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MTR-ETR TECHNICAL BRANCHES
QUARTERLY REPORT
April 1-June 30, 1962

MASTER

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ATOMIC ENERGY DIVISION

NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION

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MATERIALS TESTING REACTOR - ENGINEERING TEST REACTOR TECHNICAL BRANCHES
QUARTERLY REPORT
APRIL 1 - JUNE 30, 1962

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MTR-ETR TECHNICAL BRANCHES QUARTERLY REPORT
1962 QUARTER 2
APRIL 1 - JUNE 30, 1962

SUMMARY

Studies of the variation of vertical neutron leakage in the ARMF core as a function of the radial distance from the center of the water hole have been made to determine whether or not this is a significant parameter for future calculations on the ARMF. The studies indicate that little variation in vertical leakage occurs over the ARMF core.

A four-group diffusion calculation was made on a special core in the ETRC. A comparison between calculated and measured activation distributions showed that the calculation adequately represented the epithermal distributions. The calculated thermal distributions were in good agreement with the measured values except in the control rods.

The total cross section of Pu-238 was measured with the MTR fast chopper over the energy range 0.02 to 100 ev. With the use of an unseparated sample of irradiated Th-232, the total cross section of Pa-233 also was measured by employing the radioactive sample changer in conjunction with the MTR fast chopper. Preliminary measurements of the total cross section of natural lutetium also were made.

A new spectrometer arm control and data print-out system was installed in the MTR crystal spectrometer to permit faster and more accurate taking of data. A new set of improved high resolution collimators also was installed in the spectrometer.

The half-life of Ho-166 has been determined as $90,000 \pm 18,000$ years. The conversion coefficient for the 57-kev transition in Ir-192m was measured as 3400 ± 300 . Yield ratios for isomeric pairs formed by neutron capture have been measured for Sb-122 - Sb-122m, In-114 - In-114m, and Rb-86 - Rb-86m. Swelling-temperature-time relationships were determined for beryllium irradiated to 1×10^{21} fast n/cm² for temperatures of 800, 900, and 1000°C. Another sample of U-236 containing < 0.003% U-235 was prepared.

The MTR cold neutron facility was improved by replacement with superior neutron choppers and by installation of improved shielding. Measurements of the dispersion relation for waves propagating in the [001] and [0110] directions in beryllium were made using the MTR velocity selector, and the data were compared with lattice dynamic models. Measurements of the inelastic scattering of slow neutrons from liquid sodium were completed with data taken at 0.025, 0.7 and 0.1 ev for temperatures of 23, 100, 110, 150, and 200°C and the data (except at 200°C) machine-processed through cross section and scattering law.

A theoretical analysis and numerical evaluation of an electrical white noise source has resulted in design curves from which a random Poisson pulse generator can be designed. The usefulness of this generator can be extended to simulate by electrical signal information a time-varying nuclear radiation source. Complete redesign of the instrumentation and control for the MTR

neutron crystal spectrometer includes the use of an all-electronic scanner which has resulted in a highly reliable data accumulation system.

A remotely controlled milling machine has resulted from modifications to a Bridgeport milling machine. The servomechanisms design has resulted in milling with only electrical connections between the operator and the mill. A very desirable notch filter has been designed for use particularly with servomechanisms equipment. The filter operates from dc to 100 cycles per second with a maximum depth or height of the notch of 40 db.

The field test on the alpha-beta air monitor recently placed in operation shows that the ratio of alpha to beta yields additional information for use by health physicists.

During the months of May and June the telephone data transmission system using the IBM 1401-1009 in Idaho Falls was put into operation with the 7701-1401-7090 data processing system in Bartlesville. A number of 7090 programs have been completed, and others are in various stages of completion. A versatile double precision matrix inversion program has been coded in FORTRAN and checked out. The IBM 650 programs for gamma spectrum analysis are being expanded and converted to the 7090. In addition a number of new codes for the IBM 650 have been completed.

MTR-ETR TECHNICAL BRANCHES QUARTERLY REPORT
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I. REACTOR PHYSICS AND ENGINEERING

1. REACTOR PHYSICS

1.1 ARMF Calculations (R. A. Grimesey)

Previous calculations of two-dimensional ARMF fluxes and adjoint functions have made use of an estimated vertical buckling to represent the leakage current of neutrons in this dimension. It is not possible by these methods to determine how much this vertical leakage varies from region to region in the radial plane. Consequently two-dimensional PDQ-4 [1] R-Z geometry studies were carried out to determine the vertical flux traverses as a function of the radial distance from the center of the core. The results indicate that except for variations of a few percent, the vertical leakage from points in the central water hole and the core region are the same. From this data revised estimates of the vertical leakage factors for future two-dimensional ARMF studies are being obtained.

1.2 A Comparison of Calculated vs Experimental Activations in the ETRC (B. L. Rushton)

Activation measurements were made in a special core in the ETRC. The objective was to develop a procedure for calculating activations that would compare well with experimental measurements. Experiments were simplified to give vertical uniformity. Figure 1 is a diagram of the core.

Total gold activation measurements were made at the center position of each fuel element and at several other positions in each fuel element located in the "I" column, the "9" row, and the "10" row. Total activation measurements also were made in the control rod fuel section and in the control rod poison section located in core positions I-9 and E-9 respectively. Epithermal activation measurements were made at points along the "I" column and the "9" row. Figure 1 shows the points where these epithermal measurements were made.

For the calculation a midplane mock-up of the core was laid out in X-Y geometry. Good core detail was obtained by utilizing 10,000 mesh points. A four-group calculation was run on the Philco 2000 computer using the PDQ-4 code [1].

The first comparison in this study was between calculated and measured epithermal activation distributions along the "I" column and the "9" row. Most

Fig. 1 Diagram of ETRC core.

gold activation above thermal is caused by neutrons in the energy range from thermal to 10 ev; therefore, group 3 of the 4-group fluxes was used in the comparison. In this calculation, group 3 neutron energies range from 0.625 ev to 5.53×10^3 ev. The calculated distribution was normalized to a measured value in core position I-9. Figures 2 and 3 show excellent agreement between calculated and measured epithermal activation distributions.

Fig. 2 Comparison between calculated and measured epithermal activation distributions along the "I" column of the ETRC.

The second comparison was between calculated and measured thermal activation distributions along the "I" column and the "9" row. The epithermal activation distributions in Figures 2 and 3 were used to reduce measured total activations to thermal activations. Group 4 (< 0.625 ev) of the 4-group fluxes was compared with these values. The normalizing factor was the sum of the measured values at the center of each fuel element divided by the sum of the calculated values at the center of each fuel element. Figures 4 and 5 show this comparison.

The calculation adequately represents the epithermal activation distributions along these traverses of the core. The thermal activation distributions are in good agreement with measured values except in the control rod fuel section and in the control rod poison section in core positions I-9 and E-9 respectively. Further study is therefore needed in the representation of the control rods. Otherwise the calculation generally gives good agreement between measured and calculated activations.

Fig. 3 Comparison between calculated and measured epithermal activation distributions along the "9" row of the ETRC.

Fig. 4 Comparison between calculated and measured thermal activation distributions along the "I" column of the ETRC.

Fig. 5 Comparison between calculated and measured thermal activation distributions along the "9" row of the ETRC.

2. REACTOR ENGINEERING

2.1 Reactor Fuels and Materials Development (W. C. Francis, J. M. Beeston)

The effort of this program during the quarter was devoted to the continued irradiation of sample fuel plates in the L-51 position of the MTR, tensile testing of irradiated and unirradiated fuel samples (the latter at room temperature and at 200°F), examination of irradiated production fuel elements by ultrasonic scanning for voids, and hot cell examination for surface oxide film buildup. A conceptual design and process flow schematic for in-pile fatigue testing of structural steels was completed and a study begun on a force-motion actuation for the test specimen. A computer program was prepared to evaluate the coolant flow dynamics and temperature distribution in the test section. The maximum specimen temperature was set at 1000°F. As part of the development work for the EGCR, 12 UO₂ stainless steel lead-type capsules were irradiated in the ETR.

2.11 Materials for Irradiation (W. P. Scarrah, M. Hatch). Three new items were inserted in the fuel element development program L-piece in the MTR. These included two 35-wt% fully enriched U-Al compacts clad with 6061 and X8001 aluminum and the third contained 1 wt% of 93% enriched B-10 in stainless steel which is the material to be used for control rods in the EOGR.

Flux runs were made in the MTR at the beginning of Cycle 173 to investigate the possibility of irradiating a 20-wt% Dy₂O₃ stainless steel plate in the same L-piece holder with a 30-wt% Dy₂O₃ stainless steel plate. The flux wires show that the insertion of another plate lowers the effective flux to the first plate by

approximately 25%. As the flux wires were in an area of maximum flux (at the top of the plates), it is likely that the flux is actually perturbed more than 25%.

2.12 Test and Inspection (M. J. Graber, D. D. Jeffries, J. C. Read, C. E. May). (1) Tensile data obtained at ambient temperatures on 94 irradiated specimens of uranium alloy and uranium oxide dispersion-type sample fuel plates clad with various aluminum alloys show that 40% of the specimens had zero elongation in a 1-in. gauge length. Essentially zero ductility was found in many specimens covering a wide range of compositions and radiation levels. The maximum elongation of the irradiated specimens was 4.5% in a 1-in. gauge length compared to the unirradiated specimens which produced 8 to 31% elongation in a 1-in. gauge length. For these slightly ductile specimens, it was found that (a) strength decreases with an increase in fuel content, (b) for a given fuel content, alloys are stronger than oxides, (c) in initial stages of irradiation, the amount of strength increase depends on the type cladding material, (d) ductility decreases rapidly due to fission damage, and (e) the increase in tensile strength is proportional to the increase in hardness of the cladding material.

Some of the sample fuel plates were tensile-tested at 200°F in the un-irradiated condition. A preliminary examination of data being taken indicates very little variation in properties between room temperature and 200°F for 1100 aluminum clad plates and a decrease in strength for 6061 clad plates.

(2) Because of the interest in the oxide buildup on the ATR fuel plate surface, an ETR fuel element was examined to determine the extent and thickness of corrosion film. Three metallography specimens taken from the hottest portion of the element had film 0.0001 in. thick. The linear extent of this film was 0.03 in. out of 4-1/2 linear in. of surface viewing, although metallography techniques on sample tests gave full retention of film. Calculations show that boehmite (the suspected corrosion product) 0.0001 in. thick would increase the temperature 5 to 6°F.

(3) The ultrasonic scanning of fuel plates from a spent ETR element has been performed to determine if this technique could be used as a nondestructive test of radiation damage. Only one plate had flaw indications which could not be attributed to surface defects produced during machining off the side plates. To determine if the flaw indications represent voids or nonuniform distribution of fuel, the plate will be examined metallographically.

2.13 EGCR Fuel Element Development (F. O. Haroldson, E. H. Porter, M. W. Ellingford). The irradiation of 12 UO₂-stainless steel capsules was continued in the ETR as part of the EGCR fuel development program. One of the capsules has now achieved a burnup of 8500 Mwd/MT.

A neutron absorber in the form of a bundle of nickel rods was inserted in position F-16NE with the primary purpose of decreasing the thermal flux around a capsule which had been operating with an excessively high burnup rate.

The capsule which was discharged in March 1962 was decanned in the hot cell. Considerable difficulty was encountered in attempting to remove the two outer cans. After the usual cutting operation to remove the top portion of the capsule and the thermocouple wires, it was found that the fuel can would not slide out of the NaK container. Cutting off the lower portion of the two outer cans permitted the NaK to be reacted in butyl alcohol and allowed removal of the outer can. After consultation with ORNL personnel, it was decided to

ship the capsule to the General Electric Co. at Vallecitos with the inner part of the NaK can remaining on the fuel can.

Examination of the butyl alcohol - NaK solution revealed considerable radioactivity; more than 95% of the gamma activity was identified as 2.3-yr Cs-134 and 34-yr Cs-137 which strongly indicated a fuel can rupture.

