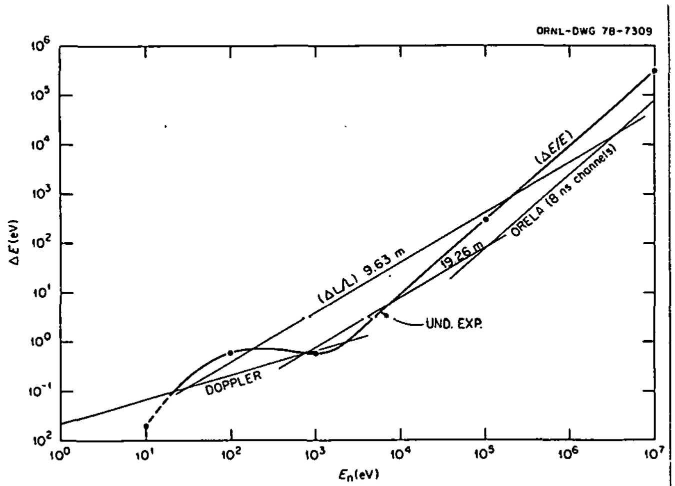
energy neutron work is essentially a large block of beryllium metal which replaces the tantalum target described above. A hydraulic mechanism permits remote

Table I gives a listing of these flight paths, their angular positions, location of the various stations together with their primary present use and the names of some users. Among these flight paths, flight paths number 1 and 6 are used for the highest resolution work because of their angular positions perpendicular to the water moderator disk of the standard tantalum target. Flight path 9 is particularly suitable for experiments in which gamma rays are detected because at its angular position very few gamma rays accompany the neutrons down the flight path. Usually, each flight path is equipped with a "shadow bar" which prevents direct viewing of the Ta portion of the target. This reduces the effect of the γ-flash by a large factor.[2]

Table I

Flight Path No.	Angle (degrees)	Station (Meters)	Type of experiment	Contact Person
1	90°	18,80,200	Transmission	J.A. Harvey
2	75°	9,33	Fission	J.W.T. Dabbs
3	60°	10,33	Inelastic	R. Winters
			Solid State	H. Mook
4	60°	20	Fission	R. Gwin
5	75°	20,85	Capture	L.W. Weston
			Fission, ν	R.R. Spencer
6	90°	20,40,150	Transmission	D.K. Olsen
			Subthreshold fission	G. de Saussure
7	105°	20,40	Capture	R.L. Macklin
8	120°	20	n,n'γ	D.K. Olsen
9	165°	50	(n,xn'γ),(n,xγ)	G.T. Chapman
11	105°	12	(n,γ spectra)	G. Slaughter

Figure 4 illustrates contributions to the energy resolution available at ORELA in the worst case, i.e., Doppler broadening associated with a heavy element target, flight path length error associated with two of the shortest flight paths, and the pulse width error associated with a 40 ns pulse and 8 ns data bins, in the three regimes from left to right in the figure. The smooth curve for underground explosions is drawn through points given by Diven.[3]



Contributions to Energy Resolution, Underground Explosion and Orela (40 ns Burst)

Fig. 4

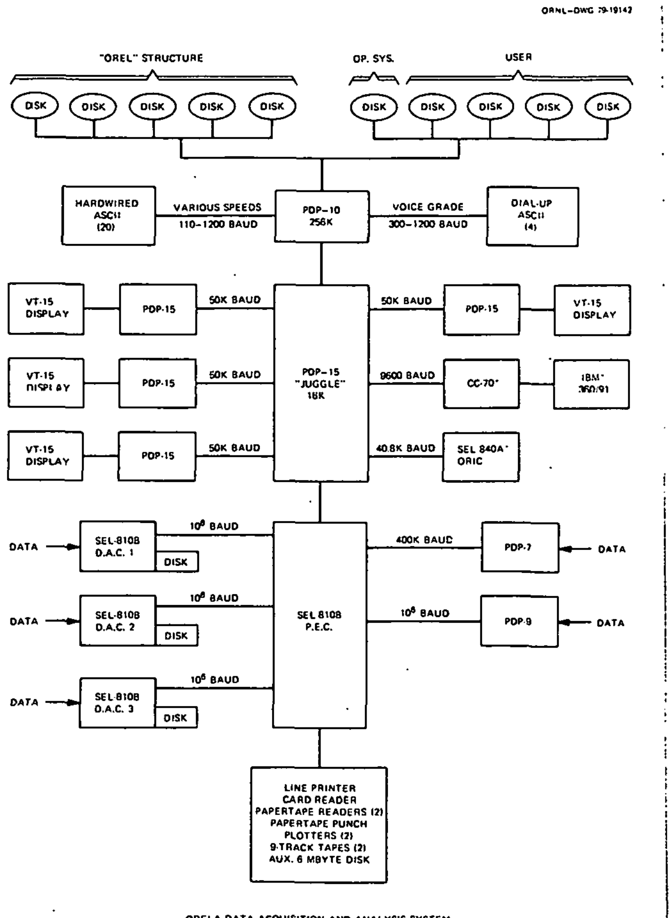
Perhaps the most important factor which makes ORELA so useful is the very multiplicity of flight paths and working stations. As will be seen in Table I there are 10 flight paths and 18 working stations. Over the last 5 months an average of 5.4 of these stations were producing data at any given operating time. This situation mandates a powerful system for the cumulation and storage of data.

