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# CPTF RUN 4 FLUX MONITORING

DECEMBER 18, 1970

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PREPARED FOR

THE UNITED STATES ATOMIC ENERGY COMMISSION

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BATTELLE-NORTHWEST
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# PTF RUN 4 FLUX MONITORING

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By


J. R. Divine

Corrosion Research & Engineering Section
Chemistry & Metallurgy Division


December 18, 1970

*This report is intended primarily for internal use by the sponsoring organization and Battelle-Northwest.*

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# CPTF RUN 4 FLUX MONITORING

## INTRODUCTION

At the present stage of reactor coolant studies it is possible to say that radiation has an effect on the deposition behavior of corrosion products in the reactor. A quantitative relation between flux and deposition rate or amount is not available, nor is there information as to exactly which component, or combination thereof, of the radiation is of most importance.

To determine these effects and those of other process parameters, Battelle-Northwest (BNW) is conducting an experimental program for the Knolls Atomic Power Laboratory (KAPL) to evaluate the behavior of corrosion products in pressurized, water-cooled nuclear reactor systems. This program is authorized by and is being performed under the terms and conditions of KAPL Purchase Order 7730-A (and Amendments).

The primary experimental system used by BNW to perform these experiments is the Corrosion Product Transport Facility (CPTF). This is a high-temperature, high-pressure, water-cooled, in-reactor loop. It is designed to operate over a wide range of experimental conditions, and to maximize flexibility for experimentation involving formation, transport and deposition of corrosion products. The CPTF is actually operated by the Irradiation Services Unit, Douglas United Nuclear, Inc. (DUN), under the technical direction of BNW.

Beginning with Run 4, CPTF experimentation was performed in KE Reactor. The In-Reactor Test Section (IRTS) was installed in a special test hole which runs from side-to-side in the reactor. It was situated to place the core test section (TS4U) in a region of constant flux; the edge test section (TS4D) was to be located in a region where the neutron flux varied by a factor of at least 1000 from one end to the other.

## EXPERIMENTAL

### System

The IRTS schematic is shown in Figure 1. In this figure all dimensions are given relative to the flange on the out-of-reactor end of CPTF. For dimensions relative to the reactor, see BNWL-CC-2620 (SECRET). For this particular report, only in the dimensions underlined in Figure 1 are of interest. These dimensions refer to the upstream end of the specimen holder, as illustrated in Figure 2.

The distance in each test section from the upstream end of the test section to the upstream end of the first test specimen is 3.130". This spacing is illustrated in the graphical presentation of the data in Appendix I.

### Test Sections

Each test section was equipped with a set of flux monitor wires. Each set was subdivided into two groups, called fluence and gradient wires. The gradient

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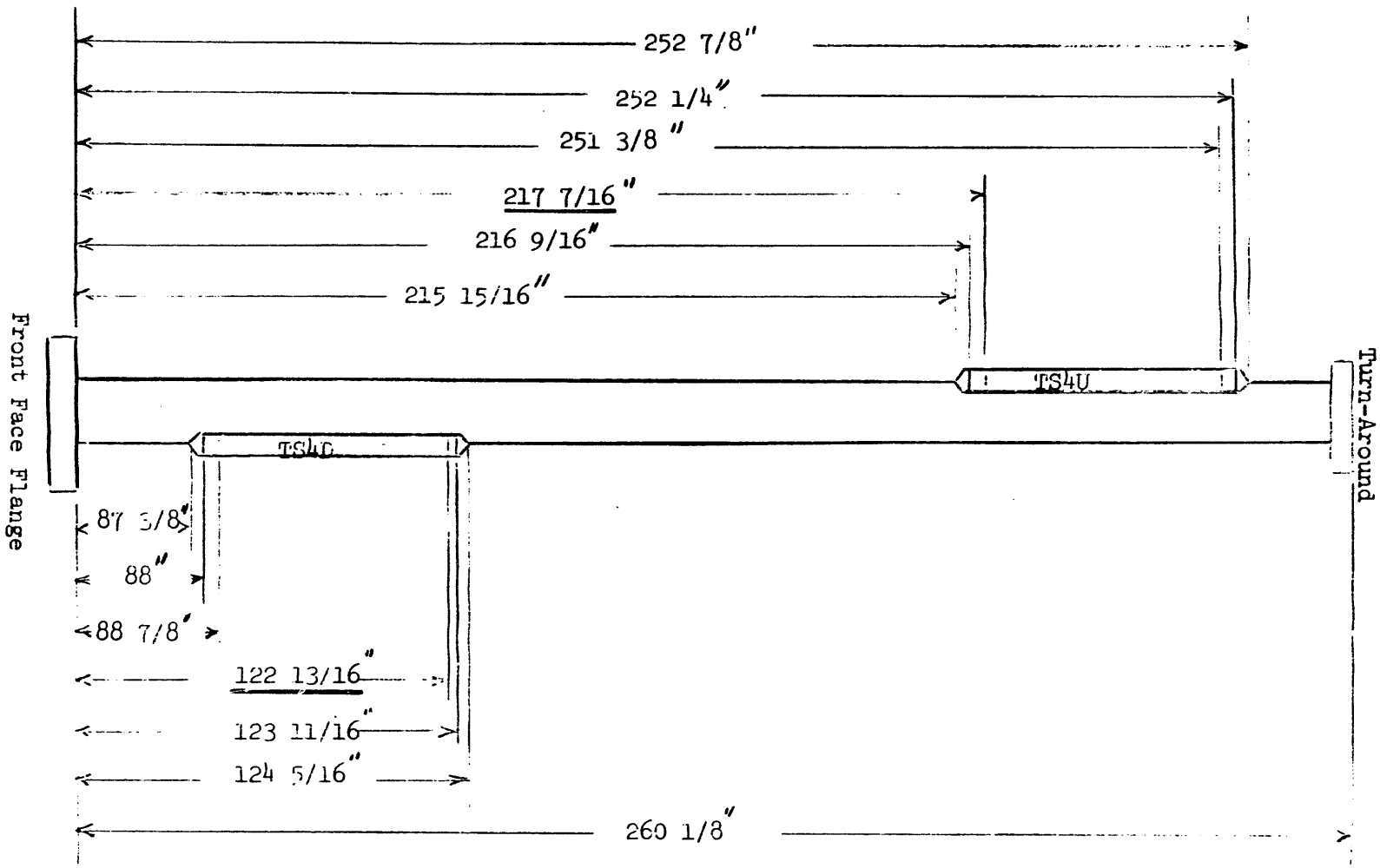
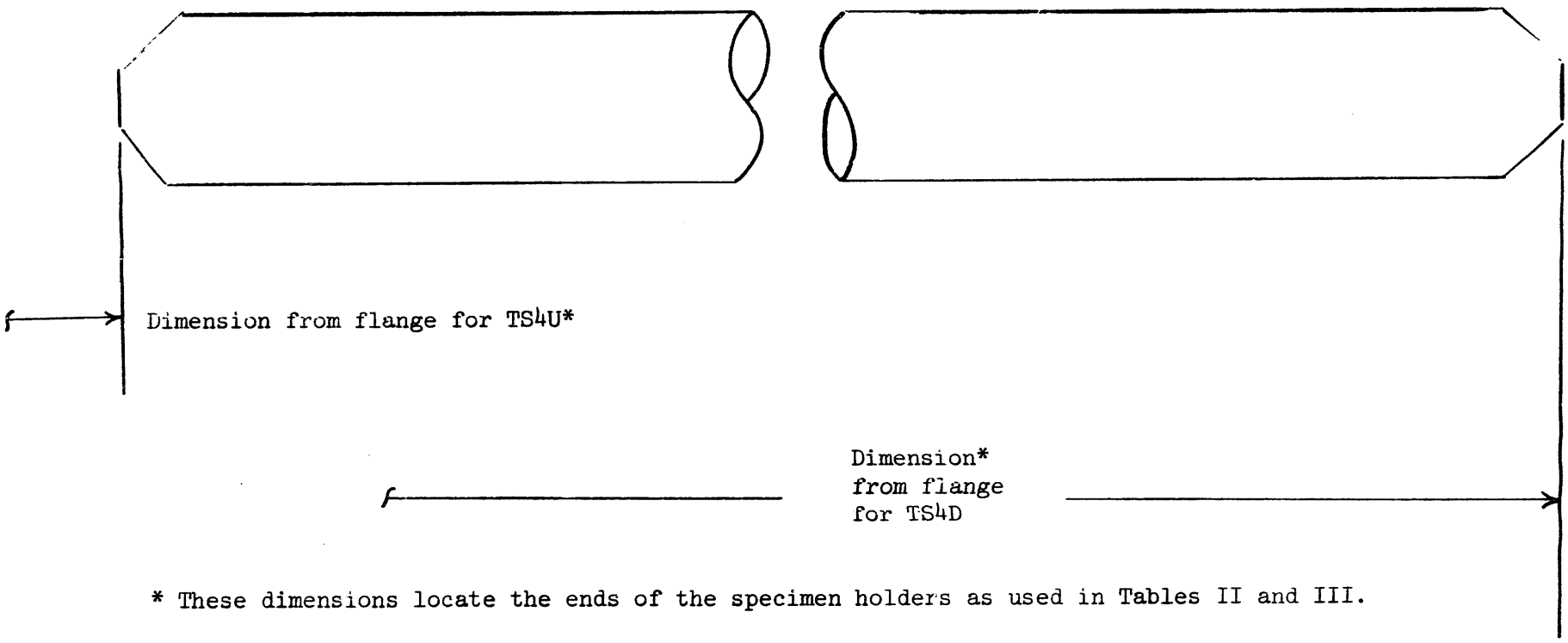



