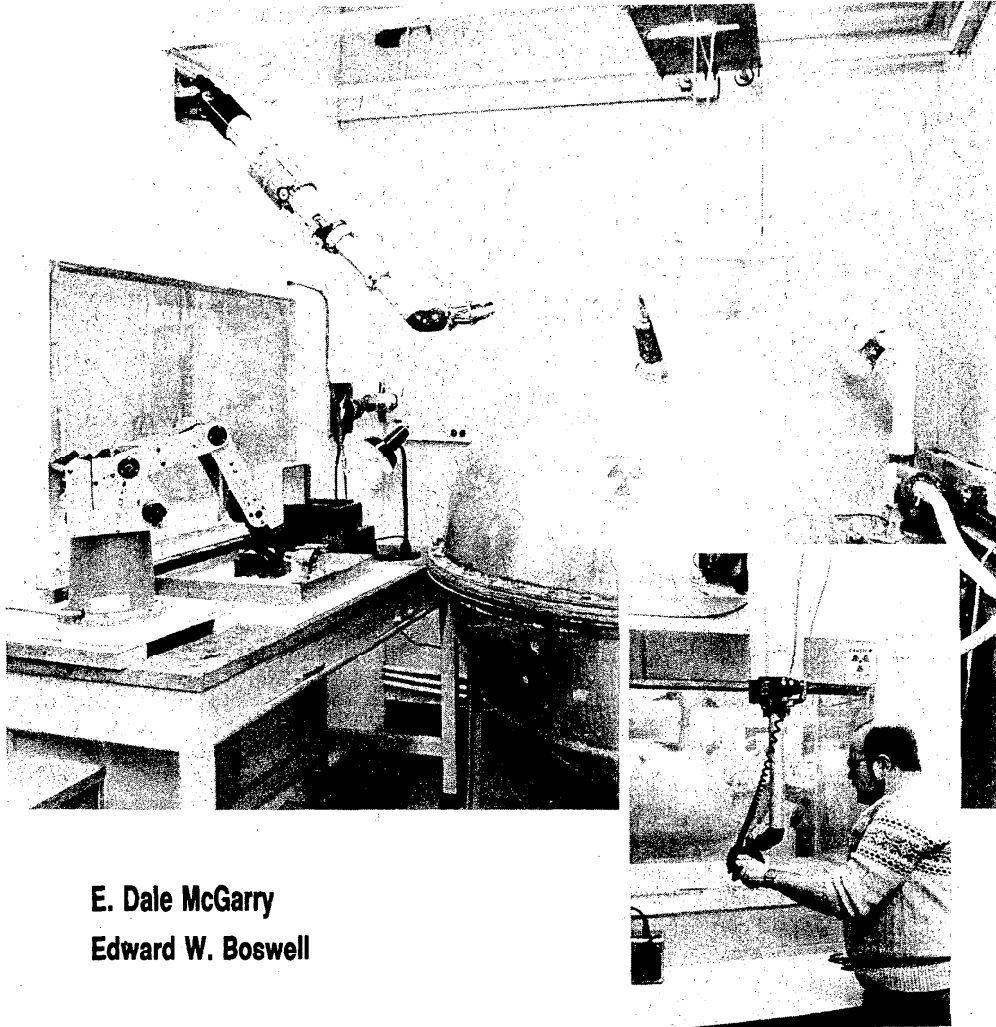# Neutron
Source Strength
Calibrations

E. Dale McGarry
Edward W. Boswell

U.S. Department of Commerce
National Bureau of Standards

Center for Radiation Research

The Center for Radiation Research is a major component of the National Measurement Laboratory in the National Bureau of Standards. The Center provides the Nation with standards and measurement services for ionizing radiation and for ultraviolet, visible, and infrared radiation; coordinates and furnishes essential support to the National Measurement Support System for ionizing radiation; conducts research in radiation related fields to develop improved radiation measurement methodology; and generates, compiles, and critically evaluates data to meet major national needs. The Center consists of five Divisions and one Group.

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Carries out basic theoretical and experimental research into the spectroscopic and radiative properties of atoms and highly ionized species; develops well-defined atomic radiation sources as radiometric or wavelength standards; develops new measurement techniques and methods for spectral analysis and plasma properties; and collects, compiles, and critically evaluates spectroscopic data. The Division consists of the following Groups:

- Atomic Spectroscopy
- Atomic Radiation Data
- Plasma Radiation

Radiation Physics Division

Provides the central national basis for the measurement of far ultraviolet, soft x-ray, and electron radiation; develops and disseminates radiation standards, measurement services, and data for for these radiations; conducts theoretical and experimental research with electron, laser, ultraviolet, and soft x-ray radiation for measurement applications; determines fundamental mechanisms of electron and photon interactions with matter; and develops advanced electron- and photon-based measurement techiques. The Division consists of the following Groups:

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- Electron Physics
- Photon Physics

Radiometric Physics Division

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- Spectral Radiometry
- Spectrophotometry
- Radiometric Measurement Services

Radiation Source and Instrumentation Division

Develops, operates, and improves major NBS radiation facilities including the electron Linac and race track microtron; develops, designs, and builds electronic and mechanical instrumentation for radiation programs and facilities; provides national leadership in the standardization of nuclear instrumentation; and develops new competence in radiation sources and instrumentation. The Division consists of the following Groups:

- Accelerator Research
- Linac Operations
- Electronic Instrumentation
- Mechanical Instrumentation

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Provides primary national standards, measurement services, and basic data for applications of ionizing radiation; develops new methods of chemical and physical dosimetry; conducts theoretical and experimental research on the fundamental physical and chemical interactions of ionizing radiation with matter; provides essential standards and measurement support services to the National Measurement Support System for Ionizing Radiation; and develops and operates radiation sources needed to provide primary radiation standards, fields, and well-characterized beams of radiation for research on radiation interactions and for development of measurement methods. The Division consists of the following Office and Groups:

- Office of Radiation Measurement
- Radiation Theory
- Radiation Chemistry and Chemical Dosimetry
- Neutron Measurements and Research
- Neutron Dosimetry
- Radioactivity
- X-Ray Physics
- Dosimetry

Nuclear Physics Group

Engages in forefront research in nuclear and elementary particle physics; performs highly accurate measurements and theoretical analyses which probe the structure of nuclear matter; and improves the quantitative understanding of physical processes that underlie measurement science.

NBS MEASUREMENT SERVICES: NEUTRON SOURCE STRENGTH CALIBRATIONS

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PREFACE

The calibration and related measurement services of the National Bureau
of Standards are intended to assist the makers and users of precision
measuring instruments in achieving the highest possible levels of
accuracy, quality, and productivity. NBS offers over 300 different
calibration, special test, and measurement assurance services. These
services allow customers to directly link their measurement systems to
measurement systems and standards maintained by NBS. These services
are offered to the public and private organizations alike. They are
described in NBS Special Publication (SP) 250, NBS Calibration Services
Users Guide.