On-line Data Acquisitions Systems

Generally speaking the time-of-flight portion of each experiment requires that events at a particular time after the accelerator burst must generate a digital word which describes the time at which the event occurred. In a number of cases information such as pulse height must also be folded into this digital word. In the ORELA system the standard word comprises 32 bits. Four bits are reserved for identifying the particular detector involved. Two other bits are reserved for system control and the remainder are used for time-of-flight information and in many cases other information such as pulse height. Each "event" is presented to the data acquisition computer as two 16 bit words which, taken together, comprise the 32 bit word. Almost all of the experiments at ORELA utilize the TDC-100 time digitizer[4] to produce the time of flight portion of the data. Approximately 12 of these units are in use at ORELA.

The data acquisition computer complex comprises 3 model SEL-810B computers which are 16 bit 32K word units with a cycle time <1 μs. Each of these computers has 4 input ports which permit the reception of data from 4 experiments simultaneously under a buffering and priority scheme which avoids distortion of the data in one experiment by another. Input rates totalling 5000 events/second are permissible provided no average individual rate exceeds 1800/second. Each of the 3 computers is equipped with an extremely fast head-per-track disk. Total storage capability of these 3 units is 2.08×10^6 channels. Each of these channels can store a count of 65 536. These disks are used only for data storage during data acquisition and for a short time thereafter. Rather elaborate facilities are provided for observing the data as it is being acquired with the aid of a cathode ray tube and a light pen on each of the 3 data acquisition computers. A fourth SEL-810B computer is connected to the al equipment controller or PEC. This computer drives a line printer, card reader, 2 plotters, 2 magnetic tape drives, a paper tape reader, and a paper tape punch, as well as a high speed link via a PDP-15 to the remainder of the facility.

The largest of the ORELA computer facilities is located in the same hall with the data acquisition computers. A PDP-10 time sharing computer with 240 K 36 bit words of main memory and with 250 Mbytes of magnetic disk storage serves as the main data storage and analysis computer. A schematic diagram of the entire computer system is shown in Figure 5.



ORELA DATA ACQUISITION AND ANALYSIS SYSTEM
* LOCATED IN OTHER BUILDINGS

Fig. 5

The PDP-10 computer may be accessed by 24 users simultaneously. Four user stations are equipped with graphic display terminals which permit visual analysis of data. Four telephone dial-up lines are also provided. Major output functions are handled by a 300 line/minute line printer, two drum plotters, and two 9-track magnetic tape drives attached to the PEC. No operator is required, except during one 4-hour downtime/week for maintenance; users mount their own 25 Mbyte disk packs.

Recent Improvements

During the last year, the following improvements have been made to the data acquisition and handling system at ORELA:

1. A new 1000 card per minute card reader which replaced a 400 card per minute card reader has been installed on the PEC and is operating without problems.
2. Bids are out for two new 75 inch per second tape units which will replace the 45 inch per second tape units.
3. An additional 16K for each SEL 810B has been installed and software is currently being changed to make use of it. Each SEL now has 32K of core.
4. The amount of core for the PDP-15 displays has been increased from 12K to 16K for 3 of them and to 32K for the fourth. Software has been changed to make use of the new memory.
5. The high speed link between the PEC and the PDP-15 (PDP-10) has been installed increasing the speed from 80 KBaud to 800 KBaud.
6. A Motorola M6800 microprocessor to control two Calcomp plotters has been installed on the PEC and is operating without problems.
7. Bids for the RP04 disk for the PDP-10 are going out. The first RP04 will add 80 000 disk blocks; each additional RP04 will add 160 000 disk blocks.
8. The PEC disk has been replaced. The new disk is twice as fast, and has twice the storage.