Note: Underlined dimensions refer to the upstream ends of test specimen holders, see Figure 2.

FIGURE 1 - IRTS Run 4 As-Built Dimensions.




* These dimensions locate the ends of the specimen holders as used in Tables II and III.

FIGURE 2 - Specimen Holder Reference Point.

wires were of iron only and were distributed the length of the test section to define the neutron flux gradient. The fluence wires consisted of Fe, CoAl, Ti, and AgAl wires. Capsules containing samples of each of these wires were positioned along the test section. These fluence wires are used to determine, roughly, the energy spectrum of the neutron flux.

## Flux Monitors

The flux monitors consisted of 0.020" diameter wire in lengths of about 0.25". Their lengths and weights were transmitted to KAPL previously.* Their compositions are given in Table I.

TABLE I

Flux Wire Composition

| Wire | Composition |
|---|---|
| Ti | 99.96% Ti, 0.020% Mn, 0.005% Fe, 0.005% Ni |
| Fe | 99.99% Fe, 0.003% Si, 0.002% Mg |
| CoAl | 0.1% Co, 99.8% Al, <0.01% Cu, <0,0k% Ag |
| AgAl | 0.1% Ag, 99.8% Al |

The weighed monitors were placed in 0.050" O.D. stainless steel capsules after which the ends were welded shut. These capsules were then placed at the outer radius of the specimen holder as shown in Figure 3.

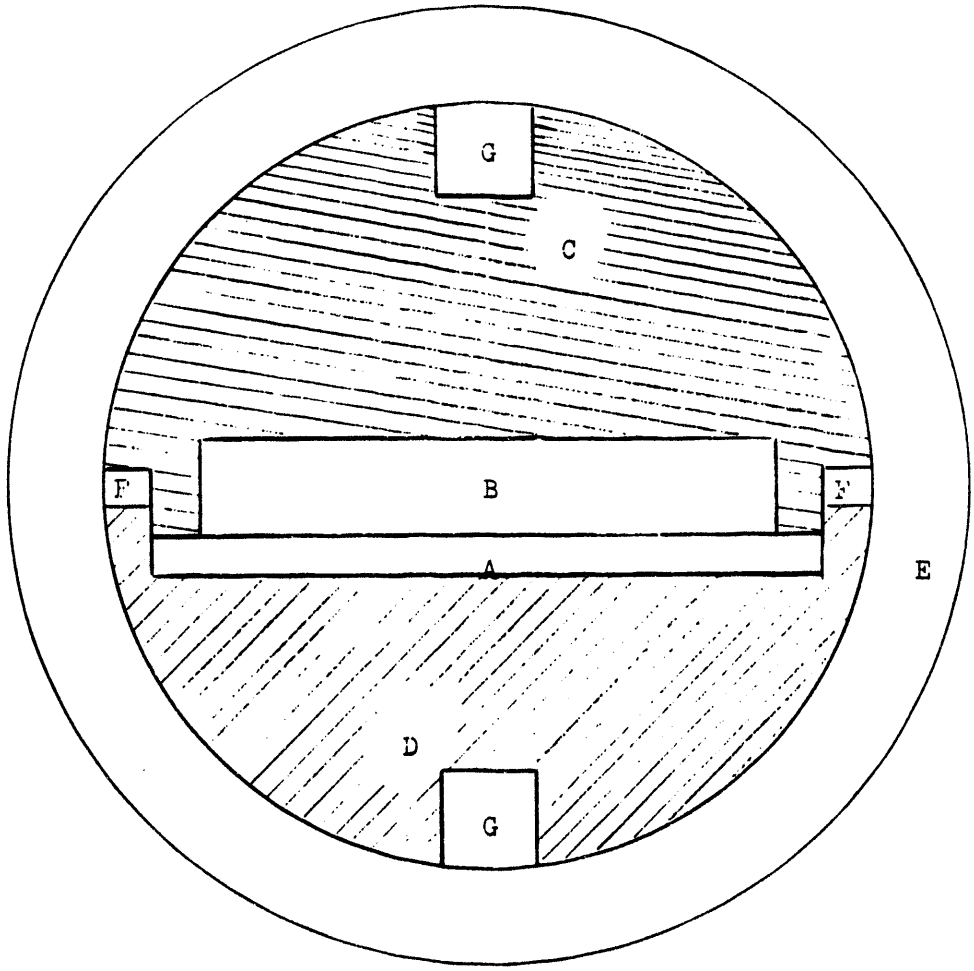
## Results

The results are presented as dps/mg of total sample, not of the isotope of interest. Thus alloy composition, Table I, and natural abundance must be considered in reducing these data to actual flux values. For example, the AgAl foils which contain 0.1% Ag (which in turn contains 41.18% $Ag^{-109}$) would be corrected so that an activity of $1.00 \times 10^5$ dps/mg (total) is equal to $2.43 \times 10^8$ dps/mg ($Ag^{-109}$). These activity data are given together with their location relative to the upstream end of the respective specimen holder.

The data are provided in Tables II and III, for accurate transmittal of the data, and in figures Appendix I, for visual comparison.

The irradiation time for this Run was 689 hr.

*Letter to S. R. Wages from J. R. Divine on Flux Monitor Data for Runs 4 and 5, dated 25 June, 1970.