The Users Guide is being supplemented by a number of special
publications (designated as the "SP 250 Series") that provide a
detailed description of the important features of specific NBS
calibration services. These documents provide a description of the:
(1) specifications for the service; (2) design philosophy and theory;
(3) NBS measurement system; (4) NBS operational procedures; (5)
assessment of measurement uncertainty including random and systematic
errors and an error budget; and (6) internal quality control procedures
used by NBS. These documents will present more detail than can be
given in an NBS calibration report, or than is generally allowed in
articles in scientific journals. In the past NBS has published such
information in a variety of ways. This series will help make this type
of information more readily available to the user.

This document (SP 250-18), NBS Measurement Services: Neutron Source
Strength Calibrations, by E. Dale McGarry and Edward W. Boswell, is the
18th to be published in this new series of special publications. It
describes the calibration of the neutron emission rate of sources of
unknown source strength by use of the manganese sulfate bath method to
compare their strengths to a Ra-Be standard photoneutron source (see
test numbers 44010C and 44020C in the SP 250 Users Guide). Inquiries
concerning the technical content of this document or the specifications
for these services should be directed to the authors or one of the
technical contacts cited in SP 250.

The Center for Radiation Research (CRR) is in the process of publishing
21 documents in this SP 250 series, covering all of the calibration
services offered by CRR. A complete listing of these documents can be
found inside the back cover.

NBS would welcome suggestions on how publications such as these might
be made more useful. Suggestions are also welcome concerning the need
for new calibration services, special tests, and measurement assurance
programs.

Joe D. Simmons   Chris E. Kuyatt
Acting Chief   Director
Measurement Services   Center for Radiation Research

ABSTRACT

The manganese sulfate ($MnSO_4$) bath method of neutron source strength calibration at NBS is described and compared briefly with other $MnSO_4$ bath techniques used internationally. The accuracy of source calibration is discussed from the viewpoints of international intercomparisons and practical limitations of the NBS system. In particular, there is discussion of uncertainties associated with system limitations and with corrections necessary for neutron capture in the source, capture of fast and thermal neutrons by competing reactions in the $MnSO_4$, capture of neutrons in the source container, and the correction for leakage of neutrons from the bath, which is 1.27 meters in diameter.

Key words: calibrations; emission rate; manganese sulfate; neutron source; source strength determination

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1. DESCRIPTION OF CALIBRATION SERVICES AND ACCURACIES

1.1 Services Available

The available services are described in the current edition of the Ionizing Radiation Section of NBS Special Publication 250, "NBS Calibration Services Users Guide, 1986-1988". Basically, they are as follows:

1.1.1 Allowable Source Strength Range

SP-250 44010C applies to calibrations of neutron sources in the range from 5×10^5 to 5×10^7 neutrons/second. Such sources may be calibrated to an uncertainty of about $\pm 1.1\%$, depending upon what is known about their encapsulations. SP-250 44020C applies to sources in the range 5×10^7 to 5×10^9 neutrons/second and these may be calibrated to an uncertainty of about $\pm 1.2\%$, again with some dependence on their encapsulations. The quoted uncertainties are at the 68% confidence level.

About two months should be allowed for source calibrations, and advance arrangements must be made including the following information:

1) A diagram showing the source location in the shipping container and instructions for removal of the source, if necessary.
2) A description of any special markings on the source.
3) The dimensions of the source, including the relative internal location of the active ingredients.
4) The nature and amount of radioactive materials and the ratio of neutron producing ingredients.
5) The kind of metal enclosing the source and, if possible, the number of grams of each element.
6) The date the source was sealed.

1.1.2 General Method

Emission rates (neutrons/second) of neutron sources of unknown source strength are determined by the Manganese Sulfate Bath Method. At NBS, the neutron sources are calibrated by comparing their strengths to a Ra-Be photoneutron source known as NBS-I. A comparison of source strengths is made by activating a manganese sulfate bath solution and continuously counting the induced, saturated ^{56}Mn radioactivity with a scintillation counter.

1.2 Summary of Accuracy

1.2.1 Accuracy of NBS-I Source Strength

The present emission rate of NBS-I, which is absolutely determined, is 1.243E+06 neutrons/second with an estimated uncertainty of $\pm 0.85\%$ (one sigma). See Section 2.2 for discussion of this uncertainty. Uncertainties in this document refer to either one standard deviation (experimental) or estimates of non-random uncertainties that have the character (68% confidence limit) of one standard deviation.

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1.2.2 Other Uncertainty Components of Interest

1) Depending upon the activity of the source, different scintillation counters are used. The use of separate counters for high level ($>2\times10^8$ n/s) sources introduces an additional 0.4% uncertainty because of the methods of calibration. See Section 3.1 for discussion of calibrations of the "main" and "remote" counters.

2) Corrections (always less than five percent total) are made for neutron absorption in the source itself. See Sections 3.2.3 and 3.2.4 for detailed discussion of these leakage and absorption corrections.

3) The half-life of the principal neutron-emitting isotope in Cf neutron sources, ^{252}Cf, is 2.645 $\pm$ 0.008 years. The next most significant isotope is ^{250}Cf with a half-life of 50 years. If the composition of the source is limited to no more than 3% ^{250}Cf, it will not contribute more than a fraction of a percent to the neutron strength even 10 years after separation of the californium. See Section 4 for further discussion of a possible source-dependent half-life.

2. DESIGN PHILOSOPHY

The design philosophies that dominate the operation and achievable accuracy of the neutron source-strength calibration service are discussed in the following paragraphs. Perhaps the most notable characteristic of the NBS $MnSO_4$ bath calibration method is that it is the only such calibration in the world based entirely on relative measurements of unknown source strengths against a known standard Ra-Be (n,γ) source, NBS-I (see Fig. 1). All other $MnSO_4$ facilities calibrate by determination of absolute ^{56}Mn activity.

2.1 Bath Size and Manganese Concentration

Sources are calibrated by comparison with NBS-I in a large spherical tank, 1.27m in diameter, containing $MnSO_4$ solution with a density of 1.37 kg/l of solution. Calibrations depend upon measurements of gamma rays from the activity induced in manganese through the capture of neutrons. Corrections to the bath activity for fast neutron capture by oxygen, sulfur and teflon, as well as escape from the bath, all require knowledge of the source spectrum. The correction for absorption by the source itself, which in some cases leads to fission, requires detailed knowledge of the isotopic content of the source material and the weights and thickness of all encapsulations.

The neutron sources are suspended at the center of the bath until equilibrium of the ^{56}Mn activity is reached. This takes about 25 hours. The source is enclosed in a teflon cylindrical shell which creates a void in the manganese sulfate that serves to minimize absorption of thermal neutrons by the source.