Almost all data is handled in a standardized format called "ORELA Data Files" or ODF. Very substantial facilities exist for performing operations upon these data files so as to facilitate background subtractions, resolution corrections, curve fitting, averaging, summation, and alignment. The latter capability uses a program called "ESHIFT" which automatically aligns sets of data taken with different zero times and flight path distances to a common flight path distance and zero time. In this way one can, for example, reduce the data from a number of detectors to a common time (hence energy) scale. Extensive plotting capabilities are usable with well chosen default options, minimizing the effort required.

Some Experiments at ORELA

Experiments Reported at this Conference[5]

The following is a list of 7 papers presented at this conference which involved ORELA:

Neutron Total Cross Sections of H, C, O, and Fe from 500 keV to 60 MeV

High Resolution Neutron Fission Cross Section of ^{231}Pa

Measurement of ^{238}U(n,n'γ) and ^{7}Li(n,n'γ) gamma ray production cross sections

Neutron Total Cross Section of ^{233}U from 0.01-1.0 eV

Neutron Total Cross Section Measurements on ^{249}Cf

Absolute Measurement of $_p$ for ^{252}Cf by the Large Liquid Scintillator Tank Technique

Measurement of the 2.35 MeV Window in ^{16}O + n

Papers at Meeting of Division of Nuclear Physics[6]

Six papers based on ORELA work were presented at last week's American Physical Society meeting:

M1 Ground-state Radiative Strength in ^{207}Pb for E_x = 6.74-7.34 MeV

Statistical Distributions of Spacings of Resonances in ^{64}Zn, ^{66}Zn, ^{68}Zn and ^{70}Zn Nuclei

Neutron Capture Cross Sections in ^{67}Zn

High Resolution Neutron Total Cross Sections in ^{67}Zn

^{187}Os 30 keV Inelastic to Elastic Cross Section Ratio

Measurement of Fission Cross Section of ^{241}Am

Discussion of Selected Experiments

Because of restricted space only a few carefully selected experiments will be discussed herein. These experiments represent recent improvements in techniques of data acquisition, reduction, or new instruments.

Precision Total Cross Section Measurements

The most prevalent material in modern nuclear reactors is ^{238}U. Accordingly the nuclear properties of this nuclide are among the most important. Until recently it could not be said that the total cross section of ^{238}U as a function of neutron energy had been well measured in spite of some 24 previous determinations. At ORELA, two very carefully fashioned experiments have now been completed[7] in which a precision determination of the total cross section for energies up to 4 keV and 100 keV were made. These measurements were characterized by the following features: (1) 7 sample thicknesses, (2) black resonace background determinations for each sample thickness, (3) precise determination of time dependent gamma ray backgrounds, (4) especially careful attention to the response of the neutron detectors used, (5) careful determination of the accelerator-on background.

After appropriate background subtractions have been performed the data were subjected to simultaneous multi-level fits for all 7 samples Figure 6 shows the results of such a fit. For clarity the results

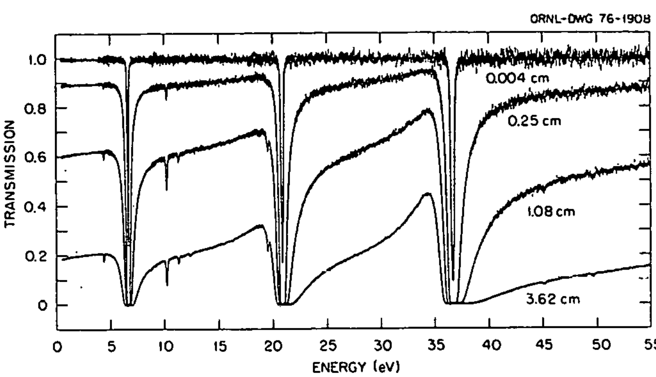


Fig. 6. Transmission of ^{238}U.

for only 4 of the 7 samples are shown. Each curve consists of data and a line which corresponds to the simultaneous least squares fitting curve appropriate for that sample. It is essentially impossible to see the calculated curve because the fit is so perfect. It is important to note that the response of the detector played a very important role in a readjustment of the best values for the neutron width of many of the resonances which were studied. This was important in resolving a long standing discrepancy. In the near future a similar experiment to this is being planned for ^{232}Th.