A: Test specimen, Zry-4, Inc-600 or 347 S/S - 0.020" x 0.350" x 10.0"
B: Water channel - 0.050" x 0.300"
C: Upper half of specimen holder
D: Lower half of specimen holder
E: Restraining sleeve, Zry-4
F: Relief gaps, filled with water - 0.020" x 0.025"
G: Channels for flux monitors - 0.050" x 0.052", top-fluence, bottom-gradient

Scale 1" = 0.1"

FIGURE 3 - **Flux monitor distribution in the specimen holder.**

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TABLE II

TS4D Activity Data

| Position (in.)* | Activity (dps/mg)** | | |
|---|---|---|---|
| | Fe-59 | Mn-54 | |
| 2.6 | $6.38 \times 10^4$ | 183.5 | Gradient wires |
| 6.25 | $4.6 \times 10^4$ | 54.1 | |
| 11.1 | $2.66 \times 10^4$ | 12.1 | |
| 12.85 | $1.882 \times 10^4$ | 27.5 | |
| 14.5 | $1.326 \times 10^4$ | 24.1 | |
| 16.8 | $6.53 \times 10^3$ | 14 | |
| 20.6 | $9.3 \times 10^2$ | - | |
| 21.4 | $2.42 \times 10^2$ | 0.773 | |
| 23.15 | $1.31 \times 10^2$ | 0.37 | |
| 27.1 | $1.708 \times 10^2$ | 0.653 | |
| 32.8 | $1.015 \times 10^1$ | - | |
| 0.4 | $7.42 \times 10^4$ | 198 | Fluence wires |
| 1.4 | $7.89 \times 10^4$ | 173.5 | |
| 10.8 | $1.533 \times 10^4$ | 44.9 | |
| 11.8 | $1.256 \times 10^4$ | - | |
| 21.3 ± .05*** | $2.00 \times 10^2$ | 3.39 | |
| | $1.84 \times 10^2$ | 0.725 | |
| 20.2 | $3.04 \times 10^2$ | 0.2495 | |
| 33.8 | $2.03 \times 10^0$ | 0.0124 | |
| 32.8 ± .05*** | $3.68 \times 10^0$ | 0.0144 | |
| | $4.16 \times 10^0$ | 0.0307 | |

| | Fluence Wires | | | |
|---|---|---|---|---|
| | Co-60 | Sc-46 | Sc-47 | Ag-110m |
| 0.6 | $2.1 \times 10^4$ | | | |
| 0.9 | | 81.5 | $3.33 \times 10^2$ | |
| 1.2 | | | | $5.26 \times 10^3$ |
| 11.0 | $3.96 \times 10^3$ | | | |
| 11.3 | | 16.1 | - | |
| 11.55 | | | | $8.2 \times 10^2$ |
| 20.4 | $6.13 \times 10^1$ | | | |
| 20.7 | | 1.41±30% | - | |
| 21.0 | | | | $2.08 \times 10^1$ |
| 33.0 | $9.07 \times 10^{-1}$ | | | |
| 33.3 | | 0.055±53% | - | |
| 33.6 | | | | $3.37 \times 10^{-1}$ |

* Measured from upstream end of specimen holder.

** Per mg of total sample, not of specific isotope.

*** Two short pieces of Fe were found, one a spacer, one the monitor, but the two could not be distinguished from one another so their exact location is uncertain.

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TABLE III

TS4U ACTIVITY DATA

| Position (in.)* | Activity (dps/mg)** | |
|---|---|---|
| | Fe-59 | Mn-54 |
| | Gradient Wires | |
| 1.15 | $5.33 \times 10^5$ | $1.505 \times 10^4$ |
| 6.0 | $5.46 \times 10^5$ | $1.274 \times 10^4$ |
| 11.1 | $5.52 \times 10^5$ | $1.151 \times 10^4$ |
| 12.8 | $5.48 \times 10^5$ | $1.133 \times 10^4$ |
| 14.5 | $5.55 \times 10^5$ | $1.134 \times 10^4$ |
| 16.7 | $5.34 \times 10^5$ | $1.639 \times 10^4$ |
| 20.3 | $5.6 \times 10^5$ | $1.152 \times 10^4$ |
| 21.5 or 23.3*** | $5.37 \times 10^5$ | $1.24 \times 10^4$ |
| 32.8 | $5.41 \times 10^5$ | $1.412 \times 10^4$ |
| | Fluence Wires | |
| **** | | |
| 10.1 | $5.55 \times 10^5$ | $1.368 \times 10^4$ |
| 11.1 | $5.64 \times 10^5$ | $1.35 \times 10^4$ |
| 20.2 | $5.56 \times 10^5$ | $1.41 \times 10^4$ |
| 21.25 | $5.49 \times 10^5$ | $1.318 \times 10^4$ |
| 32.8 | $5.33 \times 10^5$ | $1.468 \times 10^4$ |
| 33.85 | $5.34 \times 10^5$ | $1.522 \times 10^4$ |

| | Fluence Wires | | | |
|---|---|---|---|---|
| | Co-60 | Sc-46 | Sc-47 | Ag-110m |
| **** | | | | |
| 10.35 | $1.568 \times 10^5$ | | | |
| 10.6 | | $1.041 \times 10^4$ | $6.7 \times 10^4$ | |
| 10.9 | | | | $1.00 \times 10^5$ |
| 20.4 | $1.572 \times 10^5$ | | | |
| 20.7 | | $1.024 \times 10^4$ | $7.2 \times 10^4$ | |
| 21.0 | | | | $9.99 \times 10^4$ |
| 33.0 | $1.53 \times 10^5$ | | | |
| 33.3 | | $1.005 \times 10^4$ | $5.93 \times 10^4$ | |
| 33.6 | | | | $9.87 \times 10^4$ |

* Measured from upstream end of specimen holder.
** Per mg of total sample not of specific isotope.
*** Capsule at one position was lost, but could not identify which.
**** Capsule at the 1" position was lost.

[redacted]

DISCUSSION

The data for TS4U are quite constant which indicates this test section was properly placed in the flat flux zone. The reactions, with average activities for TS4U, are given in Table IV.

TABLE IV

AVERAGE TS4U ACTIVITIES

| Reaction | Average (dps/mg) | Std. Deviation (dps/mg) |
|---|---|---|
| 1. Fe-58 (n,γ) Fe-59 | $5.46 \times 10^5$ | $0.10 \times 10^5$ |
| 2. Fe-54 (n,p) Mn-54 | $1.35 \times 10^4$ | $0.15 \times 10^5$ |
| 3. Co-59 (n,γ) Co-60 | $1.557 \times 10^5$ | $0.017 \times 10^5$ |
| 4. Ti-46 (n,p) Sc-46 | $1.023 \times 10^4$ | $0.015 \times 10^4$ |
| 5. Ti-47 (n,p) Sc-47 | $6.61 \times 10^4$ | $0.52 \times 10^4$ |
| 6. Ag-109 (n,γ)Ag-110m | $0.995 \times 10^5$ | $0.006 \times 10^5$ |

Based on a thermal neutron absorption cross-section of 1.2 barns* for reaction 1, the activity of $5.46 \times 10^5$ dps/mg converts to a thermal flux of $3.66 \times 10^{13}$ n/cm$^2$sec. The comparison to the theoretical calculations** is not immediately possible because the theoretical values have been normalized to a flux, <0.683 ev, of $2.52 \times 10^{13}$ n/cm$^2$sec. (This nevertheless, does not affect the relative magnitude of the fluxes for the various energy groupings, in the theoretical calculation.)

On examining the edge holder (TS4D) data, it is noted that the experimental data for reaction 1, extrapolated to the upstream end of the test section is $8.5 \times 10^4$ dps/mg$^2$. This is equivalent to a flux of $5.7 \times 10^{12}$ n/cm$^2$sec. Ratioing the theoretical flux up by the ratio of 3.66/2.52 (from above), we find $5.77 \times 10^{12}$ n/cm$^2$sec predicted which is very near the experimental value. At the downstream end of the edge section, we measure an activity equivalent to $1.34 \times 10^8$ n/cm$^2$sec. The corrected theoretical flux however is $2.5 \times 10^8$ n/cm$^2$sec. This discrepency is caused by two factors. First, the activity of the wires at this location was only 2 dps/mg (or about 10 dps for the total sample). This leads to large counting errors. Secondly, there is some question about the neutron absorption and scattering properties of the concrete in the reactor shielding; small variations in these properties can easily lower the calculated flux by a factor of 5, which would put it below the experimental value. Improvement of this information can be made as we gather data on flux profiles.

As noted earlier, a flux gradient variation, in the edge holder, of at least 1000 from one end to the other was desired. The gradient achieved for the thermal flux, though not of constant slope, was about $10^5$. It should be noted that a shift of the IRTS inwards or outwards by as little as 6" will change the thermal gradient by a factor of 10.