The in-pile fission break detection system for the capsule did not indicate any fission break before discharge, and since the alcohol-NaK activity after decanning this capsule was much greater than that from an earlier capsule which did show gas activity in the in-pile fission break detection test, it is possible that the fuel can ruptured during the decanning process. This will be more accurately ascertained when the inner fuel can is opened in GE's Vallecitos hot cell.

Because of the difficulties encountered in decanning the capsule in the hot cell and the possible loss of fission gas data, it has been decided to ship the remaining capsule complete, ie, with the two outer cans still intact, to Vallecitos for post-irradiation metallurgical examinations.

II. NUCLEAR PHYSICS

1. CROSS SECTIONS PROGRAM (M. S. Moore)

1.1 Crystal Spectrometer (J. R. Smith, R. R. Spencer)

A new spectrometer arm control and data print-out system was installed in the crystal spectrometer. The new equipment was designed and built by personnel of the Instrument Development Branch at MTR. A detailed report on the design and construction is being prepared by them. The essential features of the new system are:

(1) A completely transistorized scanning system replaces the old 102-position, 14-pole mechanical stepping switch as the central data-sensing element. The new system eliminates the problems caused by contact deterioration in the switch and relays of the old system. The wiring is also greatly simplified in the new system, and modifications and repairs are made easier by improved layout.

(2) New glow-transfer scalers replace the old scalers, which had reached the end of their useful life. The new scalers made use of improved, transistorized driving elements, are faster, and have greater storage capacity (10^8 counts) than the old ones (1.6×10^7 counts).

(3) A two-speed arm drive system greatly increases the versatility of energy selection. The higher speed, about three degrees per minute, makes it possible to reach any possible arm position in a reasonable time without the necessity of manually releasing the arm drive worm from its gear. Moreover, the arm will drive to as many as 10 preset angular positions, taking a preset number of data points in the vicinity of each position. It will repeat runs upon the completion of a sequence, automatically taking up the gear backlash as it resets to the initial position. Provision also is made for taking a check point at a preselected energy at intervals throughout a run.

(4) A separate logic system governs the motions of the arm, crystal data-background positions, two sample changers, and a filter changer. An extremely versatile selection makes it possible to use these elements in almost any order or combination.

(5) A new date-time printer replaces the old model, which had an agonizing degree of noise susceptibility.

In addition to the new data readout system, a new set of high resolution collimators was installed. These were built essentially by the method described by Joki, Evans, and Smith [2] but the end clamps have been modified to decrease the possibility of wrinkling the foils. The divergence of the new collimators is approximately 1.9 min, which is about 2.7 times that of the previous MTR solar

collimators, but close to that of the collimator used by Sailor at Brookhaven [3]. The present collimators use no coating on the nickel foils, so the effective collimation is dominated by the critical angle below about 1 ev.

Rocking curves taken with calcite (200) planes as monochromator at several energies are shown in Figure 6. Since calcite has a mosaic width not greater than 15 sec of arc, the widths of these rocking curves are due to total reflection and collimator divergence. It appears from these curves that the effective collimator divergence of the two-collimator system is about 1.5 min.

Fig. 6 Calcite (200) rocking curves.

The rocking curve for the beryllium crystal at about 4 ev shows a 7.6-min width. This indicates a crystal mosaic structure width of about 7.5 min.

Most of these curves were measured by keeping the crystal fixed and moving the arm with the detector. This was done both for convenience and to check the operation of the new automatic system. The run-repeating mode of the system was used to repeat some of the rocking curves several times. Even on such rapidly changing functions, the repeatability was well within the excellent statistics obtained.

1.2 Fast Chopper

1.21 Total Cross Section of Pu-238 (T. E. Young, F. B. Simpson). The following is the abstract of a paper concerning the cross section of Pu-238 presented at the American Physical Society meeting in Washington, D. C.:

The MTR fast chopper and radioactive-sample changer were used to measure the total cross section of Pu-238 from 0.02 to 100 ev. The sample contained 0.280 gram of Pu-238 in the form of PuO₂ powder pressed in a matrix of Al powder to form a target containing only Al powder. Sample preparation techniques were checked by measuring the cross section of gold in the thermal region using a target prepared in the same manner as the Pu-238 sample. A non-1/v

cross section was observed for Pu-238 in the thermal region, with a 2200-m/sec value of 615 ± 10 b/atom. Isolated neutron resonances were detected at energies of 2.89 ± 0.02 , 5.18 ± 0.04 , 9.98 ± 0.06 , 18.56 ± 0.10 , 60.0 ± 0.3 , 70.3 ± 0.4 , and 83.2 ± 0.5 ev.

Analysis of the first three resonances in Pu-238 was made with the use of the single-level Breit-Wigner formula and the parameters are given in Table I. A plot of the data for the resonances below 20 ev is shown in Figure 7. The relatively large widths obtained indicate that an appreciable fission component may exist. Analysis of the contaminant resonances at 1.04 ev (Pu-240) and 5.18 ev (U-234) yielded values for the total widths which are in agreement with presently accepted parameters for these resonances.

TABLE I

Pu-238 RESONANCE PARAMETERS

E_0 (ev)	Γ_{abs} (mv)	Γ_n° (mv)	
	B-W Fit	B-W Fit	Area Analysis
- 0.5	45	0.87	—
2.89 ± 0.02	45 ± 10	0.040 ± 0.005	0.041 ± 0.005
9.98 ± 0.06	75 ± 30	0.063 ± 0.010	0.066 ± 0.010
18.57 ± 0.10	175 ± 50	0.34 ± 0.10	0.36 ± 0.10

Fig. 7 Total neutron cross section of Pu-238.

1.22 Total Cross Section of Pa-233 (F. B. Simpson, R. P. Schuman). Preliminary cross section measurements in the thermal energy region on irradiated samples of Th-232 were made. Analysis of these data gives a very preliminary value of approximately 50 barns for the 0.0253-ev total cross section of Pa-233. A small resonance is believed to exist at approximately 0.38 ev. The thermal cross section may be revised at a later date pending complete decay of the sample so that an accurate determination of the sample thickness can be made from the U-233 content. Plans are also to repeat these measurements with another sample.

1.23 Total Cross Section of Lu (T. E. Young, R. R. Spencer). Preliminary total cross section measurements were made from 0.008 to 80 ev using a target containing Lu₂O₃ with natural abundances of the Lu isotopes.

1.24 Pu-241 Fission Cross Section (T. Watanabe, O. D. Simpson). The Pu-241 fission data in the thermal energy region are being analyzed using a multilevel formula. The fission chamber is being modified in order to increase the counting rate and to improve stability. It is hoped to accomplish the latter by replacing the original photomultiplier tubes with RCA 6342-A tubes which will permit a larger anode current and improve the discrimination against background pile-up.

1.25 4096 Channel Analyzer (F. B. Simpson et al). A new 4096 channel analyzer has been purchased and is being installed.

1.26 Li-6 Glass Scintillators (G. E. Stokes, R. R. Spencer). Investigations are being carried out to determine the feasibility of using Li-6 glass scintillators as an efficient neutron detector on the fast chopper. For these tests a glass 2 in. in diameter by 1/2 in. thick mounted on the face of an RCA 6342 photomultiplier was used.

The tests showed that the glass is very sensitive to gamma rays as well as neutrons. The gamma rays in the chopper beam obscure the neutron peak of the Li-6 scintillator. Possibilities are being explored to use tunnel diode discrimination with this system to make it practical for use on the fast chopper. The present system is adequate for use on the MTR crystal spectrometer.

1.27 Fission Cross Section Measurements (M. S. Moore). A gas scintillation fission chamber has been designed and built. Preliminary determinations of rise-time characteristics and discrimination stability indicate that the chamber is adequate for measurement of the fission cross section of such materials as U-232 and Pu-238.

2. NUCLEAR CHEMISTRY (W. H. Burgus)

2.1 Half-life Determination of Ho-166 (B. Keisch, K. T. Faler)

The half-life measurement [4] of the long-lived isomer of Ho-166 has been completed. This previously had been reported as having a half-life greater than 30 years. The determination was based on a specific activity measurement of a sample irradiated to 5.6×10^{21} n/cm² and on the assumption that all decay goes via the 180-kev gamma ray transition. Mass analysis of the irradiated holmium showed that 0.6% was Ho-166. Since no direct measurement of the

internal conversion coefficient of the 180-keV gamma ray has been made, the theoretically calculated value of 0.30 was assumed to be correct. The largest uncertainty in the measurement was in weighing the 20- μ g sample. The half-life value calculated, with its estimated uncertainty, is $90,000 \pm 18,000$ yr. This value gives a formation cross section of about one barn for this isomer which is consistent with the absorption cross section [5] and the cross section for formation of the short-lived (27 hr) isomer as described below.

2.2 Formation Cross Section of 27-hr Ho-166 (B. Keisch)

The cross section for formation of 27-hr Ho-166 by thermal neutron activation was found to be 64 ± 6 barns. The determination was made using a cobalt flux monitor, and the activity of the Ho-166 was measured with a $4\pi\beta$ - γ coincidence counting system. The decay rate of the source was followed as a check on the radiochemical purity of the sample.

2.3 Isomer Yield Ratios (B. Keisch)

The program for accurately determining yield ratios of isomers produced by neutron activation was concluded and all the data prepared for publication. The following values of yield ratios not reported in previous progress reports are included in the article:

(1) Sb-122, -122m - The yield ratio for thermal neutrons was determined to be 0.066 ± 0.008 by $4\pi\beta$ - γ coincidence counting of the two isomers in the same sample.

(2) In-114, -114m - The yield ratio [6] for thermal neutrons was determined to be 2.1 ± 0.1 and for epi-cadmium neutrons 2.4 ± 0.2 . The measurements were made by counting samples in a standardized position with an end-window β -proportional counter. An absorber was used to prevent counting of electrons from the upper isomeric state while the decay of the isomers was followed. A 100-fold reirradiation of each sample was necessary in order to obtain good counting statistics for the longer lived isomer. Gold foil monitors were used to compare the neutron exposures of the two irradiations. Formation cross sections were also determined for the two isomers (for thermal neutrons only) by standardizing the counting setup with an Re-188 source. The best values obtained for these cross sections are:

3.9 ± 0.4 barns for the formation of 72-sec In-114, and

8.1 ± 0.8 barns for the formation of 49-day In-114m.

(3) Rb-86, -86m - The yield ratio (for thermal neutrons) was determined by first counting "to death" the 560-keV gamma ray emitted in the decay of the 1-min. isomer and then (on the same sample) counting the 1080-keV gamma ray emitted by the 18.7-day isomer. The yield ratio was found to be 0.12 ± 0.01 . The cross section for the formation (by thermal neutron activation) of the 1-min. isomer was determined using the same counting technique but incorporating a gold foil flux monitor. The cross section was found to be 0.061 ± 0.006 barn. The cross section for the formation (by thermal neutron activation) of the 18.7-day isomer was determined by $4\pi\beta$ - γ coincidence counting of a weighed sample

and by using a cobalt flux monitor. The value obtained was 0.46 barn but this must be considered tentative until confirmatory experiments are completed.

2.31 Conversion Coefficient for the 57-kev Transition in the Decay of Ir-192m (B. Keisch). By using the yield ratio (2.0) previously reported [7] and measuring the gamma ray emission rate for the Ir-192 isomers, the conversion coefficient for the 57-kev isomeric transition in the decay of Ir-192m was determined. The value found, 3400 ± 300 , was in very good agreement with the theoretical value (3330) obtained from Slivs' and Rose's tables [8, 9] for an E3 transition. A report of this determination was prepared and submitted for publication as a letter to the editor of a journal.