It is interesting to consider the data storage requirements for such an experiment. In the proposed thorium experiment[8] 8 transmission samples will be used. A typical measurement cycle will consist of the following steps: open beam measurement, 8 samples in succession, 8 samples in succession with black resonance filters in place, 2 successive measurements with different thickness of C_2H_2 for gamma ray background determinations and one period with a thick beam stop in place, for a total of 21 individual determinations. This cycle will be repeated once per hour for a period of roughly 5 weeks. Each measurement spectrum but three will occupy 23 535 channels. The total data requirement is 431 874 channels. There are at present at ORELA at least 4 distinct experiments or types of experiments which require this order of data acquisition capability. One proposed experiment is expected to require 900 000 channels of data storage.

Medium Energy Neutron Detector

For neutrons in the energy range 10 keV to 1 MeV it has long been difficult to have a detector which did not show a strong dependence on some threshold bias. Recently a detector has been developed by N. W. Hill of ORNL which removes this dependence in a new way and very well. The detector (Figure 7) consists of a block of NE-110 plastic scintillator and 3 or more photomultiplier tubes attached to its various faces with epoxy. In the particular unit shown in

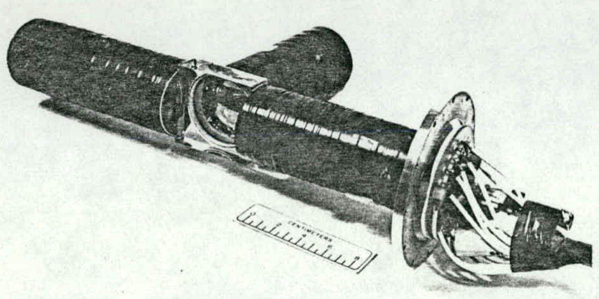


Fig. 7. Majority logic neutron detector.

Figure 7 the NE-110 is 2 cm thick and 6 cm square. Photomultipliers (in this case 2" diameter 8850 units) may be attached to each of the edges and to the face opposite the entrance face. Thus, up to 5 photomultipliers may be coupled to the scintillator. The bias for each discriminator-photomultiplier is set

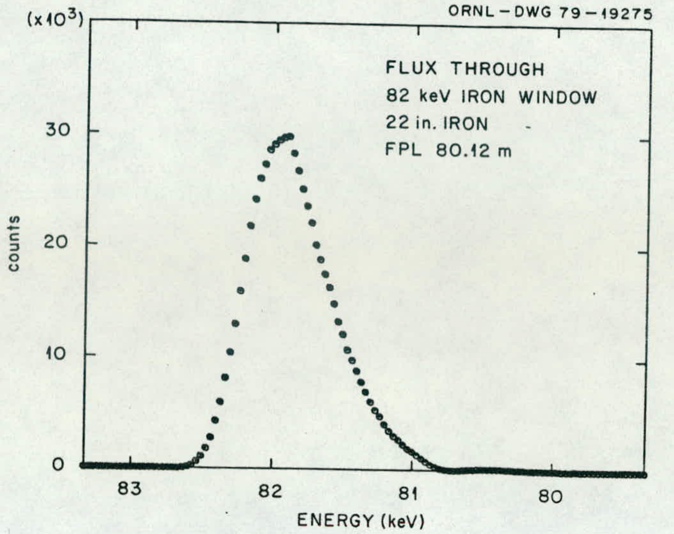


Fig. 8. Incident flux.

well below the single photoelectron level; indeed, it is set at the edge of the amplifier noise. A two-out-of-N majority logic circuit then serves to require a single photoelectron coincidence between at least two of the photomultipliers. This arrangement turns out to be extremely advantageous. The counting rates which are found, of course, depend upon the efficiency of the NE-110 in stopping that particular neutron energy; however, the response is almost totally independent of the actual bias settings within reasonable variations, say 20-30%. The net result is that this detector provides an extremely reliable detector which is very reproducible under almost all circumstances.