2.2 Standard Source Calibrations

The absolute emission rate of NBS-I has been measured by three independent methods. See references 1,2, and 3 for reports of these

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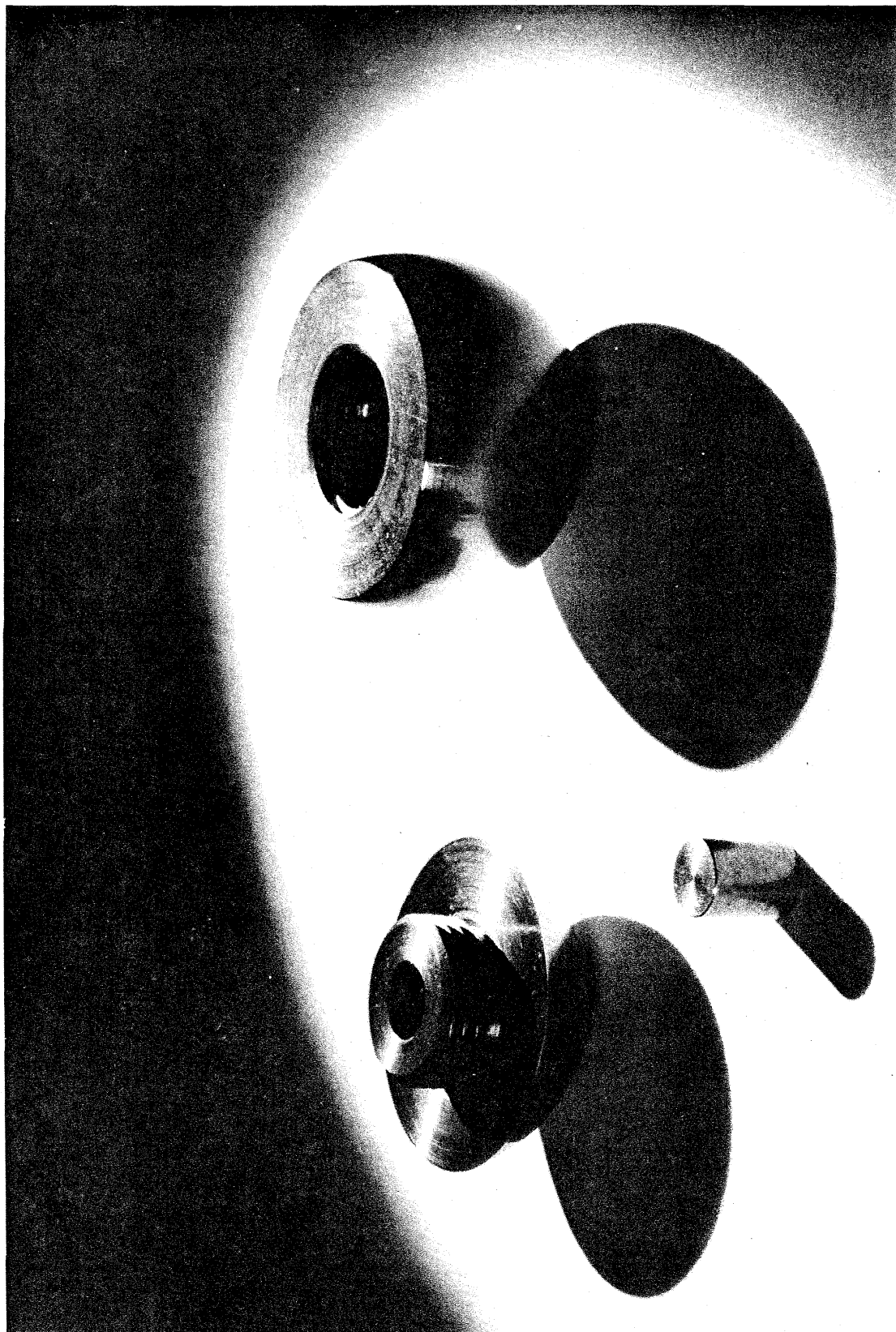
FIG. 1. Radium Beryllium Photoneutron Source NBS-I.

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calibrations. In the first calibration, the thermal neutron density
was determined from the activity induced in thin indium and magnesium
foils as a function of distance from the source when both the source
and foils were under water. The second calibration involved the
capture of neutrons by a surrounding manganese sulfate ($MnSO_4$) bath,
followed by a measurement of the activity of the manganese-56. The
third method involved a relative comparison to an antimony-beryllium
source which had been calibrated absolutely in a heavy-water manganese
sulfate bath. The final value of NBS-I was determined from the results
of these measurements in June 1961 and was 1.257 x 10^6 n/s ±1%.
Subsequent to this, the emission rate has been checked against the
number of neutrons of ^{252}Cf that are emitted per fission, $\bar{\nu}$. The
uncertainty was reduced to ±0.85%.

As the half life of radium is 1600±5 years, the emission rate of the
standard can be accurately calculated over a long period of time.
Table 1 gives the emission rate since 1976. As mentioned, the emission
rates of sources are determined by comparison with NBS-I in the $MnSO_4$
bath. Table 1 is particularly significant in that only the values
listed there have been used by NBS for the source strength of NBS-I
since 1976, even though some discussions of a possible ±0.35% bias
exists in the literature. See bottom of Table 8 and Ref. (4). The
present (September, 1986) emission rate of NBS-I is 1.243 x 10^6
neutrons/second with an estimated uncertainty of ±0.85%.

3. DESCRIPTION OF FACILITIES AND METHODS

Figure 2 schematically shows the bath, the remotely located
scintillation counters, and various pumps and radiation shields. For
calibration, the sources are located at the center of the spherical
bath - see Figure 3. The spherical tank is aluminum, lined completely
with 2 mm of polyethylene to prevent long-term interaction of the
acidic $MnSO_4$ solution with the aluminum. The bath contains nominally
1050 liters of $MnSO_4$ at a solution density of 1.37 kg/l of solution.
The bath solution is circulated through plastic tubing to a
scintillation counter, located outside of a polyethylene-lined,
high-density-concrete shielding wall.

3.1 Calibration of Sources With Very Different Source Strengths

A factor of 10,000 in source strength range is spanned by using two
scintillation counters that differ in sensitivity by a factor of 70.
The choice of counter depends upon the counting rate; all source
strengths are compared to the NBS-I rate.

Details of the operations of the counters and calibration of their
response are discussed in Section 6. Only the more sensitive of the
two counters can be directly calibrated with NBS-I. An additional
multiplicative factor of 70, and its uncertainty, are required to
relate the secondary (or "remote") counter's calibration to that of the
first. Quality assurance procedures are necessary to insure the long
term stability of this ratio. Originally it was planned to use the
half life (2.645 years) of ^{252}Cf as a measure of quality control by
following the decay of ^{252}Cf sources over three to four half lives.