2.4 Fission Mass Yields of U-235 as a Function of Neutron Energy (K. T. Faler, R. L. Tromp)

Experimental work in this study was completed with five irradiations of U-235, two at 0.04 ev with neutron crystal spectrometer neutrons, one a cadmium-covered background determination in the thermal column, and two with carbon-filtered neutrons from the cold neutron facility. All data were processed and the final results are shown in Table II. A preliminary report of the study was included in a paper presented at the June meeting of the American Nuclear Society. A full report is being prepared for publication as a journal article.

TABLE II

2.5 Beryllium Gases Experiment (R. L. Tromp)

High-purity beryllium samples irradiated to fast neutron dosages of 10^{21} n/cm^2 were heated at various lengths of time until nearly constant density was reached. Temperatures used were 800, 900, and 1000°C. The results are shown in Table III. In addition, an effort was made to more closely pinpoint the swelling threshold temperature. A sample previously used for 600°C heating (in which negligible density change was observed) was re-annealed at 750°C. The results, shown in Table IV, indicate an initial density decrease, followed by an increase and then a further decrease. The observed effects are too large to ascribe to experimental error, and are unlike the density trends at higher temperatures where smoothly decreasing densities were observed which approached minimum values. At present no explanation has been reached for this behavior at 750°C.

R VALUES FOR U-235 FISSION AS A FUNCTION OF NEUTRON ENERGY

Energy (ev)	R ^(a)	Standard Deviation
~ 0.0002	0.765	0.044
~ 0.004	0.875	0.042
Thermal	1.000	0.032
0.040	0.880	0.047
0.060	0.783	0.021
0.100	0.796	0.059
0.250	0.730	0.022
0.284	0.746	0.026
0.330	0.708	0.022
0.500	0.841	0.033
All epi-Cd	1.181	0.081

(a) R =

$\frac{\text{Peak-to-valley ratio at energy E}}{\text{Peak-to-valley ratio at thermal}}$

TABLE III

BERYLLIUM DENSITY CHANGE AS A FUNCTION OF HEATING TIME

Conditions: Beryllium irradiated to fast neutron dosage of 10^{21} n/cm².

800°C		900°C		1000°C	
Total Heating Time (hr)	Density	Total Heating Time (hr)	Density	Total Heating Time (hr)	Density
0	1.8482	0	1.8450	0	1.8421
1	1.7823	0.5	1.6780	1	1.4759
2	1.7302	1	1.6255	4	1.3049
4	1.6658	2	1.5235	8	1.1993
6	1.6482	4	1.4329	20	1.1125
10	1.6361	8	1.3552	30	1.1165
20	1.6168	20	1.2045		
30	1.6070	40	1.2004		
50	1.5892	60	1.1841		

Density change curves for all temperatures investigated for the 10^{21} fast n/cm² samples are shown in Figure 8. Final (maximum) swelling values as a function of temperature for these samples are plotted in Figure 9.

Gas samples of the non-condensable gases collected during each heating period at 800, 900, and 1000°C consisted mainly of helium and hydrogen isotopes produced from neutron reactions. These were collected and analyzed with the results as tabulated in Table V.

Apparently the reaction gases fractionate significantly at 800°C since very little of the He-4 is evolved. Total evolution at 1000°C approaches the value of 2.03 cc/cc Be obtained by vacuum melting.

In addition to gaseous reaction products evolved, heating at 900°C and 1000°C produced sublimation of radioactive nuclides (formed from activation

TABLE IV

BERYLLIUM DENSITY CHANGES
AT 750°C(a)Conditions: Be irradiated to fast neutron dosage of 10^{21} n/cm².

Cumulative Heating Time (hr)	Density	σ Density(b)
0	1.8473	0.0015
1	1.8318	0.0013
4	1.8051	0.0025
10	1.8182	0.0040
20	1.8231	0.0016
30	1.7829	0.0006

(a) Sample first heated at 600°C where no density change was observed, and then later heated at 750°C.

(b) Standard deviation of a number of density determinations.

Fig. 8 Density change in 10^{21} fast n/cm^2 Be at constant temperature.

Fig. 9 Maximum swelling in 10^{21} fast n/cm^2 Be vs temperature.

of trace impurities in the original beryllium) and subsequent condensation in a metallic mirror on the colder portions of the quartz heating tube. At 900°C a very pure gamma spectrum of Zn-65 was found, while at 1000°C a mixture of Zn-65 and Ag-110 activity was collected from the tube.

2.6 Chopper Measurements of the Cross Section of Ta-182 (R. P. Schuman, J. R. Berreth)

Calculations were made of the composition of irradiated tantalum in order to determine the best way to produce Ta-182 for chopper cross section measurements. The calculations assume the effective resonance integral measurements reported in the last quarterly report [10], the 21-barn thermal cross section for Ta-181, a 17,000-barn thermal cross section for Ta-182 reported in BNL-325 [11], and a guess of 10,000 barns for the resonance capture integral of Ta-182.

Figures 10 and 11 show the calculated composition of Ta irradiated in the L-45 position of the MTR ($\phi_{th} \sim 5 \times 10^{14}$ n/cm^2 sec, $\phi_{res} \sim 3.5 \times 10^{13}$ n/cm^2 sec), unshielded and inside a cadmium shield, respectively. It is planned to irradiate a number of 10-mil-thick strips of Ta foil inside a Cd shield for one cycle (~ 28 days) in the ETR in order to produce a Ta-182 chopper sample.

2.7 Relative Thermal Capture Cross Sections (R. P. Schuman)

Duplicate ~ 50 - μg samples of U-233, U-235, Pu-239, Pu-240, and Pu-241 were irradiated in the essentially pure thermal flux of the VG-41 position of the MTR. These samples, after cooling for about one year, have been chemically purified preparatory to mass analysis. The uranium samples were purified by absorption on a Dowex 1 column from concentrated HCl and elution with

TABLE V
COMPOSITION OF GAS EVOLVED FROM HEATED BERYLLIUM

Conditions: Be irradiated to fast neutron dosage of 1×10^{21} n/cm².

<u>Cumulative Heating Time (hr)</u>	<u>Total Reaction Gas (cc/cc Be)</u>	<u>H₂¹</u>	<u>H₂³</u>	<u>He³</u>	<u>He⁴</u>
<u>800°C</u>					
1	0.06				
2	0.08				
4	0.14				
6	0.27				
10	0.36				
20	0.44				
30	0.52				
50	0.59	0.50	0.05	—	0.04
<u>900°C</u>					
0.5	0.07				
2	0.12				
4	0.25				
8	0.39				
20	0.84				
40	1.12				
60	1.36	0.26	0.02	0.01	1.07
<u>1000°C</u>					
1	0.35				
4	0.69				
8	1.01				
20	1.54				
30	1.96	0.85	0.06	0.01	1.04

very dilute HCl. The plutonium samples were purified by absorption on a Dowex 1 column from concentrated HCl plus a little HNO₃, and elution with concentrated HCl plus ~ 2% HI.

Preliminary mass analyses were made of the uranium samples at the ICPP and show an increase in the U-234 abundance in the U-233 of about 0.06%, and an increase in the U-236 abundance in the U-235 of about 0.10%. It is planned

Fig. 10 Composition of unshielded tantalum irradiated in L-45.

Fig. 11 Composition of cadmium-shielded tantalum irradiated in L-45.

to have all the samples mass-analyzed with a double-focusing spectrometer with the hope that the abundances of the capture isotopes can be obtained to ± 10 parts/million.

2.8 Alpha Spectrum of Pu-241 (R. P. Schuman)

A sample of enriched Pu-241 was purified by absorption on a Dowex 1 column from concentrated HCl plus a little HNO₃, and elution with concentrated HCl plus $\sim 2\%$ HI. A small aliquot of the purified material was electroplated on platinum, and the alpha spectrum studied with an ORTEC silicon surface barrier detector. In addition to the two PU-241 alpha groups previously detected [12], three other low-intensity groups could be detected. A typical spectrum, after the Am-241 had grown in for 4 days, is shown in Figure 12. A gamma spectrum of the purified material was the same as that shown in a previous quarterly report [13].

A mass analysis of the Pu-241 will be obtained in conjunction with the relative capture experiment, and it is planned to calculate the abundances of the alpha groups and the alpha half-life of Pu-241.

2.9 Remote Pressing of Matrix Alloys (J. R. Berreth)

In the preparation of matrix alloy samples for cross section measurements as previously described [14], highly radioactive materials present a

Fig. 12 Alpha spectrum of purified, enriched Pu-241.

special problem. In order to prepare these highly α -, β -, γ - active samples, a special sample preparation box is being set up to fit inside the MTR alpha cave [15]. The box will contain a special remotely operated press and die, a small mixer-grinder for preparing the samples, and a semi-micro balance for weighing.

The press has a four-column guided platen for rigid alignment of the die. The 30-ton-capacity, double-acting, hydraulic cylinder is remotely operated from the front face of the cave by an electric pumping unit. Only the relatively inexpensive press is exposed to contamination.

Due to the necessity of performing operations with manipulators inside the cave, a special die is necessary. The die has a multipiece removable die insert retained in a floating ring. The floating die allows compacting of the powdered mixture from two directions simultaneously, resulting in a uniform compact. The compact is removed by counter action of the press on the die insert. This arrangement allows easy removal of the compact, facilitates cleanup of the die surfaces, and necessitates the handling of only the lightweight die inserts with the manipulators. All removable pieces are keyed, thus eliminating alignment problems on reassembly of the die. This equipment, combined with the cave, will provide a very useful means of preparing radioactive samples for the MTR fast chopper.

2.10 Monitoring of Thermal and Resonance Flux Using Au and Mn (J. R. Berreth). Gold can be used as long term neutron flux monitor if the total neutron capture is determined by separating the mercury formed after complete decay of the Au-198 and Au-199 in the irradiated gold [16]. Since gold has a high ratio of resonance capture integral to thermal cross section, an appreciable fraction of the Hg formed will be due to resonance neutrons. Therefore, both the resonance flux and the thermal flux can be determined by monitoring with gold and another monitor with a low ratio of resonance integral to thermal cross section such as manganese. The total capture in Mn is determined by allowing the Mn-56 to completely decay and then colorimetrically analyzing for the iron decay product.

In comparing the two monitors the amounts of Au and/or Mn remaining after irradiation may be expressed by the following equation:

$$N = N_0 e^{-\phi_{th} t (\sigma_{th} + \frac{\phi_{res}}{\phi_{th}} \sigma_{res})}$$

where N and N_0 are the final and original amounts, ϕ_{th} and ϕ_{res} are the thermal and resonance flux, and σ_{th} and σ_{res} are the thermal cross sections and resonance integrals for the particular material. From data obtained from concurrent irradiation of Au and Mn monitors it is possible to solve two sets

of simultaneous equations in terms of the quantity $\phi_{\text{res}}/\phi_{\text{th}}$ as shown in the following equation:

$$\frac{\phi_{\text{res}}}{\phi_{\text{th}}} = \frac{\ln \frac{N_m^0}{N_m} \sigma_{\text{th}_a} - \ln \frac{N_a^0}{N_a} \sigma_{\text{th}_m}}{\ln \frac{N_a^0}{N_a} \sigma_{\text{res}_m} - \ln \frac{N_m^0}{N_m} \sigma_{\text{res}_a}}$$

The subscripts m and a refer to Mn and Au, respectively.

To check out measurements of ϕ_{th} and ϕ_{res} a series of irradiations using 1- and 5-mil Au foils, Mn foils, and Co + Al alloy wires was performed in the MTR. After the Au and Mn activation products had decayed, the Hg and Fe products were determined. The Co + Al alloy wire was used as a guide, since the ratio of $\phi_{\text{res}}/\phi_{\text{th}}$ for Co had been previously determined from Cd ratio experiments. Cobalt is a poor comparison monitor to use with gold because the ratio of the resonance integral to the thermal cross section for Co is nearly as large as the effective ratio for the thick gold used.