* Chart of the Nuclides, KAPL, 10th Ed., Dec. 1968.

** The theoretical flux was calculated by the BNW Analytical Physics Section. The results of this calculation are in Appendix II in the form of the report submitted by Analytical Physics.

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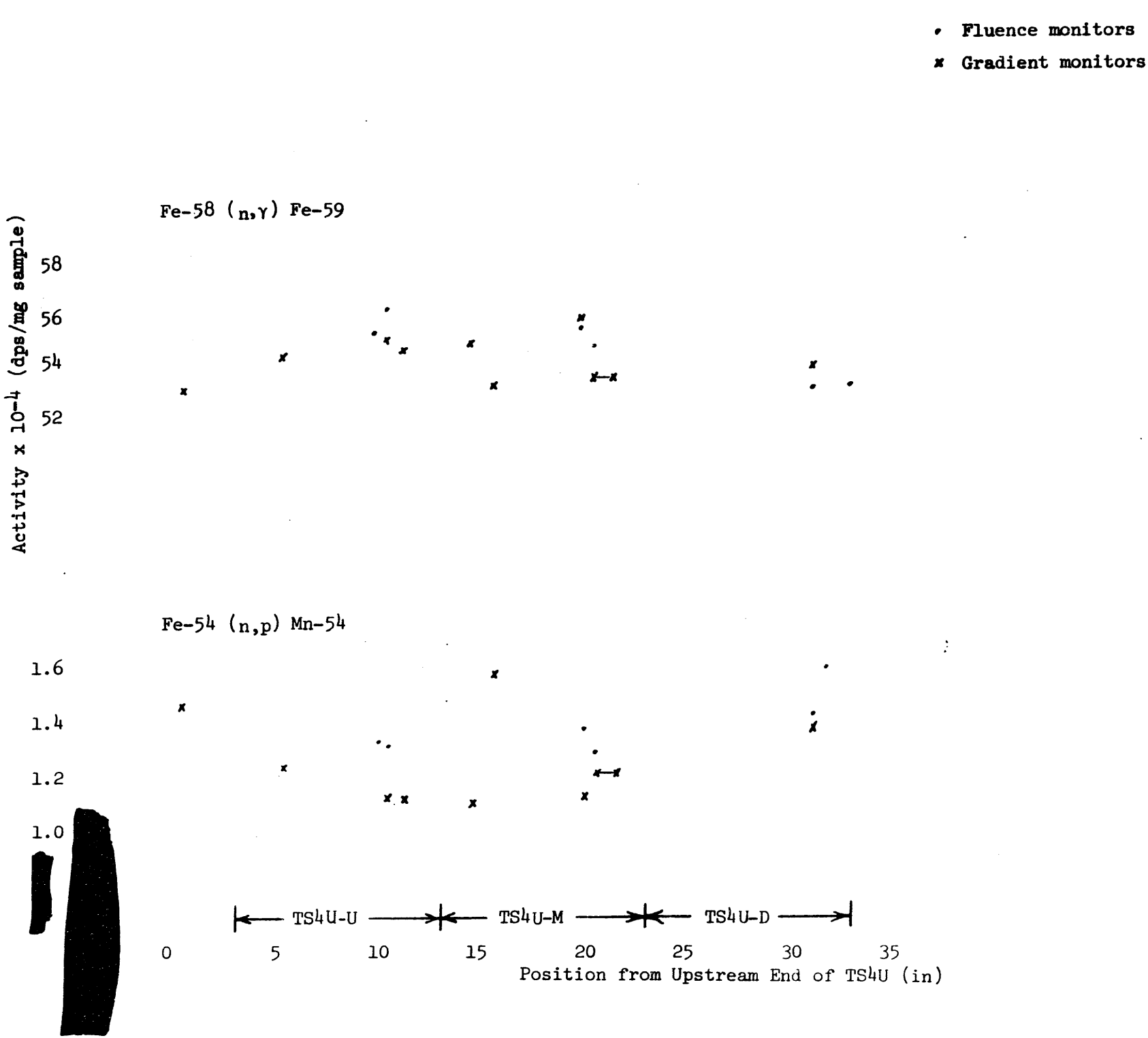
# APPENDIX I

Activity data for the Run 4 flux wires.

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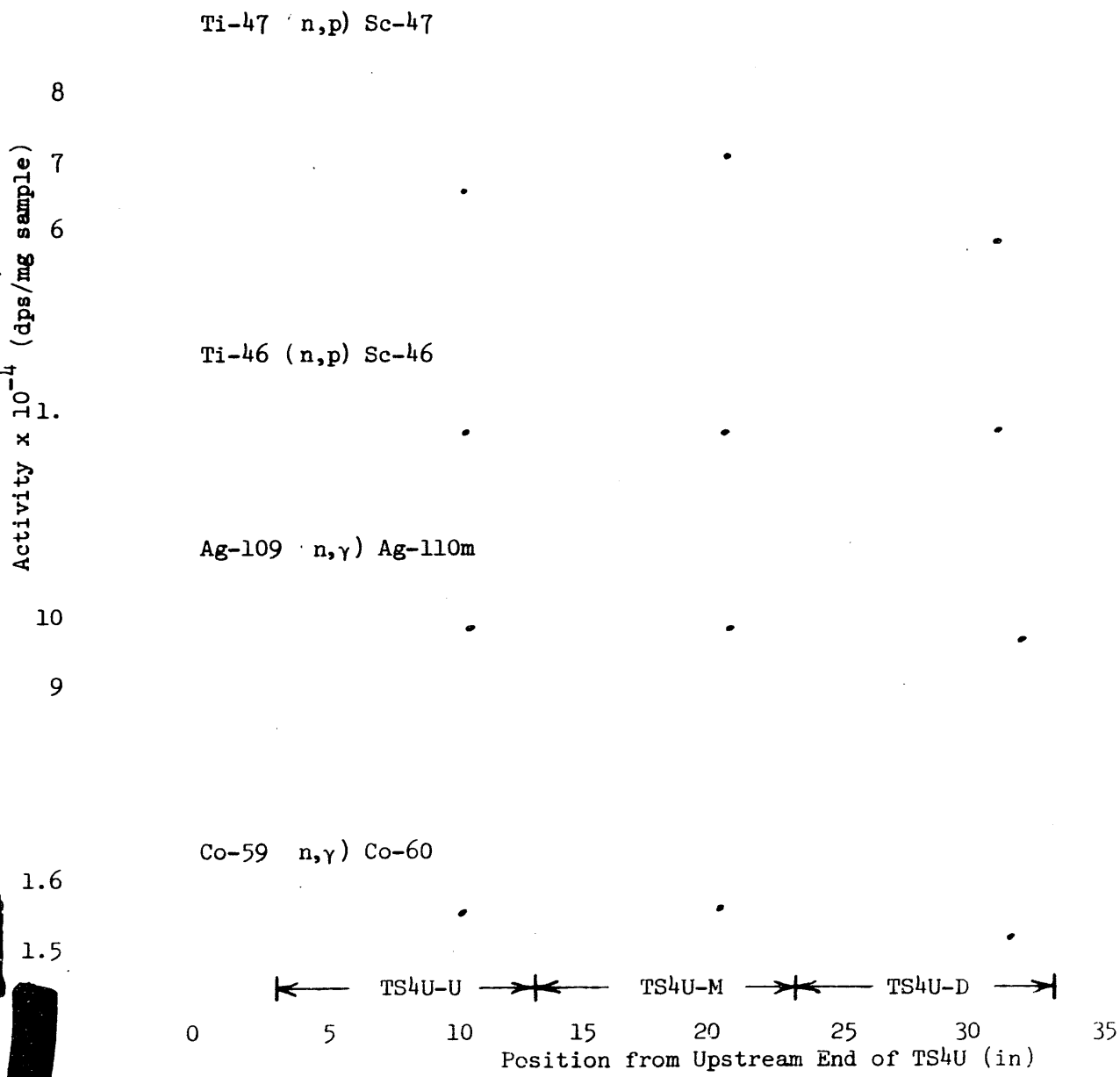