TABLE 1.

NBS-1 EMISSION RATE TABLE BASED ON THE CALIBRATION OF 1.257E6
IN JUNE 1961 AND A HALF LIFE OF 1600 YEARS

	1976	1977	1978	1979	1980
JAN	1.2491E+06	1.2485E+06	1.2480E+06	1.2475E+06	1.2469E+06
FEB	1.2490E+06	1.2485E+06	1.2480E+06	1.2474E+06	1.2469E+06
MAR	1.2490E+06	1.2485E+06	1.2479E+06	1.2474E+06	1.2468E+06
APR	1.2489E+06	1.2484E+06	1.2479E+06	1.2473E+06	1.2468E+06
MAY	1.2489E+06	1.2484E+06	1.2478E+06	1.2473E+06	1.2467E+06
JUN	1.2489E+06	1.2483E+06	1.2478E+06	1.2472E+06	1.2467E+06
JUL	1.2488E+06	1.2483E+06	1.2477E+06	1.2472E+06	1.2467E+06
AUG	1.2488E+06	1.2482E+06	1.2477E+06	1.2471E+06	1.2466E+06
SEP	1.2487E+06	1.2482E+06	1.2476E+06	1.2471E+06	1.2466E+06
OCT	1.2487E+06	1.2481E+06	1.2476E+06	1.2471E+06	1.2465E+06
NOV	1.2486E+06	1.2481E+06	1.2476E+06	1.2470E+06	1.2465E+06
DEC	1.2486E+06	1.2480E+06	1.2475E+06	1.2470E+06	1.2464E+06

	1981	1982	1983	1984	1985
JAN	1.2464E+06	1.2458E+06	1.2453E+06	1.2448E+06	1.2442E+06
FEB	1.2463E+06	1.2458E+06	1.2453E+06	1.2447E+06	1.2442E+06
MAR	1.2463E+06	1.2458E+06	1.2452E+06	1.2447E+06	1.2441E+06
APR	1.2462E+06	1.2457E+06	1.2452E+06	1.2446E+06	1.2441E+06
MAY	1.2462E+06	1.2457E+06	1.2451E+06	1.2446E+06	1.2440E+06
JUN	1.2462E+06	1.2456E+06	1.2451E+06	1.2445E+06	1.2440E+06
JUL	1.2461E+06	1.2456E+06	1.2450E+06	1.2445E+06	1.2440E+06
AUG	1.2461E+06	1.2455E+06	1.2450E+06	1.2444E+06	1.2439E+06
SEP	1.2460E+06	1.2455E+06	1.2449E+06	1.2444E+06	1.2439E+06
OCT	1.2460E+06	1.2454E+06	1.2449E+06	1.2444E+06	1.2438E+06
NOV	1.2459E+06	1.2454E+06	1.2449E+06	1.2443E+06	1.2438E+06
DEC	1.2459E+06	1.2453E+06	1.2448E+06	1.2443E+06	1.2437E+06

	1986	1987	1988	1989	1990
JAN	1.2437E+06	1.2431E+06	1.2426E+06	1.2421E+06	1.2415E+06
FEB	1.2436E+06	1.2431E+06	1.2426E+06	1.2420E+06	1.2415E+06
MAR	1.2436E+06	1.2431E+06	1.2425E+06	1.2420E+06	1.2414E+06
APR	1.2435E+06	1.2430E+06	1.2425E+06	1.2419E+06	1.2414E+06
MAY	1.2435E+06	1.2430E+06	1.2424E+06	1.2419E+06	1.2414E+06
JUN	1.2435E+06	1.2429E+06	1.2424E+06	1.2418E+06	1.2413E+06
JUL	1.2434E+06	1.2429E+06	1.2423E+06	1.2418E+06	1.2413E+06
AUG	1.2434E+06	1.2428E+06	1.2423E+06	1.2418E+06	1.2412E+06
SEP	1.2433E+06	1.2428E+06	1.2422E+06	1.2417E+06	1.2412E+06
OCT	1.2433E+06	1.2427E+06	1.2422E+06	1.2417E+06	1.2411E+06
NOV	1.2432E+06	1.2427E+06	1.2422E+06	1.2416E+06	1.2411E+06
DEC	1.2432E+06	1.2427E+06	1.2421E+06	1.2416E+06	1.2410E+06

4" LEAD SHIELD

Na I CRYSTALS

1/2"

NEUTRON & GAMMA SHIELDING WALL

1"

PUMP

DIFFUSER

10 cm dia. TEFLON SOURCE-HOLDER

1.25 m. dia. POLYETHYLENE SPHERICAL BATH OF Mn SO₄

ST. STEEL MARINELLI BEAKER 10" dia. X 10"
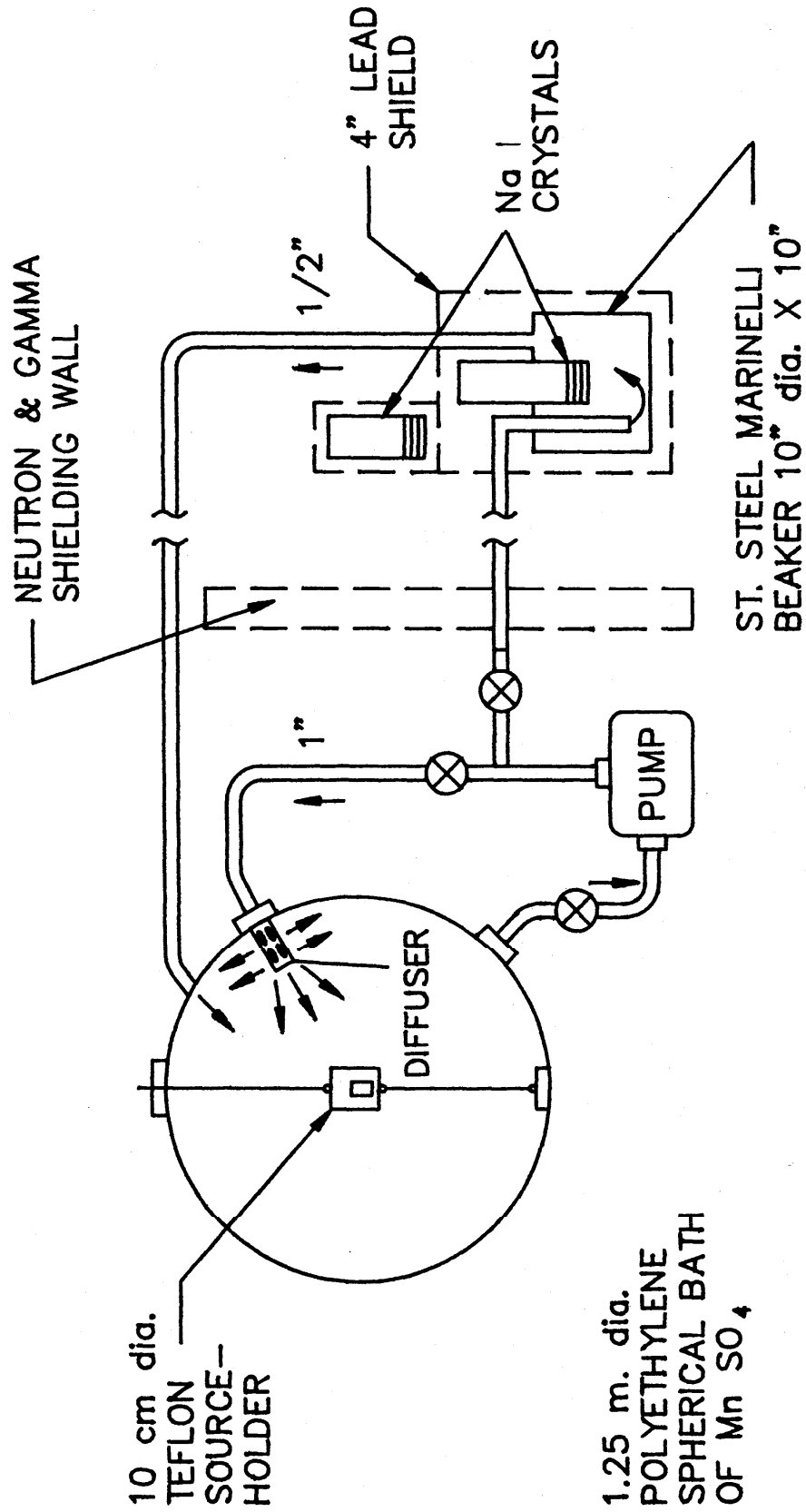
FIG. 2. Circulating Manganese Sulfate Bath and Shielded Gamma Ray Detectors. System is not shown in full detail.