Table VI lists the results of three different experiments for samples irradiated in the MTR. If the thermal flux values as determined by the Mn and Au are compared with the values determined by the Co - Cd ratio, there is as much as 10% difference between the two methods. The resonance flux varies to an even greater extent. There are two possible explanations for these differences. The Co - Cd ratios were determined in earlier irradiations and

TABLE VI

COMPARISON OF MONITORS

MTR Position	Comparison	$\phi_{\text{res}}/\phi_{\text{th}}$	ϕ_{th} (n/cm ² /sec x 10 ¹⁴)	ϕ_{res} (n/cm ² /sec x 10 ¹³)
VH-2	Mn + 1 mil Au	0.082	1.68	1.39
	Co-Cd ratio	0.055	1.88	1.03
L-45 NW 11 in. to 13 in.	Mn + 1 mil Au	0.049	2.91	1.41
	Mn + 5 mil Au	0.035	2.95	1.04
	Co-Cd ratio	0.063	2.97	1.86
L-45 SE 28 in. to 30 in.	Mn + 1 mil Au	0.055	4.33	2.38
	Mn + 5 mil Au	No results	No results	No results
	Co-Cd ratio	0.063	4.51	2.82

this ratio may have changed due to different reactor loading. Furthermore, there are indications that the resonance neutron flux in certain positions of the MTR is not $1/E$. This is borne out by the observation that resonance integrals of Mn and Co determined by comparison with thin gold in separate Cd-shielded experiments in facility VG-7 are lower than the quoted values in the literature.

It was found that quantitative removal of Hg from 5-mil gold is difficult and unreliable; however, the removal of Hg from one-mil gold is accomplished without difficulty. A short Cd-shielded irradiation with thin foils is planned in facility VH-2 of the MTR to better establish the resonance integrals of Mn and Co. Also, a long (10 days) irradiation is planned using 1/2-mil Au, Mn, and Co + Al alloy. The 1/2-mil Au will provide a better comparison monitor with Mn because the larger ratio of effective resonance integral to thermal cross section for the gold will allow a more accurate determination of the resonance flux from the Au and Mn monitors.

2.11 Preparation of U-236 Sample (J. W. Coddington and R. P. Schuman). Uranium from a second sample (MTR 30-7) of irradiated U-236 was recovered and purified using the procedure previously outlined for sample MTR 30-6 [17]. A mass analysis of the second product has been done by the Vallecitos laboratory; the results are listed in Table VII. Total uranium recovered was 63.6 mg, based on the optical density of the product solution at 415 m μ . Alpha pulse height analysis showed 62.8 mg of U-236 in the final product, equivalent to about 64.4 mg of total uranium based on the mass analysis.

The amounts by weight of the various alpha-active constituents in the U product have been calculated from the alpha spectrum and are given in Table VIII. Figure 13 shows the alpha spectrum of the U product.

The plutonium-rich and curium-rich fractions remaining after uranium purification also have been examined. Amounts of Pu-238 and Cm-244 recovered from each irradiation are shown in Table IX; also listed are the uranium material

TABLE VII

ISOTOPIC COMPOSITION OF U-236
SAMPLE FROM MTR 30-7

Nuclide	Before Irradiation (wt%)	After Irradiation (wt%)
U-234	—	0.048
U-235	4.39	< 0.003
U-236	93.60	97.453
U-238	2.02	2.500

TABLE VIII

U-236 PRODUCT COMPOSITION BASED
ON ALPHA PULSE HEIGHT ANALYSIS

Nuclide	Weight in Total Product (mg)
U-236	62.8
U-234	3.0×10^{-2} (a)
Pu-238	2.0×10^{-4}
Cm-244	$\sim 10^{-6}$

(a) Corresponds to 0.047 wt%; cf
0.048 wt% from mass analysis.

balances and reported nvt for each case. The U-236 recovered from each irradiation is considerably higher than expected from calculations based on IDO-16571 [18] and the reported nvt values. It was anticipated that nearly 50% of the U-236 would be destroyed during irradiations, whereas only half this amount was burned up; even so, the U-235 content was satisfactorily low in each case.

The amounts of curium produced during each irradiation also were higher than anticipated, by a factor of 10 to 20. The curium-rich fraction from sample MTR 30-7 was analyzed by alpha pulse height analysis after selective elution with hydroxyisobutyric acid from a heated Dowex 50 column. The composition of the fraction, in terms of alpha activity and weights, is shown in Table X.

In spite of the disagreement between calculated and experimental yields, these U-236 irradiations and subsequent uranium purifications have yielded a total of nearly 127 mg of uranium which is >97% U-236, <0.003% U-235, and sufficiently decontaminated from fission products and plutonium to be easily handled in a conventional laboratory hood. Thus, the uranium product should be of satisfactory quality for the purpose of measuring the fission cross section of U-237 by in-pile fission counting of reirradiated material.

Part of the uranium from the MTR 30-7 product has been further purified from plutonium by selective absorption of the uranium on Dowex 1 from a concentrated HCl plus 2% HI solution, and subsequent elution of the uranium with very dilute HCl. The purified uranium shows essentially no alpha activity

Fig. 13 Alpha pulse height analysis of electroplated U-236 product from MTR 30-7.

TABLE IX

COMPARISON OF MTR 30-6 AND MTR 30-7 U-236 IRRADIATION

Irradiation	Reported nvt (n/cm ²)(a)	Weight U-236 (mg)		U-236 Burned (%)	Composition of Uranium Product (b)		Pu-238 Recovered (mg)	Cm-244 Recovered (mg)
		Initial	Final		U-235	U-236		
MTR 30-6	1.89 x 10 ²²	80.2	60.8	24.2	< 0.003	97.592	0.95	0.016
MTR 30-7	2.52 x 10 ²²	86.2	62.8	27.2	< 0.003	97.453	1.54	0.11

(a) Supplied by Project Engineering.

(b) Mass spectrometric analysis performed by Vallecitos Laboratory.

TABLE X

COMPOSITION OF CURIUM-RICH FRACTION FROM MTR 30-7

Nuclide	% of Total Alpha Activity	Approximate Amount Produced During Irradiation (mg)
Pu-238	1.46	Mainly in Pu fraction
Am-241	0.93	0.028
Am-243	0.34	0.17
Cm-242	3.30	0.0001
Cm-244	93.97	0.11

due to trans-uranium isotopes. Irradiations of this purified uranium are planned to study the thermal cross section and resonance integral of U-236 activating to U-237, and also to develop methods for the absolute counting of U-237.

2.12 Preparation of Separated Pa-233 for Cross Section Measurements (J. W. Coddington). Flow sheet development of a process to produce samples of separated Pa-233 from irradiated Th was continued. Further studies were made of the selective extractions of the Pa (and U) from an aqueous solution containing hydrochloric acid, hydrofluoric acid, and the chlorides of thorium and aluminum. The extractant chosen is methylisobutylketone (hexone). Figure 14 shows the effect on Pa-231 and U-233 extraction of changing concentrations of chloride ion. The aqueous solutions were prepared by adding varying amounts of HCl to solutions of constant thorium and aluminum concentrations; thus, hydrogen ion also changes with chloride ion. The abrupt change in the effect of Cl^- concentration on protactinium extraction (E_{Pa}) at about 7 M no doubt indicates two competing reactions are occurring. Below 7 M Cl^- (which is about 5 M H^+ in this system) the hydrolysis of protactinium inhibits extraction, and above 7 M Cl^- , the formation of a seven-chloride anionic complex of protactinium likewise prevents complete extraction. For this system, the maximum separation of protactinium from uranium, ie, $E_{\text{Pa}}/E_{\text{U}}$, is about 10 for a single extraction, yielding an overall decontamination from uranium of about 100 in two extractions. Using two volumes of organic to one volume of aqueous, an overall protactinium recovery of 93% can be achieved. These values for uranium decontamination and

Fig. 14 Extraction of protactinium and uranium from a chloride system with hexone.

protactinium recovery are acceptable in the system chosen for producing about 200 mg of protactinium, as will be seen below.

Recent total cross section measurements of unseparated Pa-233 in a sample of irradiated Th-232 indicated that about 1 gram of separated Pa-233 will be required to produce a sample for the chopper with 70% transmission for thermal neutrons. To prepare this amount of Pa-233, it is planned to irradiate about 60 grams of thorium metal for one 4-week cycle in the ETR at maximum flux ($\sim 7 \times 10^{14}$ n/cm² sec). For production of a given quantity of Pa-233, the long irradiation of a small weight of thorium results in a higher U-233/Pa-233 ratio than does a short irradiation of a larger amount of thorium; thus the problem of protactinium purification with respect to uranium is made more difficult. Table XI compares the "200-mg" and "1000-mg" processes with respect to required

TABLE XI
COMPARISON OF REQUIRED DECONTAMINATION FOR
"200 mg" AND "1000 mg" PROCESSES FOR Pa-233 PRODUCTION

Process	At End of Irradiation			g/t(a)	Final Pa-233 Required (mg)	Pa Recovery (%)	Required Decontamination(b)	
	Th (g)	Pa-233 (mg)	U-233 (mg)				U(c)	Fission Products(d)
"200 mg"	200	210	15	1,000	200	95	67	1
"1000 mg"	66	1200	480	18,000	1000	83	400	15

(a) g/t = grams of mass 233 per ton of Th-232; this value is to some extent a measure of the fission product concentration at the end of irradiation.

(b) Decontamination is defined as: $\frac{\text{atoms of x in feed}}{\text{atoms Pa-233 in feed}} \div \frac{\text{atoms of x in product}}{\text{atoms Pa-233 in product}}$

(c) The values listed give a product in which only 0.1% of mass 233 is U-233.

(d) Relative values to give products which are equally "cold".

uranium and fission product decontamination. Although the extraction scheme outlined above is satisfactory for the "200-mg" process, such is not the case with respect to uranium decontamination when one gram of Pa-233 is required. Also the sample extraction scheme probably is not satisfactory with respect to overall fission product cleanup. These difficulties in "scaling up" from 0.2 to 1.0 gram of Pa-233 suggested the inclusion of another and different separative step in the purification process.

Accordingly, some scoping studies were performed on a combination scavenging and extraction scheme, whereby the major separation of protactinium from thorium and uranium is accomplished by an initial scavenging of Pa-233 from a thorium-uranium solution. The scavenger is MnO₂. A final solvent extraction step provides further decontamination from uranium and thorium and from the several fission products which accompany MnO₂. The mechanics of precipitate handling required for such a scheme have been demonstrated on a one-twentieth volume scale, from formation of the precipitate to its subsequent dissolution, including remotely controlled solution transfers and filtration, dissolver rinses, and precipitate backwashes. Tracer studies using

Pa-231 have shown the feasibility of this approach, yielding an overall protactinium recovery of about 80%, from precipitate formation through final solvent extraction with hexone. This processing method will next be tried on a one-thousandth volume scale, using full level concentrations of Pa-231 and U-233.

3. INELASTIC SCATTERING OF SLOW NEUTRONS PROGRAM (R. M. Brugger)

3.1 MTR Cold Neutron Facility (K. A. Strong)

Two neutron choppers with 30 in. radius of curvature have replaced the choppers with 42 in. radii at this facility. Because of the better matching of these slits to the operating speed and the path of the neutrons through the choppers, a factor-of-4 increase in neutron intensity was realized. A single-channel time analyzer was completed and tested in conjunction with a beam monitor fission chamber. Channel widths of the 100-channel time analyzer were changed from 20 to 40 μ sec to better cover the energy range. Background counting rates were reduced by a factor of 5 by improved shielding.

Inelastic scattering distributions of 0.0048-ev neutrons at an angle of 90° from samples of methane, ethane, propane, and butane were obtained and are being converted to cross sections. These data are good and will be reported at the Seattle APS meeting (August 27 to 29, 1962).

A paper entitled "Phasing Two Choppers from a Motor Generator Source", which describes the chopper drive and phasing system at this facility, has received patent clearance and has been submitted for publication in Nuclear Instruments and Methods.