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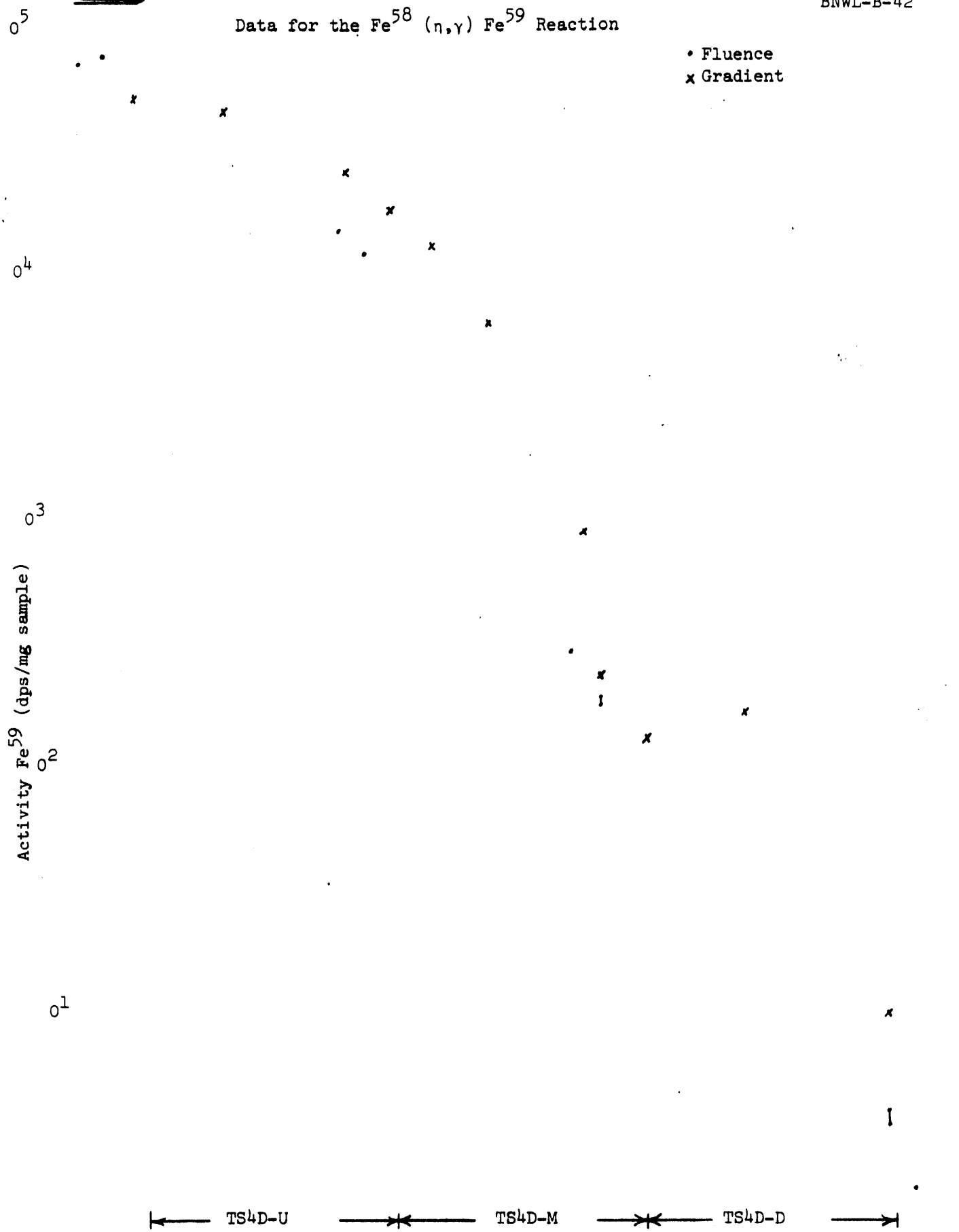
Data for the $Fe^{58}$ $(n,\gamma)$ $Fe^{59}$ Reaction

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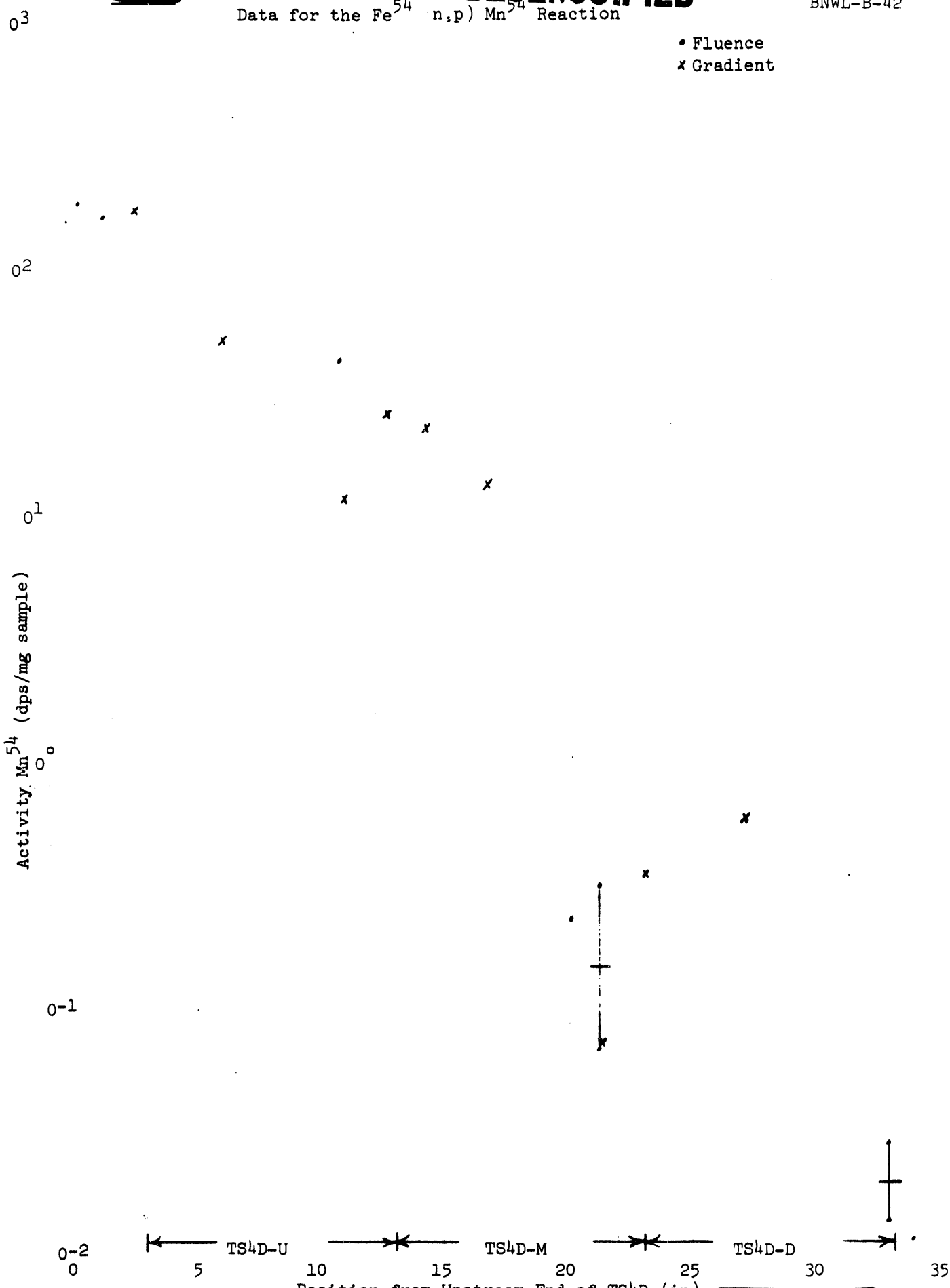
Data for the $Fe^{54}$ (n,p) $Mn^{54}$ Reaction