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FIG. 3. A photograph of the aluminum shell which supports the
polyethylene liner and $MnSO_4$ solution. Sources are pulled into the
center of the solution by a Teflon can attached to a rope on a pulley,
above, and a short steel bar at the bottom of the inside of the
spherical tank.

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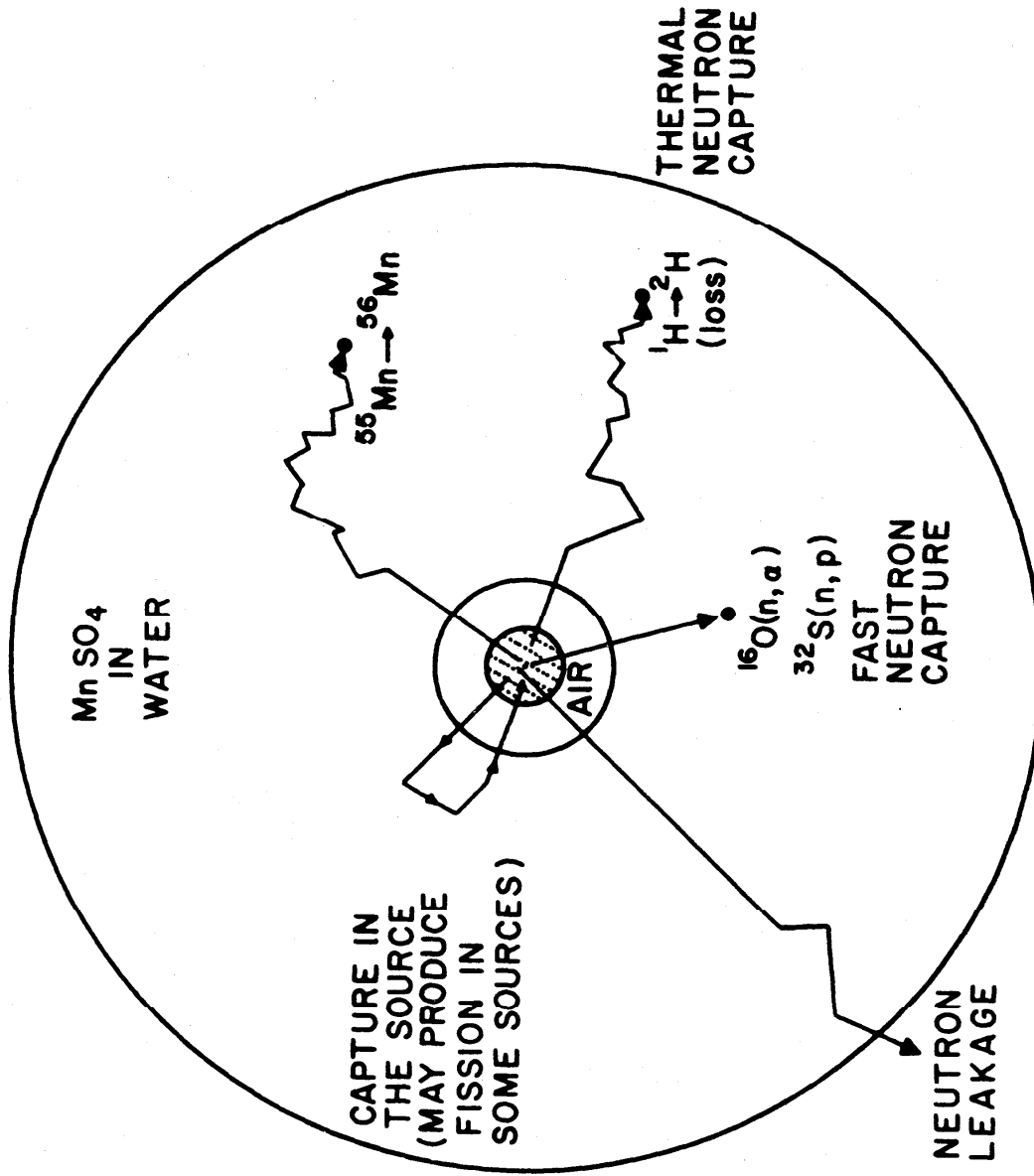
MANGANESE SULFATE BATH
SOURCE CALIBRATION
(SCHEMATIC)

Fig. 4. Events which take place in the MnSO₄ bath during a neutron source calibration. An old, but good, review article concerning these events and having 65 references is Ref. 5 by K. W. Geiger.

However, there is now sufficient evidence (5) to show that different ^{252}Cf sources exhibit measurably different "effective" ^{252}Cf half lives in the range of 2.635 to 2.657 years. Consequently, quality control procedures are related to measurements of effective ^{252}Cf half lives for about five older NBS sources.