3.2 Neutron Scattering from Beryllium (R. E. Schmunk)

A paper entitled "Lattice Dynamics of Beryllium" by R. E. Schmunk, R. M. Brugger, P. D. Randolph, and K. A. Strong has been submitted to the Physical Review for publication. Measurements were made of the dispersion relation for waves propagating in the [001] and [0110] directions in beryllium using the MTR velocity selector. Optical frequencies were found to give two branches, separated in frequency, and these branches are referred to as upper optical and lower optical. The observed optical branches are in contrast to previous observations on monatomic cubic crystals [19] for which the optical branches are degenerate, at least at the center of the Brillouin zone. The mode of vibrations for a given observed transition was determined from the area in reciprocal space in which the data were plotted. The initial slopes of the acoustical branches agree well with elastic constant data, with the exception of the longitudinal acoustical branch in the [0001] direction for which the phonon data are not sufficient to make a clear comparison. Two lattice dynamics models were compared with the data. The model of Begbie and Born [20] assumes general forces for interactions with first- and second-nearest neighbors while the model of Slutsky and Garland [21] assumes central force interactions with first-, second-, and third-nearest neighbors. The latter model was extended in the present work to include interactions with fourth- and fifth-nearest neighbors. It was found that both models gave limited agreement with the data only when the force constants in the models were evaluated directly from the neutron scattering data.

3.3 Chopper Spin Tests (R. E. Schmunk)

A velocity selector chopper, with an insert of zero curvature, was successfully spin-tested at 15,000 rpm. The results indicate that the present method of bonding chopper inserts is satisfactory for chopper speeds up to the maximum of 15,000 rpm, and that the drive motors in present use (Elinco, 400 cycle, 12,000 rpm) are also satisfactory over the desired speed range. The spin tests are continuing preparatory to operating the velocity selector choppers at higher rotational speeds.

3.4 Scattering of Slow Neutrons by Sodium (P. D. Randolph)

Final runs on the inelastic scattering of slow neutrons from liquid sodium have been made. The data comprise runs made at 0.025, 0.7, and 0.1 ev at temperatures of 23, 100, 110, 150, and 200°C. Also, a long run at 100°C has been taken at 0.0415 ev. All of the data except the runs at 200°C and the 0.0415 ev have been machine processed through cross section and scattering law.

Figure 15 shows the angular distributions obtained at 100, 110, and 150°C. Each of these plots combines the data for 0.025, 0.07, and 0.1 ev. The data are plotted in the form of a diffraction

pattern. The abscissa, $S = \frac{\sin \theta/2}{\lambda_0}$ is

proportional to the neutron momentum transfer. The angle, θ , is the scattering angle and λ_0 is the wavelength of the incident neutrons. Each data point is obtained by a planimeter integration over the wavelength of the measured partial differential cross section at the angle, θ . The solid curve shown for comparison (for all three plots) is the result obtained by Gingrich and Heaton [22] for sodium at 100°C, using a crystal spectrometer. Such a diffraction pattern is relatively insensitive to the range of temperatures used in this experiment (50°C) so that the same curve may be used. Their curve was normalized to these data, since their measurements gave only relative intensities. The data are in good agreement with Gingrich and Heaton's results. At small values of

$$\frac{\sin \theta/2}{\lambda_0}$$

there are marked disagreements. These are due to the large area detectors used in this experiment which cause noticeable angular resolution effects.

Fig. 15 Experimental diffraction plots for liquid sodium at 100, 110, and 150°C as obtained using the velocity selector. The solid curve is the result of Gingrich and Heaton at 100°C normalized to these data.

It was reported in the last quarterly report^[23] that the scattering law results obtained by machine computations on the data at 100°C gave values for the first energy moment that are a factor of 2 to 3 higher than predicted, while the zero'th energy moments were in reasonable agreement with predicted values.

The zero'th moment of the scattering law, $S(\alpha, \beta)$, is given by

$$\langle 1 \rangle \equiv \int_{-\infty}^{\infty} e^{-\frac{\beta}{2}} S(\alpha, \beta) d\beta = F(\alpha) \quad (1)$$

and the first energy moment is

$$\langle \beta \rangle \equiv \int_{-\infty}^{\infty} \beta e^{-\frac{\beta}{2}} S(\alpha, \beta) d\beta = \alpha \quad (2)$$

where $\beta = \frac{E-E_0}{k_B T}$ is the neutron energy transfer in units of $k_B T$ and

$\alpha = \frac{t^2 K^2}{2Mk_B T}$ is the square of the momentum transfer in dimensionless

units. $F(\alpha)$ is known from the neutron diffraction data.

The scattering law, S , is given by

$$S(\alpha, \beta) = \frac{4\pi k_B T}{\sigma_{\text{bound}}} \sqrt{\frac{E_0}{E_0 + \beta k_B T}} e^{-\frac{\beta}{2}} \sigma(E_0, E, \theta)$$

where $\sigma(E_0, E, \theta)$ is the measured partial differential cross section for neutron scattering from energy, E_0 , to E at a scattering angle, θ , and σ_b is the bound atom total scattering cross section.

Values of $S(\alpha, \beta)$ can be obtained from $\sigma(E_0, E, \theta)$ for $0 \leq \beta \leq 2.0$. The major contribution to Equation (2) comes from values of β greater than about 0.3. These correspond to values of E lying outside the half width of the main peak in the energy spectrum. In this region, the 4-point interpolation used by the program in obtaining $S(\alpha, \beta)$ from $\sigma(E_0, E, \theta)$ does not yield values as accurate as visual interpolation from a hand-drawn curve. In the center of the peak, however, the program gives better values than can be obtained by hand. In order to reduce the point scatter in the scattering law, the scattering law at 100, 110, and 150°C was computed by hand, using smooth curves drawn through the data points. Figure 16 shows a representative comparison of the results

obtained by machine and in the hand-drawn case. The large scatter of points in the machine computation is considerably reduced in the hand-drawn case. The cause of the inconsistency is not in the actual calculation but lies in the use of the 4-point interpolations. In some regions of the spectrum, many more points would be needed, and the number needed to obtain a smooth curve through $\sigma(E_0, E, \theta)$ varies with E .

The results of redoing the scattering law by hand in every case give better values of the scattering law, in that the point spread is reduced. Using this scattering law, the moment theorems were rechecked at 100°C using best fit curves drawn through the scattering law points. Figure 17 shows this scattering law for 100°C. Table XII shows a comparison of the observed with the theoretical values of $\langle 1 \rangle$ and $\langle \beta \rangle$ at the various values of α at which the moments were evaluated.

Fig. 16 Comparison of the scattering law at $\beta = 0.5$ as calculated by the computer using an interpolation method and as calculated by hand.

Fig. 17 The scattering law for liquid sodium at 100°C.

The average values of these ratios are:

$$\frac{\langle 1 \rangle_{\text{obs.}}}{\langle 1 \rangle_{\text{theore.}}} \text{ ave.} = 1.14 \pm .16$$

and

$$\frac{\langle \beta \rangle_{\text{obs.}}}{\langle \beta \rangle_{\text{theore.}}} \text{ ave.} = 2.67 \pm .19$$

where the errors shown are the mean deviations. The zero'th moment is in reasonable agreement with theory but the first moment is much larger. Thus, although using the hand-calculated $S(\alpha, \beta)$ gives more reliable values of $S(\alpha, \beta)$, the previously noted disagreement between theory and experiment in the first moment remains.

The discrepancy cannot be due to the finite angular resolution of the apparatus since this effect would cause the largest errors at small α values and the least errors at large α . No such effect is seen. Similarly, the effects of finite energy spread of the incident beam leads to a broadening of the energy spectra and, thus, an increase in the

TABLE XII

COMPARISON OF OBSERVED AND THEORETICAL VALUES OF $\langle 1 \rangle$ AND $\langle \beta \rangle$

α	$\langle 1 \rangle$ observed	$\langle \beta \rangle$ observed
	$\langle 1 \rangle$ theoretical	$\langle \beta \rangle$ theoretical
0.005	0.95	2.52
0.008	1.05	2.75
0.010	0.75	2.87
0.013	1.27	3.06
0.018	1.24	2.87
0.034	1.30	2.74
0.06	1.31	2.39
0.10	1.22	2.34
0.20	1.20	2.45

apparent cross section outside the central maximum. Such an effect also would depend on angle; the largest error being at the most forward angle (small α) where the spectra have the narrowest peaks, the smallest error at larger angles where the peaks are broader. Table XII again shows that this is not the case. A comparison of the wavelength width of the incident beam with the wavelength width of the observed cross section, making the assumption that the shapes are roughly gaussian, indicates that the "true" width of the cross section spectrum (at 16° , $E_0 = 0.1$ ev) is the same as the incident beam width. At worst, this would give 15 to 20% errors in the observed cross sections and could not account for the anomalously high value of the first moment.

There exists the possibility that the sodium sample had in it small amounts of impurities affecting its character as a liquid. This would not materially affect the measured total cross section or even the zero'th moment. However, it could have drastic effects on the first and higher moments. To check this, the sample will be sectioned and sent to the ICPP for chemical analysis.

4. THEORETICAL PHYSICS (H. L. McMurry)

4.1 Scattering of Slow Neutrons by Liquid Methane (G. W. Griffing)

Recently, H. Stiller and S. Hautecler reported measurements of the slow neutron scattering by liquid methane [24]. Their data give the intensity of neutrons scattered through 70° with an energy loss from E_0 down to below 0.006 ev as a function of the initial neutron energy, E_0 . Peaks in this intensity distribution are attributed to the existence of rotational energy states for the

molecules. The diffuseness of the pattern is attributed to the existence of free translational motion.

To investigate this theoretically, the partial differential cross section for scattering from E_0 to $E < 0.006$ ev through a scattering angle of 70° was computed assuming that only rotational motion takes place, and also on the assumption that both the rotational and translational degrees of freedom are active. A quantum mechanical treatment was used [25].

For the case where only rotational motions are considered, the results agree well with Stiller and Hautecler's experiments for E_0 between 0.027 and 0.014 ev. For E_0 less than 0.014 ev, the calculations diverge from the experimental results.

When free translational motion is superposed on the rotational motion, there is no agreement. In particular, the structure in the curve of differential cross section vs E_0 is washed out.

Thus, it appears that the assumption of free rotation by the methane molecules in the liquid has validity, but the translational motions cannot be entirely free. These investigations are continuing with a view toward explaining the full range of experimental data.

4.2 Vibrational Modes in Large Molecules (H. L. McMurry)

A scheme has been devised for calculating the neutron scattering by large molecules such as the terphenyls which occur in Santowax [23]. The energy exchanges which occur upon scattering of neutrons by such molecules depend significantly on the characteristic vibrational energies and normal modes. While approximate estimates of those modes may suffice for neutron scattering calculations, it appears desirable to make some calculations using fairly exact normal modes and characteristic energies. These results can help in evaluating less rigorous approaches.

To facilitate such calculations, a procedure developed earlier for calculating the vibrational modes of large molecules [26] was modified so the equations are somewhat easier to set up, and the relation between the normal coordinates and the cartesian displacements of the atoms is easier to obtain. The normal modes and characteristic energies of biphenyl are being calculated. The results may be of use in resolving the controversy as to whether biphenyl exists in a planar form [27].

5. LOW ENERGY NUCLEAR PHYSICS - DECAY SCHEME STUDIES (R. L. Heath, C. W. Reich)

5.1 Investigation of High Spin States of Er-166 (J. E. Cline, C. W. Reich)

The decay of the long-lived Ho-166 isomer is being studied. Sources of this activity were prepared by irradiation of commercial grade Ho_2O_3 in a flux of $\approx 4 \times 10^{14}$ n/cm²/sec for periods of three months in the MTR. After the 27-hr activity had decayed away, the samples were purified through the use of a Dowex (12X) cation resin column using 0.4M alpha-hydroxyisobutyric acid, pH 3.2, as the eluting agent. Sources for the gamma ray studies were prepared

by evaporation of a weak nitric acid solution of the purified Ho on 10 mg/cm² plastic films. For the electron studies, sources were prepared by evaporation of the acid solution onto 0.25-mil rubber-hydrochloride films coated on both sides with $\approx 20 \mu\text{g}/\text{cm}^2$ of gold.