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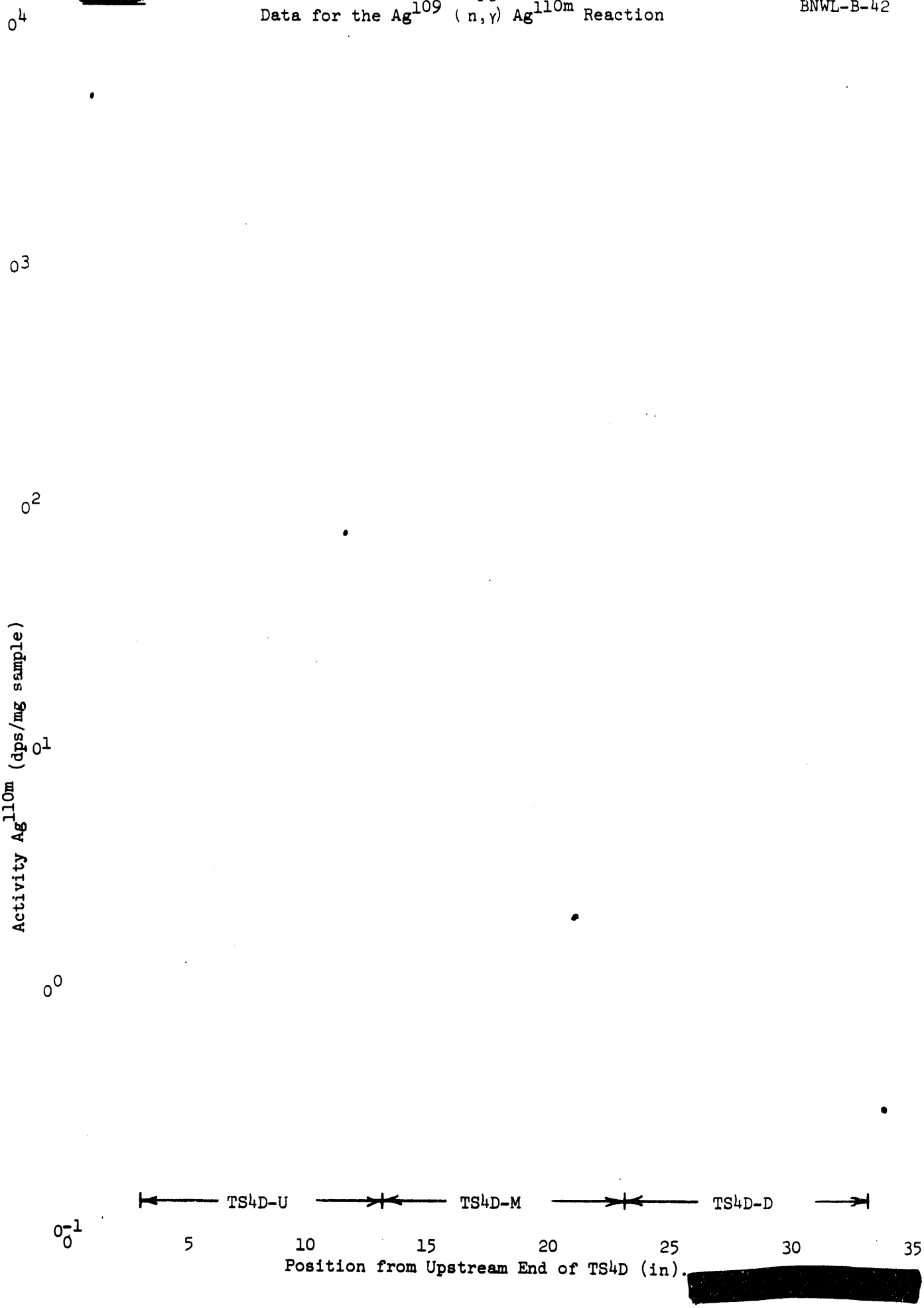
Data for the $Ag^{109}$ (n,γ) $Ag^{110m}$ Reaction



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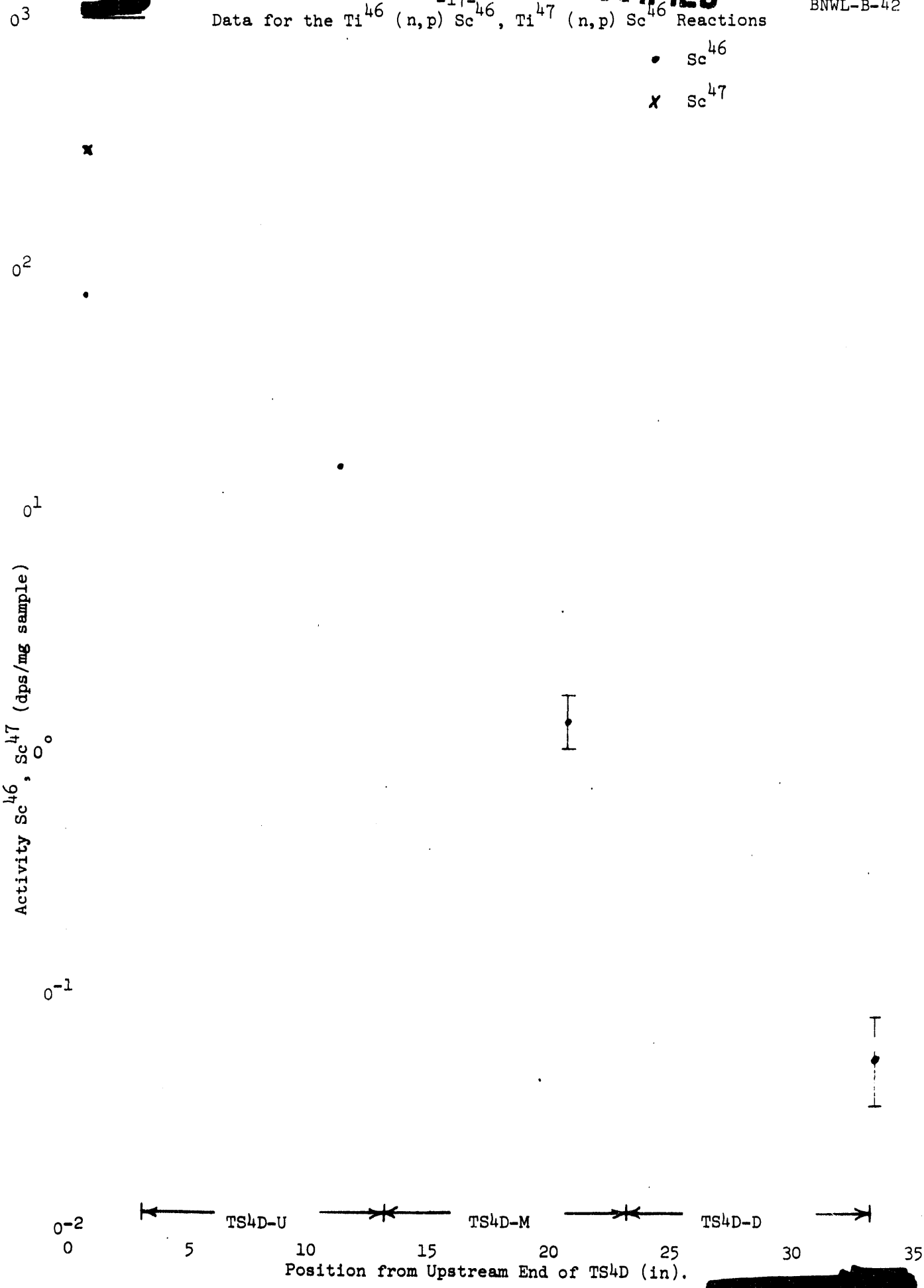
Data for the $Ti^{46}$ (n,p) $Sc^{46}$, $Ti^{47}$ (n,p) $Sc^{46}$ Reactions