3.2 Corrections to MnSO$_4$ Bath Measurements

Ideally, the neutrons emitted from a source located at the center of the MnSO$_4$ solution enter the bath, are slowed down by a series of collisions, and finally captured by a ^{55}Mn nucleus to produce ^{56}Mn. In the laboratory, we do not achieve this ideal situation and a number of small (several percent) corrections have to be made. Figure 4 shows the different neutron loss processes which take place in the MnSO$_4$ bath.

3.2.1 Neutron Absorption in Oxygen and Sulfur

Oxygen and sulfur are both present with the manganese in MnSO$_4$. Table 2 gives relative concentrations for solutions with three different densities. The density of a saturated MnSO$_4$ solution is 1.465 g/cm^3 at 20°C. The presence of oxygen (in both water and the MnSO$_4$) causes significant absorption of neutrons above 4 MeV, primarily by the ^{16}O $(n,\alpha)^{13}$C reaction. Sulfur also absorbs neutrons above 2 MeV. In addition, sulfur absorbs neutrons in the thermal and epithermal (E>0.63 eV) energy range. See Ref. (6), for NBS calculations of absorption corrections by W. Murphey.

3.2.2 Absorption Corrections for the NBS MnSO$_4$ Bath

The corrections currently used at NBS for neutron absorptions in oxygen and sulfur are based upon several studies. One is a Monte Carlo calculation performed by E. J. Axton, National Physical Laboratory, (NPL), Teddington, England. Another is from an extrapolation of transport calculations, performed for the Electric Power Research Institute, (EPRI), by H. Goldstein and Lin Chen at Columbia University (7). EPRI, as part of $\bar{\nu}$ of ^{252}Cf measurements, examined correction factors applied to MnSO$_4$ bath measurements. Results are presented in Tables 3 through 5.

Table 2 provides relationships among various factors in those tables. The Columbia results (given in Table 3) address only ^{252}Cf neutrons but consider differences in both the densities of MnSO$_4$ solutions and bath radii. The Axton results (given in Table 5) examine different types of neutron sources, some with significantly different energy spectra, but only for an NBS-type bath, i.e., 63.5-cm radius and 1.374 kg/L density. From an examination of the data in Table 3, it is concluded that the results from the "infinite medium, 1.382 g/cm^3" case are essentially the NBS-bath situation. Therefore, these data are converted, in Table 4, into the units of Table 5 by multiplying by either the concentration of oxygen or sulfur, as appropriate. The comparison is mentioned in footnote #1 of Table 5.

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TABLE 2. Atom Densities of Elements in Each Composition of the MnSO$_4$ Solutions Referred to in Tables 3 and 4.

Density (g/cm³)	1.382	1.257	1.0934
N_H/N_{Mn}	35.47	55.65	162.15
Amount of MnSO$_4$ (g/kg solution)	320.7	231.3	93.68

Concentrations (in units of nuclei/barn-cm)

C_H	6.269-2*	6.452-2	6.624-2
C_O	3.843-2	3.690-2	3.475-2
C_{Mn}	1.768-3	1.159-3	4.085-4
C_S	1.771-3	1.161-3	4.090-4

*Read 6.269 x 10^{-2}

TABLE 3. Impurity Absorption in Various Size Baths and Different Concentrations of MnSO$_4$. The Table Assumes a ^{252}Cf Fission Spectrum. (See Ref. 7)

Type & Energy Range of Reaction	Absorption Rates for Indicated Densities		
	1.382 g/cm³	1.257 g/cm³	1.0934 g/cm³
Infinite Medium			
O(n,α) fast	1.059-1	1.060-1	1.071-1
O(n,p) fast	5.406-4	5.518-4	5.704-4
S(n,α) E>0.63 eV	7.043-1	6.981-1	6.967-1
S(n,α) Thermal	2.012-1	2.461-1	3.584-1
S(n,p) E>0.63 eV	7.033-1	7.006-1	7.039-1
S(n,p) Thermal	4.059-4	4.963-4	7.229-4
52-cm sphere			
O(n,α) fast	1.045-1	1.046-1	1.056-1
O(n,p) fast	5.264-4	5.363-4	5.527-4
S(n,α) E>0.63 eV	6.989-1	6.920-1	6.891-1
S(n,α) Thermal	2.011-1	2.444-1	3.329-1
S(n,p) E>0.63 eV	6.958-1	6.929-1	6.941-1
S(n,p) Thermal	4.047-4	4.930-4	6.728-4
25-cm sphere			
O(n,α) fast	8.888-2	8.874-2	8.901-2
O(n,p) fast	4.161-4	4.205-4	4.278-4
S(n,α) E>0.63 eV	6.138-1	6.069-1	6.030-1
S(n,α) Thermal	1.722-1	2.070-1	2.775-1
S(n,p) E>0.63 eV	6.048-1	6.010-1	5.994-1
S(n,p) Thermal	3.466-4	4.175-4	5.608-4

TABLE 4. Absorption Rates per Source Neutron for Elements Other Than Manganese in the NBS MnSO₄ Bath Assuming a Concentration Density of 1.374 kg/L and a ^{252}Cf Fission Neutron-Energy Spectrum. Bath is 1.27 m in Diameter (See Ref. 7).

Type and Energy Range of Reaction	Absorption Rates (per source neutron)	
	Total	Percentage
O(n,α) fast	4.054×10^{-3}	60.0%
O(n,p) fast	2.069×10^{-5}	0.3
S(n,α) E>0.63 eV	1.204×10^{-3}	17.4
S(n,α) Thermal	3.440×10^{-4}	4.9
S(n,p) E>0.63	1.203×10^{-3}	17.4
S(n,p) Thermal	6.941×10^{-7}	0.0
	$\overline{6.826 \times 10^{-3}}$	$\overline{(100.0)}$

$C_O = 3.828 \times 10^{-2}$ nuclei/barn-cm; $C_S = 1.710 \times 10^{-3}$ nuclei/barn-cm (refer to Table 2).

See Table 5 for the Axton results and a comparison with Tables 3 and 4.

3.2.3 Neutron Absorption in the Sources and Source Holders

The correction considered here is to account for the reduction of the manganese activity due to the loss of thermalized neutrons absorbed in the neutron source itself.

1) Effects of surrounding the source in the MnSO₄ solution with a void. There are two problems associated with placing a bare neutron source directly into the MnSO₄ solution: (1) the MnSO₄ solution is sufficiently acidic to interact with the source encapsulation metals; (2) the amount of thermal-neutron absorption by the source is dependent upon the size of the void surrounding the source, because the albedo of the MnSO₄ is constant and the neutron flux within the void is proportional to the flux at the surface of a void surrounding the source. Consequently, moderate voids (400cm³ to 800cm³) around the source are used in essentially all MnSO₄ baths to protect the source and reduce the neutron absorption.