5.11 Gamma Ray Measurements. The gamma radiation was studied using 3-in.-diameter x 3-in.-cylindrical NaI(Tl) detectors. In order to study the effects of coincidence summing in the detector, spectra were taken at source-detector distances of 10, 15, 20, 30, and 40 cm. At the 10-cm distance, coincidence summing effects accounted for nearly all of the observed spectra above 1 Mev and had an appreciable effect below this energy. Since there were no observable differences in spectra below 1 Mev taken at source-detector distances ≤ 15 cm, the spectrum to be analyzed was taken at a 20-cm distance. Since the sources used in the experiment were not sufficiently strong to permit good data to be taken at the higher energies with the necessary source-detector separation of ≤ 40 cm, no data are presently available concerning transitions of energies greater than 1 Mev. A typical pulse height spectrum obtained from a purified Ho-166 sample is shown in Figure 18. The results of the gamma-gamma coincidence measurements described below, together with a preliminary analysis of this spectrum, indicated the presence of at least 23 transitions below 1 Mev. A least squares fit to the spectrum in Figure 18 was made using calculated response functions for these 23 transitions. The results of this analysis are summarized in Table XIII.

Fig. 18 Gamma ray spectrum of long-lived Ho-166.

Gamma-gamma coincidence measurements were made using a pair of 3- x 3-in. NaI(Tl) detectors. All measurements were made at 90° geometry; and a shield was placed between the detectors to reduce the scattering of photons between the crystals. The coincidence spectrometer used a single-channel pulse height analyzer operated in coincidence with a 256-channel transistorized analyzer. For these measurements, 22 single-channel-analyzer settings of approximately equal width spanned the pulse height region corresponding to energies between 80 and 980 keV. Typical coincidence spectra are shown in Figure 19. In addition to establishing the existence of transitions, these spectra provided a means of determining relative intensities for several of the gamma rays.

5.12 Electron Measurements. The electrons emitted in the decay of Ho-166 were observed using silicon diode solid-state detectors. These detectors were cooled to -70°C in order to reduce the output noise level. For the higher energy electrons, a lithium-drift detector with a depletion depth equivalent to the range of an 1100-keV electron was used. The electron spectrum obtained using this detector is shown in Figure 20. Also shown is the response of the detector to the gamma rays from the Ho-166 source. From this spectrum,

TABLE XIII

GAMMA RAY ENERGIES, GAMMA RAY INTENSITIES, AND TRANSITION INTENSITIES

<u>E (kev)</u>	<u>I_γ (%/β⁻ emission)</u>	<u>I_t (%/β⁻ emission)</u>
80 ± 2	11.6	100
185 ± 3	87.0	92.0 ± 6.0
215 ± 5	4.0	4.8 ± 2.4
263 ± 3	2.5	3.0 ± 1.5
280 ± 5	25.1	27.0 ± 3.0
300 ± 5	3.4	3.5 ± 1.8
365 ± 5	2.8	2.8 ± 0.3
410 ± 5	15.1	15.2 ± 1.7
465 ± 10	1.9	$\left. \begin{array}{l} 1.9 \pm 0.4 \\ 3.1 \pm 0.5 \end{array} \right\} 5.0 \pm 0.5$
465 ± 10	3.1	
530 ± 5	10.0	10.0 ± 1.2
565 ± 5	8.0	8.0 ± 1.0
595 ± 10	1.5	1.5 ± 0.7
620 ± 10	3.0	3.0 ± 0.8
675 ± 10	4.8	4.8 ± 2.0
690 ± 10	3.3	3.3 ± 1.5
710 ± 5	62.6	62.6 ± 6.5
765 ± 10	6.8	6.8 ± 1.0
780 ± 10	6.2	6.2 ± 2.5
810 ± 5	55.2	55.2 ± 6.0
830 ± 5	11.2	11.2 ± 3.5
880 ± 10	1.7	1.7 ± 0.5
955 ± 5	3.3	3.3 ± 0.5

it is apparent that the 810-kev and 710-kev gamma rays have different multi-polarities. For the lower-energy electrons, a phosphorus-diffused detector, operated with a depletion depth equivalent to the range of a 170-kev electron, was used. Figure 21 shows a typical spectrum taken with this detector. As may be seen from this figure, no meaningful data could be derived from this system below ≈ 20 kev. Also shown in the figure are the estimated position and intensity of the 80-kev K-conversion line and calculated β^- distributions for end point energies of 55, 70, 90, 250, and 550 kev. These curves were calculated assuming an allowed shape for the transitions and were normalized to the data using the

TABLE XIV

COMPARISON OF THE CALCULATED Er-166 ROTATIONAL LEVELS
WITH THOSE OBSERVED EXPERIMENTALLY.

Conditions: Parameters used in the calculation are $k = -0.96$,
 $A/C = 17.14$, $hC = 11.62$ kev, $b = 6.3 \times 10^{-4}$ kev⁻¹.

Level	τ (a)	K_{-1}, K_{+1} (b)	Calculated Energy (kev)	Observed Energy (kev)
1 ₂	-2	0,2	80.6	80.6(c)
1 ₄	-4	0,4	265.1	265.1(c)
1 ₆	-6	0,6	545.6	545.3(c)
2 ₂	+2	2,0	786.8	787.1(c)
1 ₃	0	2,2	860.1	860.6(c)
1 ₈	-8	0,8	909.8	910
2 ₄	0	2,2	957.6	957.2(c)
1 ₅	-2	2,4	1075.8	1074
2 ₆	-2	2,4	1219.3	1220
1 ₇	-4	2,6	1375.6	1374

(a) The value of τ appropriate to the level.

(b) The limiting values of the projection quantum number for the prolate and oblate symmetric tops.

(c) Energies reported by Jacob [32].

observed intensity of the 80-kev L line. In a comparison of these calculated curves with the data, two facts should be noted. First, the efficiency of the detector decreases rapidly for energies above ≈ 170 kev. Second, the spectrum below ≈ 30 kev is seriously degraded because of the finite source thickness. These facts were not taken into account in the calculation of the beta distributions. Nevertheless, it appears that the maximum end point energy of the most intense beta transition must be ≤ 60 kev.

5.13 Decay Scheme. A proposed decay scheme for the long-lived Ho-166 activity, based on the gamma ray and electron measurements presented above, is given in Figure 22. The level structure of Er-166 shown in this figure exhibits the familiar level sequence associated with highly deformed even-even nuclei. Although transitions involving the 2^+ level at 787 kev in Er-166 were not observed in this work, the level was included in Figure 22 for the sake of completeness. The states at 1785 kev and 1840 kev in Er-166 are intrinsic states. The other Er-166 states shown, however, are rotational states associated with the intrinsic structure of the ground state. The spin and parity assignments were made on the basis of the observed gamma ray intensities.

Fig. 19 Typical γ - γ coincidence spectra. Spectra 1, 2, 3, and 4 are coincident with ~ 40 keV single-channel energy regions centered about 900, 790, 565, and 450 keV, respectively.

A comparison of the experimental data with the predictions of the asymmetric rotator model [28, 29] of the nucleus has been made. The energies of the levels were calculated in terms of the four parameters characteristic of the rotator using the expression given by Townes and Schawlow [30]. The notation for the levels is that of Davydov and Filippov [28]. The results of this calculation are summarized in Table XIV. The agreement of the calculated energy levels with those observed experimentally is seen to be excellent. The relative intensities of the E2 components of the transitions were also calculated using the wave functions appropriate to levels described by the asymmetric

Fig. 20 Electron spectrum of Ho-166 taken with lithium drift detector having a depletion thickness of ~ 1.75 mm.

Fig. 21 Electron spectrum of Ho-166 taken with phosphorus-diffused detector.

rotator model. Expressions for some of the $B(E2)$ values have been given by Mallmann [29]. However, since expressions for the $B(E2)$ values for the $n7 \rightarrow m6$, $n7 \rightarrow m5$, $n6 \rightarrow m6$, $n6 \rightarrow m8$, and $n7 \rightarrow m8$ transitions have not been published, it was necessary to work out these expressions before a calculation of these quantities could be made. From the $B(E2)$ values, the transition intensities were obtained using the relation [31] $T_\gamma = 1.23 \times 10^{-2} (E_\gamma)^5 B(E2) \text{ sec}^{-1}$, where E_γ is in keV and $B(E2)$ is in units of $e^2 \times 10^{-48} \text{ cm}^4$. The comparison of the calculated intensities with those observed experimentally is given in Table XV. The agreement is seen to be quite good.

A more complete report of this work, including the results of an investigation of the higher-energy gamma radiation presently in progress, will be submitted for publication in the Physical Review.

The authors are indebted to Mr. E. H. Turk of the Chemistry Section at the Materials Testing Reactor for his many hours of work in purifying the sources used in this experiment, and to the staff at ORNL, particularly Messrs. C. Ryan and J. Blankenship of the Instrument Group and Dr. A. Chetham-Strode of the Chemistry Group for their assistance in making the measurements using the lithium-drift detector.

Fig. 22 Decay scheme for long-lived Ho-166.

TABLE XV

COMPARISON OF CALCULATED GAMMA RAY RELATIVE INTENSITIES
WITH THE EXPERIMENTAL RELATIVE INTENSITIES

Note: In addition to the four parameters used in the calculation of the energy level structure (Table XIV), two additional parameters, $k_0 = 2.28 \times 10^{-24} \text{ cm}^2$ and $r = +0.18$, were used. Comparisons were made only between those transitions from common levels.

Transition ($I_i \rightarrow I_f$)	E_γ (keV)	$B(E2; I_i \rightarrow I_f)$ ($e^2 \times 10^{-48} \text{ cm}^4$)		Relative Intensity	
		"inter-band"	"intra-band"	Calculated	Experimental
$1_7 \rightarrow 1_8$	465	0.099		0.19	0.28 ± 0.06
$1_7 \rightarrow 2_6$	154		0.536	0.004	(a)
$1_7 \rightarrow 1_6$	830	0.0292		1.000	—
$1_7 \rightarrow 1_5$	300		1.37	0.29	0.31 ± 0.18

(Continued)

TABLE XV (Continued)

Transition ($I_i \rightarrow I_f$)	E_γ (keV)	$B(E2; I_i \rightarrow I_f)$ ($e^2 \times 10^{-48} \text{ cm}^4$)		Relative Intensity	
		"inter-band"	"intra-band"	Calculated	Experimental
$2_6 \rightarrow 1_8$	311	0.0344		0.022	(a)
$2_6 \rightarrow 1_6$	675	0.0721		2.25	1.3 ± 0.7
$2_6 \rightarrow 1_4$	955	0.0055		1.00	—
$2_6 \rightarrow 1_5$	146		0.714	0.01	(a)
$2_6 \rightarrow 2_4$	263		1.23	0.35	0.9 ± 0.6
$1_5 \rightarrow 1_6$	530	0.0595		0.18	0.18 ± 0.03 (b)
$1_5 \rightarrow 2_4$	117		0.960	0.002	(a)
$1_5 \rightarrow 1_4$	810	0.0392		1.000	—
$1_5 \rightarrow 1_3$	215		0.993	0.032	0.09 ± 0.06
$2_4 \rightarrow 1_6$	410	0.0134		0.014	(a)
$2_4 \rightarrow 1_3$	96		1.38	0.001	(a)
$2_4 \rightarrow 1_4$	690	0.0720		1.000	—
$2_4 \rightarrow 2_2$	170		0.615	0.01	(a)
$2_4 \rightarrow 1_2$	877	0.0115		0.524	0.56 (c)
$1_3 \rightarrow 1_4$	595	0.0401		1.000	—
$1_3 \rightarrow 2_2$	74		1.86	0.001	(a)
$1_3 \rightarrow 1_2$	780	0.0543		5.3	5.0 (c)
$2_2 \rightarrow 1_4$	522	0.0037		0.01	(a)
$2_2 \rightarrow 1_2$	707	0.0583		1.14	1.1 (c)
$2_2 \rightarrow 1_0$	787	0.0304		1.000	—

(a) Not observed.