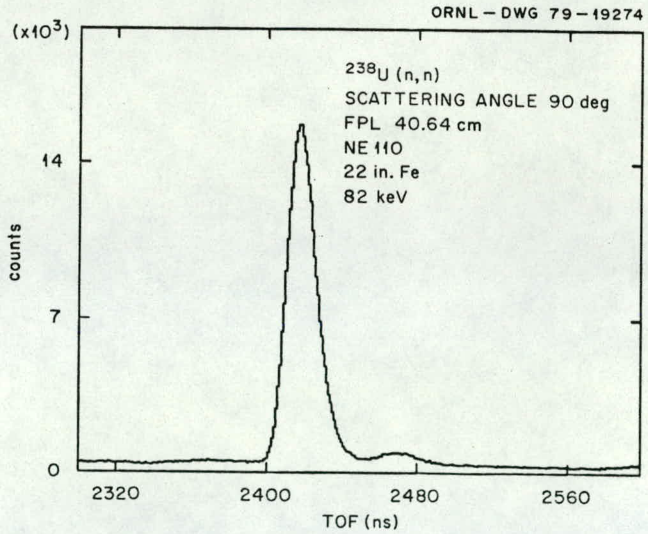


Fig. 9. Scattered flux.

Figure 8 shows the transmitted neutron beam through a 50 cm iron filter at 82 keV. In a recent experiment at ORELA[9] such a beam was allowed to scatter from a sample of ^{238}U and the scattered neutrons were detected with a time-of-flight base of 60 cm into this new detector. The result of this measurement is shown in Figure 9 where the data are plotted as a function of time-of-flight. The small secondary peak to the right of the main peak represents inelastically scattered neutrons of energy 35 keV. These neutrons have been scattered from the 44 keV level in ^{238}U. The main peak, of course, represents elastically scattered neutrons. This inelastic scattering and similar inelastic scattering from a few other levels provide an important contribution to neutron moderation in reactors which has been previously difficult to measure. This type of measurement obviously requires further development but the new detector appears to provide a means to obtain such important information in the future.

$^{6}Li(n,\alpha)$-Xenon Gas Scintillator Beam Monitor

In connection with fission cross section measurements over a wide range of energy (thermal-20 MeV) it is desirable to use the $^{6}Li(n,\alpha)$ reaction because the cross section is both well known and smooth at the lower energies. The fission reaction in ^{235}U has traditionally been used at higher energies as the cross section standard. It is, of course, useful to allow these two standards to overlap in energy for normalization and/or consistency checks. The ^{235}U ENDF/B-V fission cross section does not, however, truly become smooth until energies above 300 keV are reached.

It is well known that the usual ^{6}Li glass neutron detector has a large response to the gamma flash associated with the electron pulse at a linear accelerator; in fact recovery from the gamma flash in times less than $\sim$8 μs is very unusual. At short flight paths such as 9 meters this means that data cannot be obtained for energies higher than roughly 280 keV. Note that this does not permit the above mentioned overlap to occur. For this reason, among others, it was decided to develop a new type of neutron beam monitor. The first approach consisted of a sandwich comprising 2 sheets of 0.15 mm thick NE-110 with a thin layer of ^{6}LiF between the two sheets (in fact evaporated onto one of the surfaces). While this detector appeared to give excellent response, it was found that a very substantial amount of moderation of the neutrons occurs in the front layer of plastic scintillator (NE-110). This moderation is sufficiently severe that neutrons initially of 10 keV lead to an artificially enhanced response which may differ from that expected from the cross section of ^{6}Li by as much as 25%. In addition above 400 keV the presence of knock-on proton response also leads to a strong increase in response above that expected from the lithium cross section alone. A curve showing the magnitude of these errors is illustrated in Figure 10.

As a result of the realization that substantial errors existed in the response of the sandwich plastic scintillator, a new detector was developed which replaces the hydrogenous plastic scintillator with xenon gas.[11] The basic principle remains the same. A view of this detector is shown in Figure 11. The xenon gas scintillator system has proved itself to be quite reliable and reproducible and has the advantage that its response shows no anomalies up to above 800 keV when used at 9 meters, except strong dips where two Xe resonances at 9.4 and 14.4 eV occur. The response from the gamma flash is back to base line in about 0.7 μsec and could be improved by electronic modifications. The usual problems of gas purity has

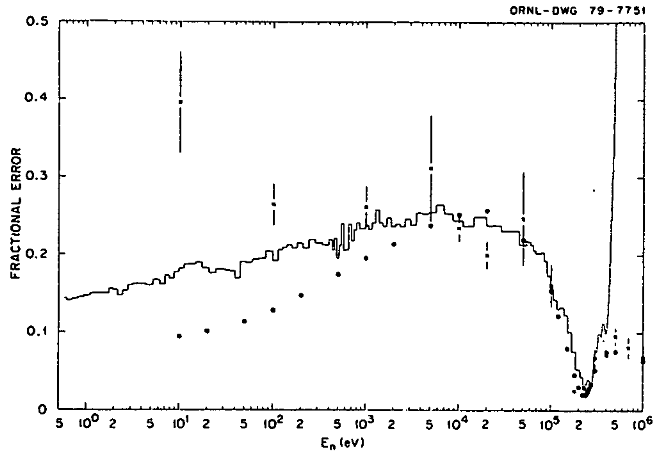


Fig. 10. Correction curves (measured) circles are calculations of R. L. Macklin. Crosses are Monte Carlo calculations of L. M. Petrie.