2) Corrections for different types of sources: A calculation of the thermal neutron self-absorption for cylindrical or spherical neutron sources has been made(6). The calculations are confirmed by the experimentally measured difference in the manganese sulfate bath activity for bare and cadmium-covered Pu-Be and Am-Be neutron sources. The calculation is done in single-interaction approximation and assumes that the incident thermal neutron flux is isotropic. The source material may be fissionable and be covered by up to three cladding materials. A computer program has been written for the numerical calculations. A comparison of the calculations with experimental results is given in Table 6.

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TABLE 5. Corrections For Leakage and Capture for Various Types of Neutron Sources. Calculations Performed by E.J. Axton, NPL, for a MnSO$_4$ Bath with Dimensions and Manganese Concentration Same as That at NBS, see Text.

Magnitude of correction or effect (in %) for the indicated types of neutron source

Source of correction	^{252}Cf	^{239}Pu-Be	Am-Be	Ra-Be (α,n)	AmB	AmF	Am-Li	Ra-Be[4] NBS-I	SbBe
Fast Leakage	0.030	0.333	0.227	0.193	0.013	0	0	0	0
Thermal Leakage	0.015	0.050	0.030	0.026	0.007	0.003	0	0	0
Oxygen Capture[1]	0.344	2.092	2.031	1.528	0.254	0	0	0	0
Sulfur Capture[1]	0.280	0.913	0.848	0.627	0.274	0.06	0	0	0
(Teflon Capture)[2]	0.170	0.700	0.680	0.530	0.160	0.095	0.095	0.002	0
(Cavity Flux/Q)[3]	0.186	0.141	0.143	0.190	0.156	0.197	0.350	0.43	0.52
Average Energy	2.3	5.8	4.5	3.9	2.2	1.5	0.5	0.35	0.023

[1] For ^{252}Cf, the sum of 0.344% and 0.280% = 0.624% is in reasonably good agreement with the 0.683% from Table 4.
[2] Not determined by Axton. Put in this table to supply a more complete set of corrections for NBS conditions.
[3] The correction must be calculated using these values and Murphey's code mentioned in Ref. (6).
[4] The (n,γ) reaction. The gamma spectrum of NBS-I was assumed to be as follows:

Energy (keV)	Abundance
1764.5	0.340
2118.5	0.0263
2204.1	0.111
2239.4	0.0067
2447.7	0.0345

Table 6. Results of Intercomparison Between Calculation and
Measurement of Source Absorption

	Pu-Be-A (%)	Pu-Be-B (%)	AM-Be (%)
Calculated difference between bare and cadmium covered source absorption	2.08	4.06	1.34
Experimentally measured difference (from bath irradiations).	1.93±0.03	4.05±0.1	1.44±0.08

3.2.4 Leakage of Neutrons From the Bath

A correction is necessary for neutrons which escape from the bath. In
principle, the larger the bath the less that escape. However, making
the bath too large has compensating disadvantages. In particular, the
specific activity of the solution decreases with increasing radius.
See Table 5 for leakage corrections.

3.3 SOURCE STRENGTH DETERMINATION

The source strength, S, in neutrons per second emitted into 4π geometry
of the bath is,

$$S = \frac{\left[\begin{array}{c}^{56}\text{Mn Counter} \\ \text{Factor when} \\ >1.000\end{array}\right]\left[\begin{array}{c}\text{Net count rate} \\ \text{of customer's} \\ \text{source in MnSO}_4\end{array}\right]\left[\begin{array}{c}\text{Corrections for} \\ \text{leakage \&} \\ \text{capture for} \\ \text{customer's source}\end{array}\right]\left[\begin{array}{c}\text{Source strength} \\ \text{of NBS-I at} \\ \text{calibration date}\end{array}\right]}{\left[\begin{array}{c}\text{Net count rate} \\ \text{of NBS-I in bath} \\ \text{on calibration date}\end{array}\right]\left[\begin{array}{c}\text{Corrections for} \\ \text{leakage and} \\ \text{capture for} \\ \text{NBS-I}\end{array}\right]}$$

where all factors are fairly obvious except the first parenthesis in the
numerator, which is the main-to-remote counter ratio.

As a representative example, Section 3.3.1 describes a check on the
calibration of the NBS bath after it had been shut down for shielding
modifications in 1985. The check was made using a Savannah River (SR)
^{252}Cf source SR-Cf-144. The percent correction to the MnSO$_4$
calibrations of that source for oxygen and sulfur neutron capture is
(0.62 ± 0.08)%; for neutron capture in the Teflon beaker which holds the
source during immersion in the bath, the correction is (0.17 ± 0.06)%;
for fast plus thermal leakage of neutrons from the bath, the correction
is (0.045 ±0.010)% and for source absorption of thermal neutrons is

(0.08 ± 0.03)%. The uncertainties of these four quantities are
estimates that are intended to have the character of one standard
deviation and are based upon the following: 1) for fast neutron capture
in sulfur and oxygen, the uncertainty stems primarily from the
differences between the Columbia and the NPL results; 2) for capture in
Teflon, the uncertainty relates to nuclear cross section uncertainties
and the complex geometry of the Teflon structure (i.e., effective
thickness); 3) for leakage, which is quite small for the NBS bath, the
correction is estimated to be uncertain by 20%; 4) for source
absorption, the uncertainty comes from the thermal absorption studies of
Spiegel and Murphey at NBS (13).

When the four corrections are added together, this gives a total
correction factor in the numerator of 1.0092 ± .0010. The uncertainty
is the quadrature sum of the four quoted uncertainties. Similar
corrections for NBS-I give a correction factor in the denominator of
1.0021 ± 0.0008. The factor for NBS-I is smaller because the neutron
spectrum is less energetic and fast capture and leakage are smaller.
The resulting net correction factor is 1.0071 ± .0013.

3.3.1 Recalibration of MnSO$_4$ Bath

On 17 July 1986, the NBS MnSO$_4$ bath was officially placed back into
operation, following extensive modifications in the radiation shielding
and external source handling capabilities. Because of reduced
background at the ^{56}Mn counters, the operation point of the system was
changed to decrease slightly (0.15%) the dependence of counting rate on
gain shift. This resulted in a new operating point; i.e., a new value
of counts per second of NBS-I on the "MAIN" counter. To recalibrate the
system, the source SR-Cf-144, previously involved in the international
comparison counting, (see Section 4.3) was remeasured, and the results
were as follows:

1) Date of Recalibration of SR-Cf-144: 17 JULY 1986 (198th day)

2) $S = \dfrac{(749.32 \pm 0.2\%)}{(178.34 \pm 0.3\%)} \cdot (1.0071 \pm 0.0013) \, (1.2434 \times 10^6 \pm 0.85\%)$

   $S = 5.261 \times 10^6 \pm 0.93\%$, at a 68% confidence level

This is to be compared to a decay-corrected source strength of 5.240 x
10^6 n/s on 17 July 1986 based upon the 20 February 1983 value of (1.270
± 0.012)x10^7 n/s .