(b) Relative intensity used to obtain parameters.

(c) Intensities reported by Jacob [32].

III. INSTRUMENT DEVELOPMENT

1. DIGITAL SYSTEMS INSTRUMENTATION

1.1 The Generation of Poisson Time Distributed Random Pulses (N. Wilde)

An electrical "white noise" source is considered for the random element in a Poisson pulse generator. Figure 23 is an illustration of a random current (or voltage) having zero mean value and a normal amplitude distribution.

If an adjustable threshold level is established and divided into small time increments, the binomial probability distribution describes the probability that the threshold level will be exceeded x times in n increments. In Figure 23 the threshold level has been exceeded four times in 32 increments. Thus, the probability of having a pulse in a given increment is approximately $4/32$ or 0.125 .

Under certain conditions, the binomial distribution is an excellent approximation for the Poisson distribution [33]. A random pulse generator design based on the concept illustrated in Figure 23 will generate binomial pulses. However, if these conditions are observed, the resulting pulses can be considered as Poisson distributed pulses.

Fig. 23 Random noise and threshold level.

The three average time rates of interest are:

(1) The average rate at which $I(t)$ will pass through a level, I_1 , with positive slope. This rate is called the "positive slope rate", v_s .

(2) The average rate of maxima (points of zero slope and downward concave) of $I(t)$ occurring above a level, I_1 . This rate is called the "rate of maxima", v_m .

(3) The average rate at which $I(t)$ will pass through a level, I_1 , with positive slope and have a value greater than I_1 at a later increment of time, τ , measured from the crossover. This rate is called the "overlap rate", v_τ .

A theoretical analysis and numerical evaluation of these rates has resulted in the curves of Figure 24. The symbols are defined as follows:

v_s = positive slope rate

v'_s = the derivative of v_s with respect to y_1

v_m = rate of maxima

v_τ = overlap rate

f_c = the cutoff frequency of a uniform band of noise extending from zero cycles per second to f_c cycles per second

I_1 = threshold level

σ = standard deviation (rms value) of a noise signal having zero mean value

y_1 = ratio of I_1/σ

τ = discrete time increment

$$r = \frac{2\pi f_c \tau - \sin 2\pi f_c \tau}{2\pi f_c \tau + \sin 2\pi f_c \tau}$$

For values of $2\pi f_c \tau$ greater than 2.78, the parameter, r , has a decaying oscillation about unity. This region is represented by the shaded area in Figure 24. The curve for ν_s/f_c has been verified by laboratory measurements. Figure 24 is useful as a set of design curves for designing a Poisson pulse generator. An experimental generator operating at a maximum average rate of 20 kc has demonstrated the validity of the design curves and feasibility of operation. Additional calculations suggest the possibility of maximum average rate of 1 Mc. Theoretical and experimental details are contained in IDO-16783 [34].

Fig. 24 Normalized average time rates.

1.2 A Nuclear Signal Simulator (N. Wilde)

The usefulness of the proposed Poisson pulse generator can be extended by using it as the random time element in a system to simulate the electrical signals from a nuclear radiation detector. Two additional functions are required: (a) A means of randomly varying the amplitude of each pulse to a predetermined pulse height amplitude probability distribution function and (b) a means of randomly varying the pulse shape (jitter) about some average pulse shape. The first function is required to simulate the effect of the nuclear radiation energy spectrum as modified by the detector. A typical example is the pulse height spectrum as found in gamma ray scintillation spectroscopy. The second factor is required to simulate the varying geometry associated with the origin of each pulse. A typical example is the effect of the orientation of the ionizing path in an ionization chamber on the pulse shape.

A change in the average rate of pulses, as found in short half-life isotope or reactor power measurements, can be simulated by varying the amplifier gain in a predetermined manner. The integrating effect as found in certain nuclear detectors is simulated by electrically integrating the output of the simulator.

Figure 25 illustrates one possible configuration for such a simulator. The random Poisson pulses are used to trigger an amplitude sampler. If a

Fig. 25 Nuclear signal simulator.

normal pulse height amplitude distribution is desired, the white noise source can be used to provide this distribution. A sufficiently long time delay must be inserted to destroy the correlation between the time and height probability distribution. Standard deviation (amplifier gain) and mean value (dc insertion) are readily controllable. Several normal pulse height distributions can be superimposed by using parallel channels. Each must be sufficiently displaced in time by means of time delays to prevent correlation.

Pulse height distributions other than normal are obtainable by generating a repetitive waveform in the shape of the desired cumulative probability function. This waveform is then sampled by the Poisson pulses. The time relationship must be chosen in a manner to prevent correlation.

A normal distributed pulse shape probably is adequate for most applications. Once again the white noise with appropriate time delay can be used to generate this variation.

The simulator shown in Figure 25 would be useful as (a) a research tool for the development of new instrumentation techniques, and (b) a signal source for testing existing instrumentations. Since the physical size of this equipment may well prohibit moving from location to location, an analog tape recorder is included. A signal or signals meeting given requirements can be simulated and recorded. The tape can be readily taken to and used at another location. As an example, the output of an ionization chamber instrumentating the changing power level of a reactor may be simulated and recorded. The tape is taken to the reactor site and played back into the actual reactor instrumentation for test purposes. Thus, the effect of unsafe operating conditions on the instrumentation and control can be analyzed in a safe manner.

1.3 Instrumentation and Control for MTR Neutron Crystal Spectrometer (T. J. Boland)

Pictured in the photograph in Figure 26 is the new instrument and control system for the Neutron Crystal Spectrometer which was placed in service during

Fig. 26 Photograph of instrumentation and control for MTR neutron crystal spectrometer.

this quarter. Included in the system are six new 8-decade high-resolution, 1-megacycle scalars, and an automatic programmer and sequencer which provides completely automatic operation. Several modes of operation are provided including incremental arm drive in angle increments of 10 sec or larger. A two-speed drive is incorporated which provides a speedup of arm travel by a factor of nine when moving from one major angle to another and when reversing for background calibration or rerun. A manual override feature is provided. The system uses the new all-electronic scanner previously described [35] as well as some other circuits recently developed [36, 37].

Initial calibration runs during equipment "shakedown" yielded satisfactory data. Data are read out on both an electric typewriter and an IBM serial card punch.

2. SPECIAL ELECTRONIC INSTRUMENTATION

2.1 Remotely Controlled Milling Machine

2.11 General (F. A. Meichle). Modifications of a Bridgeport milling machine have been made to permit remote machining of contaminated materials within the shielded volume of the hot cell. The milling machine operations of longitudinal, elevation, and cross translation of the bed are controlled from a remote control console. Displacement of a calibrated knob on the control console moves the bed the same increments for all three directions. Remote position indicators for the three directions are provided on the control console. All connectors to the mill from the operating console are electrical thus requiring no mechanical linkages. This makes adequate shielding from radiation within the hot cell much easier to obtain.

2.12 Servomechanism (H. R. Hansen, R. H. Brown). The elevation servomechanism for the remote mill has been stabilized for a static accuracy of one-thousandth of an inch. The method used to stabilize the servomechanism was to divide it into two feedback loops. The first loop consists of the summing amplifier, the motor and its load, the magnetic amplifier, and the network used for obtaining tachometer feedback. The second loop is made up of the first loop plus the torque transmitter, the control transformer, and the demodulator. These feedback loops are shown in Figure 27.

Fig. 27 Block diagram of remotely controlled milling machine elevation servomechanism.

Tachometer feedback and dc feedback in the magnetic amplifier were used in order that the gain of the first loop would attenuate at a rate of 6 db per octave. It was designed to do this to as high a frequency as possible, in this case 5 cps, in order that the design of the second loop would be fairly straightforward. Then a dc compensating network was added to the second loop. This network, shown in Figure 27, has a lag at 0.015 cps and a lead at 0.7 cps. It prevented instability from occurring when gain was added. More dc gain then was available from the magnetic amplifier was required in order that the accuracy specification could be met.

Essentially the same requirements were maintained for the longitudinal servomechanism as for the cross-feed servomechanism. The problem turned out to be a much simpler one, however, because there was a gear box between the drive motor and the position readout device. This feature slowed the system response time down enough without causing any loss of "dc open-loop gain" so that the one-thousandth of an inch requirement with no overshoot was relatively easily obtained.

Requirements similar to those of the elevation servomechanism needed to be met for proper operation of the cross feed servomechanism with one important exception. Absolutely no overshoot was allowed. In order to meet this requirement, a standard nonlinear method of velocity limiting was used, resulting in some sacrifice of response time. This allowed the servomechanism to "creep up" on the set point without overshoot and with enough open loop gain to exceed the one-thousandth of an inch requirement.

The remotely controlled milling machine operation has been stabilized and is now ready for installation at the hot cell.

2.2 ARMF I Servomechanism Amplifier (H. R. Hansen)

After considerable trouble with shorted transistors in the servomechanism amplifier used to drive ARMF I regulating rod, a change was made to a packaged servo amplifier purchased from Inland Motor Corp. of Virginia. This is the same amplifier that will be used in ARMF II.

Expectations are that the new amplifier will improve the reliability since it uses a different type of output stage. The output stage is comprised of a bridge circuit as compared to complementary collector followers in the old amplifiers. The use of a bridge circuit reduces the voltage across the output transistors by one-half. The original failure rate was due to operating too close to the rating of the transistor and occasionally exceeding ratings. Whereas this is an acceptable procedure with vacuum tube design, it is not when designing with transistors.

2.3 Low Frequency Variable Notch Filter (K. F. Smith)

A low frequency variable notch filter has been developed whose useful frequency range is from dc to 100 cps. It was designed to be a general purpose laboratory instrument and it can be used either as a band pass or a band reject filter. The approach to the problem involved finding the transfer function of a band pass and a band rejection filter. Once these transfer functions were determined, a general transfer function was obtained. The filter was then designed using conventional analog computer techniques.

The transfer function which was realized by the instrument is

$$\frac{E_o}{E_i} = \frac{s^2 + 2z_1\omega_o s + \omega_o^2}{s^2 + 2z_2\omega_o s + \omega_o^2}$$

where z_1 and z_2 are independently variable from 0-2 and f_o ($2\pi f_o = \omega_o$) is variable from 0-100 cps. Reference to any standard graph of a system with

quadratic factors will give the reader a basic understanding of the different characteristics E_o/E_i vs ω may have with variations of z_1 , z_2 , and ω_o .

The instrument was built and tested in the laboratory. Figures 28 and 29 give typical examples of the results of the test for a band rejection and a band pass filter.

Fig. 28 Low frequency variable notch band rejection filter.

Fig. 29 Low frequency variable notch band pass filter.

The principal characteristics of this filter include: (a) the frequency range of the filter covers dc to 1 kc; (b) the independently variable center frequency, dc to 100 cps; (c) the independently adjustable mouth opening, maximum obtainable Q was approximately 100; (d) the depth or height control of the notch, the maximum depth and height was approximately 40 db and the minimum depth or height in each case was 0 db; (e) the high, 1 megohm, input impedance and the low, 0.1 ohm, output impedance. Such a filter will find use in such areas as control system problems, noise analysis, 60-cps suppression, etc.

A complete design report for this filter will be issued.

3. HEALTH PHYSICS INSTRUMENTATION

3.1 Alpha-Beta Air Monitor (J. B. Thompson)

The alpha-beta air monitor previously described [38] has been in operation for the past month. Figure 30 is a sample of the recorded output over a 24-hr period. It may be observed that during the atmospheric inversion, there was a fast buildup of alpha-beta activity. It also can be noted that the ratio between

Fig. 30 Alpha-beta air monitor record.

the alpha and the beta remains constant throughout the buildup. When the inversion breaks up, the alpha decays at a faster rate than the beta indicating there had been some long-life beta-emitting particulate collected on the filter.