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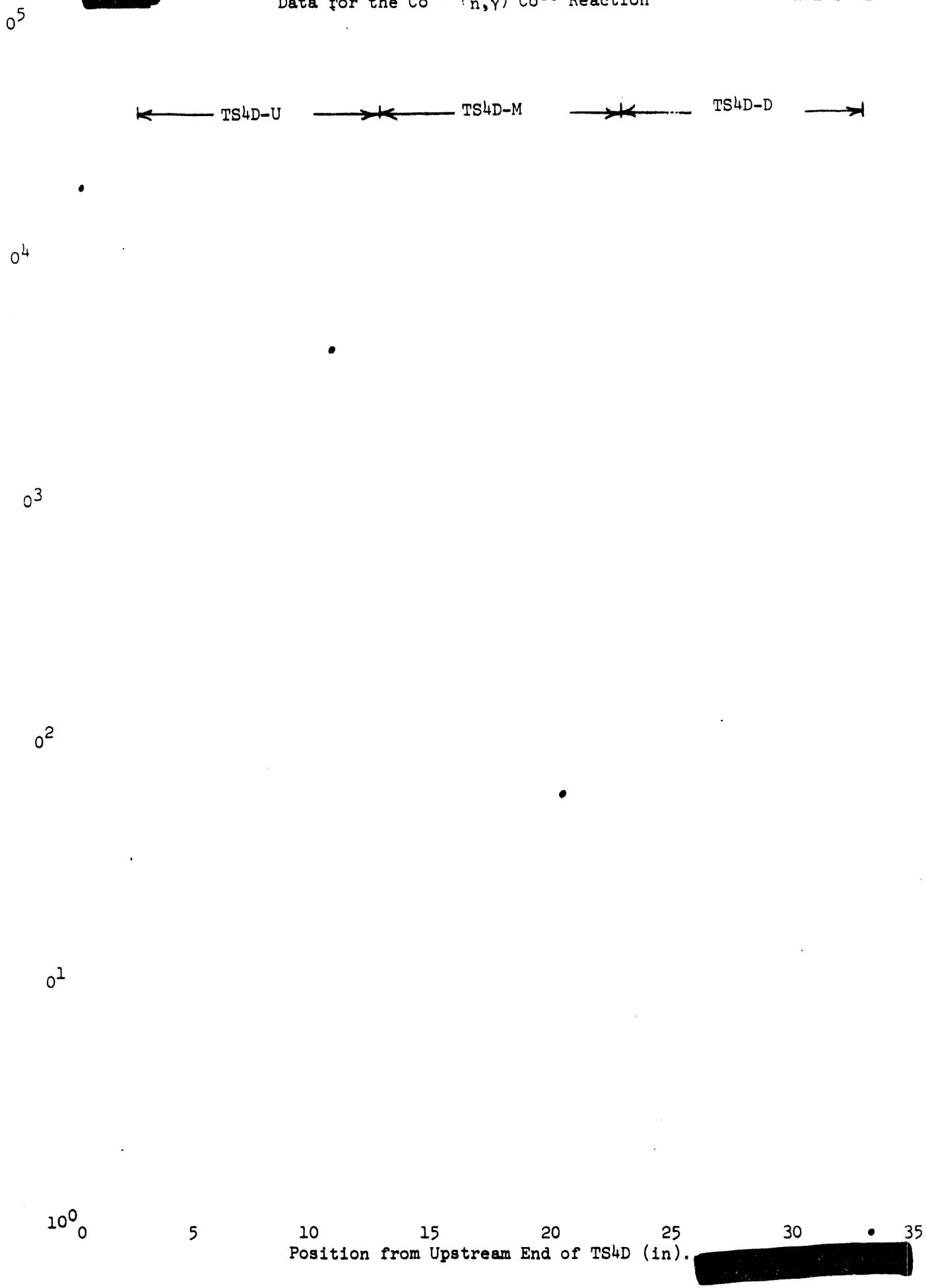
Data for the $Co^{59}$ $(n,\gamma)$ $Co^{60}$ Reaction



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# APPENDIX II

Summary Report submitted by Analytical Physics on the theoretical calculations for the CPTF neutron flux profile.

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DATE October 13, 1970

TO J. R. Divine

FROM G. L. Gelhaus

SUBJECT Neutron Spectra Calculations in KE-Reactor

The neutron spectra calculations have been performed for the KE-reactor. The test specimens which are being irradiated in a Side-to-Side General Purpose Facility were described in your letter to me dated June 23, 1970. The spectra were determined for specimens in the core and for specimens in the shield. The detailed spectra are given in the accompanying computer output. Figures 1 and 2 of this report show the calculated neutron flux for three energy ranges for the specimens in the core and the shield.

The spectra were calculated using 2DB, a two-dimensional diffusion theory code. The 26 energy group neutron cross sections were calculated using HRG for the epithermal cross sections (> 0.683 eV) and Battelle-Revised-THERMOS for the thermal cross sections. The energy group structure used in the calculations is given in Table 1.

The R-Z geometrical model used the center of the Side-to-Side Facility as the Z-axis. The spectrum was determined for the midpoint of each mesh interval in the R and Z directions. Values of the spectra are in units of neutrons per square centimeter-second. The absolute value of the flux was determined by normalizing the thermal flux to the measured iron wire activity data.

Several approximations had to be evaluated in simplifying the calculation to a two-dimensional problem: (1) the differences between the incident spectrum on the surface of the sample and the spectrum in the flux wire were negligible; (2) the variations in water gap spacing had no effect on the spectra of the flux incident upon the sample; (3) offsetting the sample position from the geometrical

center had no effect on the incident spectrum on the surface of the sample; (4) negligible error was introduced when homogeneous rather than heterogeneous cross sections were used in the schedule and test section. In evaluating these approximations, two assumptions were made: (1) the thermal flux was the most sensitive to any perturbation of the sample's position from the geometric center of the Side-to-Side Facility; (2) a slab calculation through a cylinder exaggerated the worst possible case encountered when non-concentricity was considered. Battelle-Revised-THERMOS calculations were used to evaluate the approximations. A summary of the evaluation is shown in Table 2.

Additional investigations revealed that the presence of fission foil capsules lying adjacent to the test loop introduced thermal flux depressions in the test zone ranging from three to six percent. The flux depressions at higher energies were less than one percent. Because of the small flux depressions it is not necessary to include the fission foil capsules in the calculations.