been addressed by utilizing a thermally driven gas circulation system and 2 gas purification elements.[10]

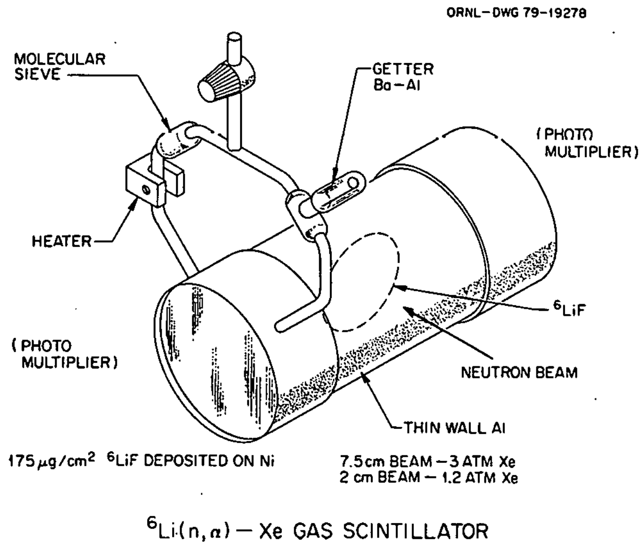


Fig. 11.

Future Directions at ORELA

In the previous paper[12] Dr. G. F. Auchampaugh has already mentioned the use of an electron prebuncher at ORELA. Recently this system was tried in a preliminary experiment. Figure 12 shows the result of applying 1/3 of the design buncher voltages to the buncher gaps. The prebuncher reduced the pulse width at the target from 17 nanoseconds to 8 nanoseconds and

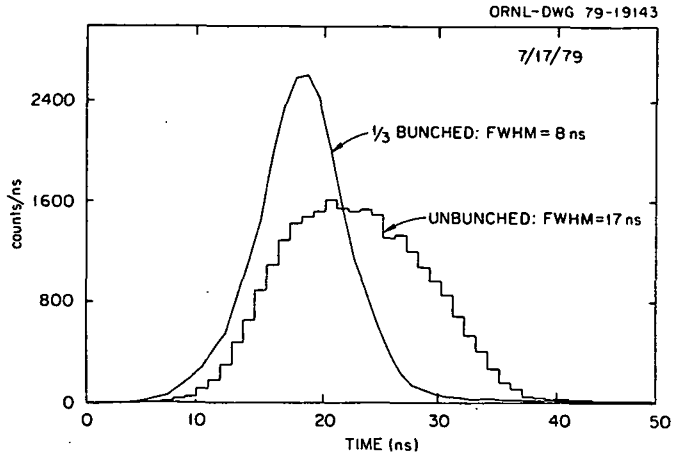


Fig. 12. Partially bunched and unbunched ORELA pulses.

represents only a first approach. At the moment some difficulty with vacuum leaks in several sections of the buncher have appeared. These are being repaired and further tests of the buncher system will be performed as soon as practicable.

A "hidden" advantage of such a buncher is that experiments that require high resolution (short pulses) and experiments that require high power (and, at present, wide pulses) can both be done simultaneously. This may increase the "utilization factor" of 5.4 mentioned above to perhaps 7 or 8.

Recently, it was realized that ORELA could produce neutron fluxes large enough to be usable in transmission measurements up to 80 MeV. In view of a very urgent need for total cross sections to be used in the shielding design of FMIT (Fusion Materials Irradiation Test Facility), such measurements on some 11 materials over the energy range up to 60 or 80 MeV have recently been made.[12] These experiments used the Be block alternate target at ORELA and were performed with an 80 meter flight path. It was found necessary to operate at somewhat reduced power and to put a filter of 20 cm polyethylene in the beam to bring the deadtime corrections to reasonable values, even with a 1 μs deadtime time digitizer. An energy resolution of .01E-.03E was obtained. Clearly this new direction is viable and useful. In the case of the FMIT design, it has been estimated that more accurate data will save roughly one million dollars in construction costs.

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