Further tests will be made by the Health Physics group to evaluate the instrument. The information collected to date indicates it is working satisfactorily.

3.2 Audible Pulse Indicator for Hand and Foot Counter (K. F. Smith)

A simple circuit to be used to give an audible indication of pulses occurring at the amplifier output of a hand and foot counter has been developed and built. Essentially the circuit consists of a one-shot multivibrator which drives an emitter follower-speaker arrangement. The circuit has been designed to draw a quiescent current of only 0.2 ma. Thus, the unit can be made completely portable by powering it from a 6-volt battery consisting of 4 size-F cells which will supply the unit for the shelf life of the battery. The circuit diagram is shown in Figure 31.

Fig. 31 Audible pulse indicator circuit.

IV APPLIED MATHEMATICS

1. DATA TRANSMISSION TO 7090 (W. A. Hestir, L. L. Marsden)

During the months of May and June the data transmission system using the IBM 1401-1009 was installed at Idaho Falls and put into operation with the IBM 7701-1401-7090 data processing system in Bartlesville.

Initially the data transmission system program which was written here transmitted and received 35 to 40 records per minute with checking to verify the correctness of the transmission.

This transmission is accomplished by preparing the data to be transmitted in punched card format. These cards are read into the 1401, sent to the 1009 where the records are converted to transmission mode characters acceptable to the Bell System data phone. The information is then sent by long distance telephone to the 7701 where the inverse operation on the characters takes place and the original card records are put onto magnetic tape by the 7701. The 7701 tape is then processed by the 1401 in Bartlesville for input to the 7090, or the 7701 tape may in some instances be processed directly on the 7090.

A new version of the data transmission program has been written and is currently in operation which condenses information prior to its transmission over the long distance telephone. This results in an effective record transfer rate of 80 to 150 records per minute depending upon the number of blanks in a record. The record transfer rate has been increased by a factor of 2 to 5 by condensing the individual records, and by increasing the number of records in a message. Once the condensed records have been written on the 7701, this tape is then taken to the 1401 where the original form is obtained by the inverse of the condensing program. These records are either punched out on cards, written onto another tape for input to the 7090, or printed on the 1403 printer.

The output from the 7090 is handled in the same way as the original data prepared for transmission in Idaho Falls.

2. IBM 7090 DOUBLE PRECISION MATRIX INVERSION FORTRAN SUBROUTINE (D. H. Gipson)

A double precision matrix inversion subroutine for the 7090 has been written, checked out, and placed in service. The subroutine may be used for matrix inversion and for solution of simultaneous linear equations.

Consider the problem $AX = B$, where A is an $m \times m$ square matrix, and X and B are $m \times r$ matrices. The subroutine will solve the system of linear equations for the r different solution vectors of X . The inverse of A is always formed in the process, and if desired the subroutine may be used solely for this purpose.

The method is basically a double pivotal Gauss-Jordan reduction method with the pivot terms being selected from the largest elements of the matrix.

The matrix is inverted and solution vectors formed in the same area in which original matrices were stored; requiring permutations of rows of columns at the end of the inversion process for proper ordering of inverse matrices. The determinant of the system is obtained in the process also.

All arithmetic operations are performed using double precision arithmetic.

3. IBM 650 PROGRAM TO COMPUTE A PROBABILITY DISTRIBUTION FOR READINGS TAKEN FROM THE ARMF DIGITAL READOUT SYSTEM (D. H. Gipson)

A probability distribution for readings taken from the ARMF digital readout system of a certain regulating rod position is to be computed. It is to be determined whether the readings follow a normal distribution.

Given the readings, x_j , ($j = 1, 2, \dots, m$), the upper limit, a_N , of the readings where $0 \leq x_j < a_N$, and the number of intervals, N , the program computes the number of readings (frequency), for each interval. Each interval has width, Δa , where

$$\Delta a = \frac{(a_N)}{N}$$

The intervals are separated by the points a_n , $n = 0, 1, 2, \dots, N$, where $a_n = n \Delta a$. The frequencies, f_n , are computed for the x_j in each interval such that $a_{n-1} \leq x_j < a_n$ for $n = 1, 2, \dots, N$.

The program uses the following method of determining in which interval the x_j are located.

Let

$$x_j = a_n + \epsilon, \quad \epsilon < \Delta a$$

$$x_j = n \Delta a + \epsilon$$

$$\frac{x_j}{\Delta a} = n + \frac{\epsilon}{\Delta a}$$

The quotient, n , of the above division is then used as an index to put a count on the n th frequency counter.

The program computes the mean and variance from the midpoints, y_n , of the intervals, thus

$$y_n = \frac{a_n + a_{n-1}}{2} \text{ for } n = 1, 2, \dots, N$$

The formula for the total frequency is

$$m = \sum_{n=1}^N f_n$$

The formula for the mean is

$$\mu = \sum_{n=1}^N \frac{(y_n)(f_n)}{m}$$

The formula for the variance is

$$\sigma^2 = \sum_{n=1}^N \frac{(y_n - \mu)^2 f_n}{m}$$

To obtain a probability function the frequency distribution is normalized so that the area under the curve is equal to one.

Thus

$$A_n = \frac{f_n}{m} \text{ for } n = 1, 2, \dots, N$$

$$\sum_{n=1}^N A_n = 1$$

The width of the area, A_n , is equal to Δa , and from the formula for the area of a rectangle the height, P_n , can be determined.

$$P_n = \frac{A_n}{\Delta a}$$

The probability function for the midpoint interval values, y_n , is then given by the formula

$$P_n = \frac{f_n}{m\Delta a} \text{ for } n = 1, 2, \dots, N$$

The normal probability function is given by the formula

$$f(y) = \frac{1}{\sqrt{2\pi} \sigma} e^{-(y-\mu)^2 / 2\sigma^2}$$

using the computed mean μ , and variance σ^2 . The program computes P_n and $f(y_n)$ for $n = 1, 2, \dots, N$, and punches the values in unnormalized floating point form for plotting purposes to enable determination of how closely P_n follows the normal distribution, $f(y_n)$.

4. IBM 650 DOUBLE PRECISION NORMAL EQUATION GENERATOR (D. H. Gipson)

The IBM 650 program (Phillips Program No. 00.047) was revised recently to take up to 25 independent variables.

The program computes the normal equations for polynomial-type functions in double-precision floating-point arithmetic. The normal equations are standard equations for the linear least squares method of approximation of a function.

5. IBM 7090 PROGRAMS FOR GAMMA SPECTRUM ANALYSIS (G. A. Cazier, D. D. Metcalf)

A comprehensive set of programs is being written for the IBM 7090 to analyze gamma spectra. The system will incorporate the following components: (a) A gain-shift program, (b) a non-linear least squares program, (c) detector response curve generation, (d) linear least squares. These building blocks will be fitted together to perform automatically the "stripping" of a complex gamma spectrum.

The individual components above are currently in operation on the IBM 650 and over the past three months have been used to process several hundred sets of data. Almost completed for the 7090 is the linear least squares program with provision for gain-shifting the composite spectrum, or the standards into which the composite is to be analyzed. Data from the multichannel analyzer will be transmitted to Bartlesville via the IBM 1401-7701 teleprocessing link, and the results transmitted back the same way.

6. IBM 650 REACTOR PHYSICS CODES (Steven Tong)

Three short programs for the 650 were written, checked out, and placed in service.

The first computes the average velocity of thermal neutrons using the Wigner-Wilkins spectrum from the 650 SOFOCATE code. The second computes the average velocity of fast neutrons from the 650 MUFTR code.

The third program computes resonance escape probabilities for a UO_2 cylinder by the Weinberg-Wigner method, so that values of the "L" factors of MUFTR can be determined.

7. IBM 7090 BESSEL FUNCTION SUBROUTINE (L. J. Gannon)

The IBM 7090 Fortran subroutine BESI computes the Bessel Function, $I_n(x)$, for x real and n a non negative interger. For x less than 4.4 the following series expansion is used.

$$I_n(x) = \sum_{r=0}^{\infty} \frac{1}{r!(n+r)!} \left(\frac{x}{2}\right)^{n+2r}$$

The series is terminated when the ratio of the r th term to the sum is less than 10^{-5} . The following asymptotic expansion is used for x equal or greater than 4.4.

$$I_n(x) = \frac{e^x}{\sqrt{2\pi x}} \left[1 - \frac{4n^2-1}{1!(8x)} + \frac{(4n^2-1)(4n^2-3^2)}{2!(8x)^2} - \frac{(4n^2-1)(4n^2-3^2)(4n^2-5^2)}{3!(8x)^3} + \dots \right]$$

This series is truncated when the r th term is less than 10^{-5} , or when the $(r+1)$ st term is larger than the r th term. The subroutine has been tested by generating a table with values of x from 0 to 25 in increments of 0.5 and values for n of 0, 1, 2, 3, 4. The maximum error occurs around the values for $x = 5$, where the computed value agrees with the actual value to five places.

8. NUMERICAL EVALUATION OF THE INCOMPLETE GAMMA FUNCTION (Steven Tong)

An IBM 650 subroutine was written to evaluate the incomplete gamma function,

$$G_z(x) = \int_0^z e^{-t} t^{x-1} dt$$

where $0 < x < \infty$ and $0 < x \leq 3$. The integral is split into two components,

$$G_z(x) = \int_0^1 e^{-t} t^{x-1} dt + \int_1^z e^{-t} t^{x-1} dt = P^*(x) + Q(x)$$

where,

$$P^*(x) = \frac{1}{x} - \frac{1}{1!} \frac{1}{x+1} + \frac{1}{2!} \frac{1}{x+2} + - \dots + \frac{1}{10!} \frac{1}{x+10}$$

and $Q(x)$ is evaluated by trapezoidal integration.

V. PUBLICATIONS OF MTR-ETR TECHNICAL BRANCHES

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IDO-16769, Propane Vibrational Analysis, June 12, 1962, by G. D. Marshall

IDO-16749, Differential Scattering Cross Sections of Moderators in the Short Time Approximation, Part I. Theoretical, April 30, 1962, by H. L. McMurry

IDO-16698, Tabulation of Pa-231 Total Neutron Cross Section, January 31, 1962, by O. D. Simpson, W. H. Burgus

IDO-16744, Thermal Neutron Cross Sections of the Co-58 Isomers and the Effect on Fast Flux Measurements Using Nickel, June 18, 1962, by C. H. Hogg, L. D. Weber, and E. C. Yates.

IDO-16784, Data Analysis Techniques for Gamma Ray Scintillation Spectrometry, May 29, 1962, by R. L. Heath

IDO-16783, The Generation of Poisson Time Distributed Random Pulses, June 1, 1962, by Ned Wilde

PAPERS PRESENTED AT MEETINGS

Presentation at the BNL Neutron Thermalization Conference, April 30 - May 2, 1962 Experimental Information for Thermalization Problems by R. M. Brugger

Presentation at the BNL Neutron Thermalization Conference, April 30 - May 2, 1962 Calculation of Partial Differential Scattering Cross Sections for Slow Neutrons by H. L. McMurray; Evaluation of Techniques for Computing Partial Differential Scattering Cross Sections by H. L. McMurry, L. J. Gannon and W. A. Hestir

Presentation at ANS Meeting, Boston, June 18 - 21, 1962, Variation in U-235 Mass Yields at Neutron Energies Below 0.5 ev by K. T. Faler and R. L. Tromp

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Errata Sheet for IDO-16805

Materials Testing Reactor-Engineering Test Reactor Technical Branches
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Page 25

Near the center of the page, replace the equation:

$$\alpha = \frac{t^2 K^2}{2Mk_B T} \text{ is the square of the momentum transfer in dimensionless}$$

with

$$\alpha = \frac{\hbar^2 K^2}{2Mk_B T} \text{ is the square of the momentum transfer in dimensionless}$$

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