## Table 1

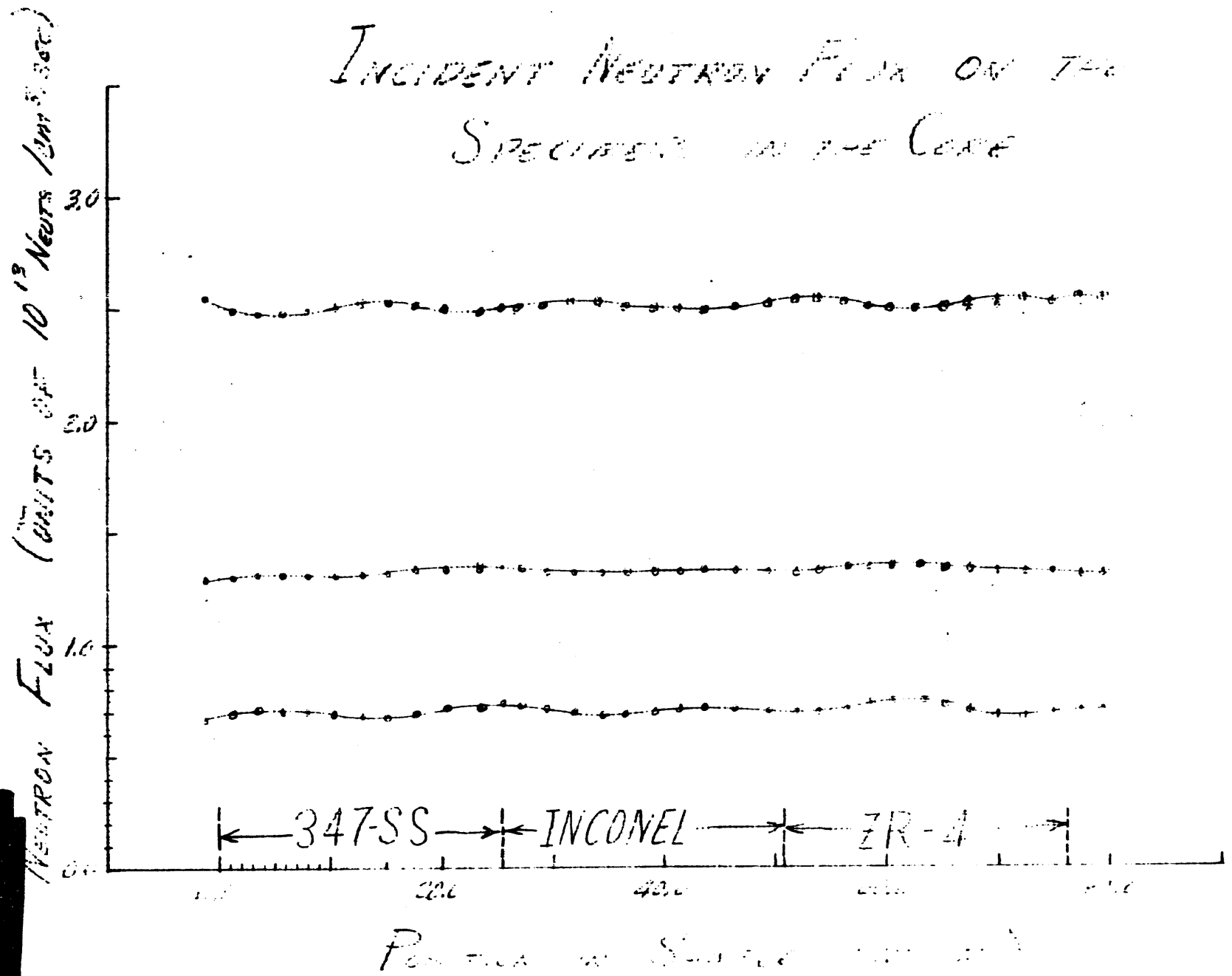
ENERGY GROUP BOUNDARIES

| Energy Gp. No. | Energy Group Upper Boundary |
|---|---|
| 1 | $1.00 \times 10^{7}$ eV |
| 2 | $7.79 \times 10^{6}$ |
| 3 | 6.07 |
| 4 | 4.72 |
| 5 | 2.23 |
| 6 | 1.35 |
| 7 | $8.21 \times 10^{5}$ |
| 8 | 3.88 |
| 9 | 1.83 |
| 10 | 1.11 |
| 11 | $4.09 \times 10^{4}$ |
| 12 | 2.48 |
| 13 | 1.17 |
| 14 | $4.31 \times 10^{3}$ |
| 15 | 2.04 |
| 16 | 1.23 |
| 17 | $4.54 \times 10^{2}$ |
| 18 | 2.15 |
| 19 | 1.01 |
| 20 | $4.79 \times 10^{1}$ |
| 21 | 2.26 |
| 22 | 1.07 |
| 23 | $5.04 \times 10^{0}$ |
| 24 | 2.38 |
| 25 | 1.13 |
| 26 | $6.83 \times 10^{-1}$ |

Table 2

DIFFERENCES IN TWO-DIMENSIONAL APPROXIMATIONS

| Approximation | Percent Difference in Magnitude of Flux | Percent Difference in Average Velocity |
|---|---|---|
| • Flux monitor spectrum versus sample spectrum | - 1.9 | + 0.5 |
| • Maximum effect of water gap thickness variations | + 2.6 | - 1.7 |
| • Sample assumed in geometrical center of schedule | + 2.4 | - 0.1 |
| • Homogenized cross sections versus heterogeneous cross sections for test loop | - 2.9 | + 0.1 |

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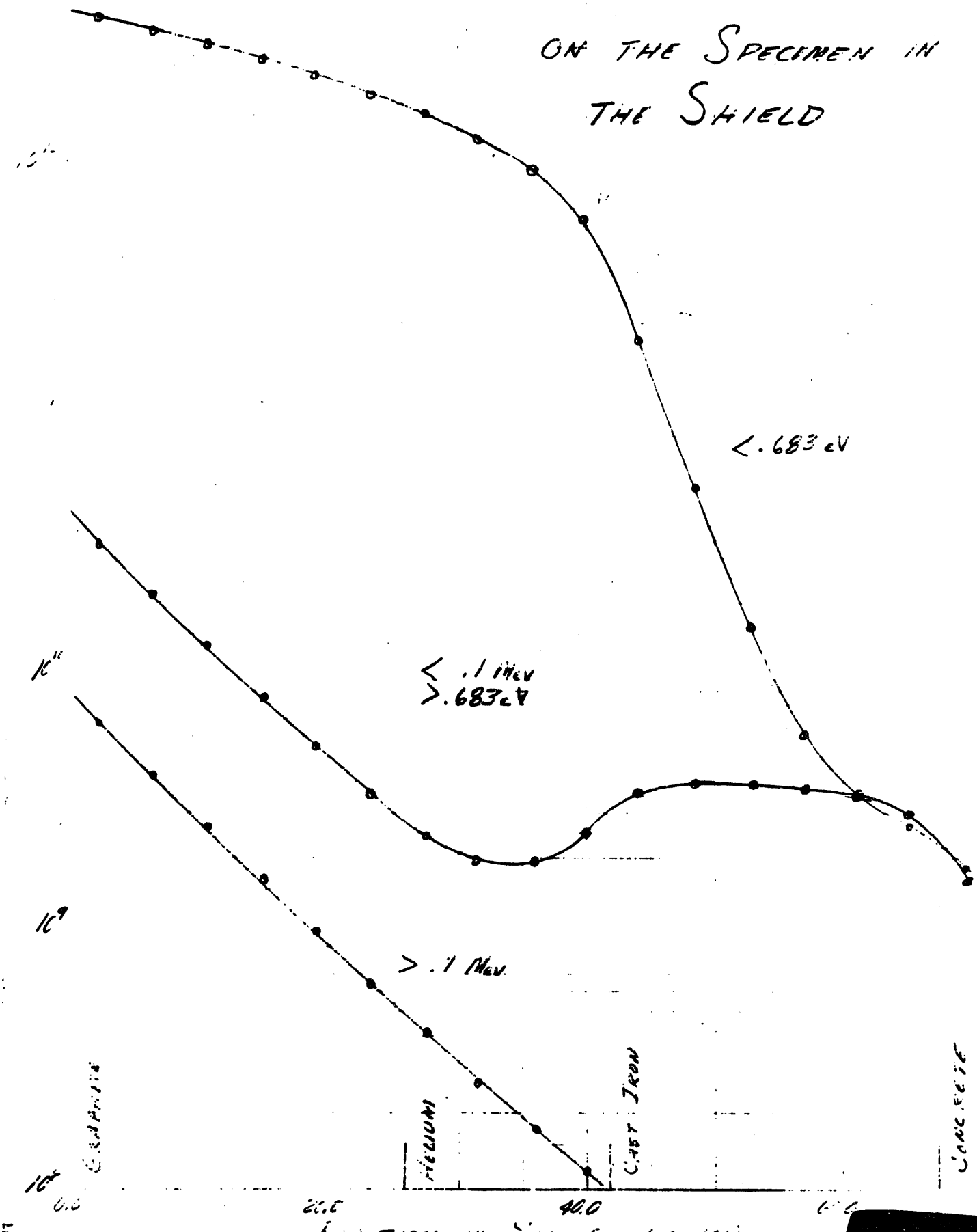


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