3) Comparison: 5.261/5.240 = 1.0040

4. OVERALL UNCERTAINTY OF A SOURCE STRENGTH MEASUREMENT

It is instructive to bring the various aspects of the source-strength
calibration procedure together in an example to see how the final
uncertainty is derived. One interesting example is that for a
singly-encapsulated ^{252}Cf source fabricated at ORNL and used for a

variety of measurements at NBS in the years 1976 - 1984. This source is identified as NS-100. The uncertainty estimated for the Cf-252 source NS-100 is ±1.1% (1σ). The uncertainty is derived as follows.

4.1 Recapitulation of Uncertainty Components

NS-100 was calibrated by comparing its strength to that of NBS-I. The emission rate of NBS-I was at that time 1.245×10^6 neutron/second with an estimated uncertainty of ±0.85%.

There are four fractional uncertainty components which make up a ±0.63% uncertainty attributed to the $MnSO_4$ bath measurements of Cf source NS-100 relative to NBS-I. These uncertainties have been observed to be somewhat larger than would be predicted by statistics alone. Although gross counting statistics are usually <0.1%, there are three factors which control the limits of uncertainty:

1) for low counting rates (e.g., NBS-I counts 178.3 cps on the more sensitive crystal), a time variable background of a few counts per second limits reproducibility to ±0.3%;

2) for high counting rates (> 3000 cps), electronic gain instabilities limit reproducibility to about ±0.35%;

3) for strong sources like NS-100 (>10^8 neutrons/second), the less sensitive crystal is used thereby introducing the additional multiplicative factor of 70 with a ±0.4% uncertainty.

Finally, there is an additional ±0.13% uncertainty on the corrections for leakage and absorption (see Table 5). These four components, taken in quadrature, yield the ±0.63% uncertainty mentioned above.

Therefore, the resultant uncertainty of the ^{252}Cf source NS-100 is the quadrature sum of 0.85% and 0.63% or 1.06%. Table 7 summarizes these uncertainties.

4.2 Uncertainty Estimate in Light of Reported Measurements and the ^{252}Cf Half Life

It is worth noting that five determinations of the NS-100 source strength have been made at NBS in the period 15 May 1979 to 26 July 1984. These measurements when fitted to Y = A exp(-Bt) for ^{252}Cf decay give a weighted-fit uncertainty of ±0.5% which is consistent with an average half life of (2.645 ±0.007) years. The maximum-to-minimum ratio of the fitted and measured results is 1.0088. If this ratio is interpreted as an estimate of the two-sigma uncertainty interval, even the outer lying values are consistent with a 68% confidence level of ±0.5%.

Table 7. Summary of Uncertainties Associated with Californium
Neutron Source Strength Calibrations

Source Strength NBS-I	±0.85%	s *
Main-to-Remote Counter Response Ratio	±0.40%	s
Fast neutron capture by oxygen and sulfur for the Cf neutrons	±0.08%	s
Capture in Teflon for the Cf neutrons	±0.06%	s
Leakage of Cf neutrons	±0.01%	s
Cf Source absorption of thermal neutrons	±0.03%	s
Counting imprecision (Cf source) caused by gain drift	±0.35%	r
Counting imprecision for NBS-I which is dominated by time variability of the background	±0.30%	r
Capture and leakage for NBS-I	±0.08%	s

Combined uncertainties (in quadrature) =   ±1.06%   (68% confidence)

* r = random
  s = non-random

4.3 International Intercomparison of Neutron Source Strength Measurements

A previous intercomparison of neutron source emission rates was based on measurements of a Ra-Be(α,n) source. The source was circulated to eleven laboratories between 1959 and 1965, and the results were published by V. Naggiar in 1966 (14). The results showed a total spread of 3.7%, and the reported uncertainties varied from ± 0.9% to ± 3.0%. Over the following decade significant improvements in the accuracy of neutron source measurements were achieved. It was therefore decided that a new intercomparison should be arranged. After some discussion of various types of sources, a ^{252}Cf source was chosen as being the most suitable. The source could be made small, the neutron spectrum is such that corrections for fast neutron losses would be small, and the low gamma-ray emission allows for easy transportation around the world.

The intercomparison, begun in 1977, was concluded in 1986. E. J. Axton, NPL, has written a report to be published soon in Metrologia (Ref. 10). Figure 5 is an Axton summary of results from that intercomparison. Table 8 compares the NBS result to the world average.

Before considering Table 8, some discussion of how the data were selected is necessary. The evaluation in Table 8 considers only the data from Ref. 10 that relate to measurements of neutron source SR-Cf-144 by different laboratories which use the $MnSO_4$ technique. Fig. 5 is taken from Ref. 10 and shows 21 data points representing measurements from 14 laboratories. Only the 17 data points below which the symbol "Mn" appears use $MnSO_4$. Note that PTB is, therefore, not included in Table 8. Of the 17 laboratories activating $MnSO_4$, only 10 measured the same (SR-Cf-144) neutron source. However, the ASMW result

was assumed to be biased and was also excluded.

Of the remaining results, multiple data points from any laboratory were averaged to yield the values listed in Table 8. The NBS results were treated somewhat differently, however, because the very first NBS data point on Fig. 9 represents NBS measurements made in 1978 prior to circulation of the source. The later three NBS values, which are 1983 measurements, were averaged (see footnote 1 to Table 8) to produce the second NBS result in Table 8.

4.3.1 Further Discussion

Comments are necessary on two items related to Table 8. First, the reported total uncertainties on the NBS values are larger, in most cases by factors of 2 or 3, than uncertainties reported by other laboratories. As indicated by the last footnote to Table 8, this is due to the ±0.85% uncertainty assigned to NBS-I. If one extracts 0.85% in quadrature from the NBS uncertainties, what remains is about ±0.4% uncertainty indicating that the precision of the NBS calibrations is essentially the same as other laboratories. The issue here is that the NBS results are dependent upon calibrations of NBS-I that are about 20 years old. This could be changed by recalibration of NBS-I; but to be worthwhile, the effort should reduce the uncertainty on NBS-I by a factor of 3 or more and that will require substantial effort. Periodic reviews of the situation fail to justifiy this recalibration.

Second, the total uncertainty on the measurement of the SR-Cf-144 source strength are smaller than the ±1.1% typically reported for customer's sources. This is a result of: (1) smaller uncertainties on corrections for structural effects and isotopic composition, because the source due to its intended international exposure was carefully selected for known characteristics; and (2) because the source strength selected for convenience of shipping could be calibrated at NBS, both in 1978 and 1983, without the need for the remote counter assembly, and therefore, the uncertainty is also free of the uncertainty on the ratio factor.

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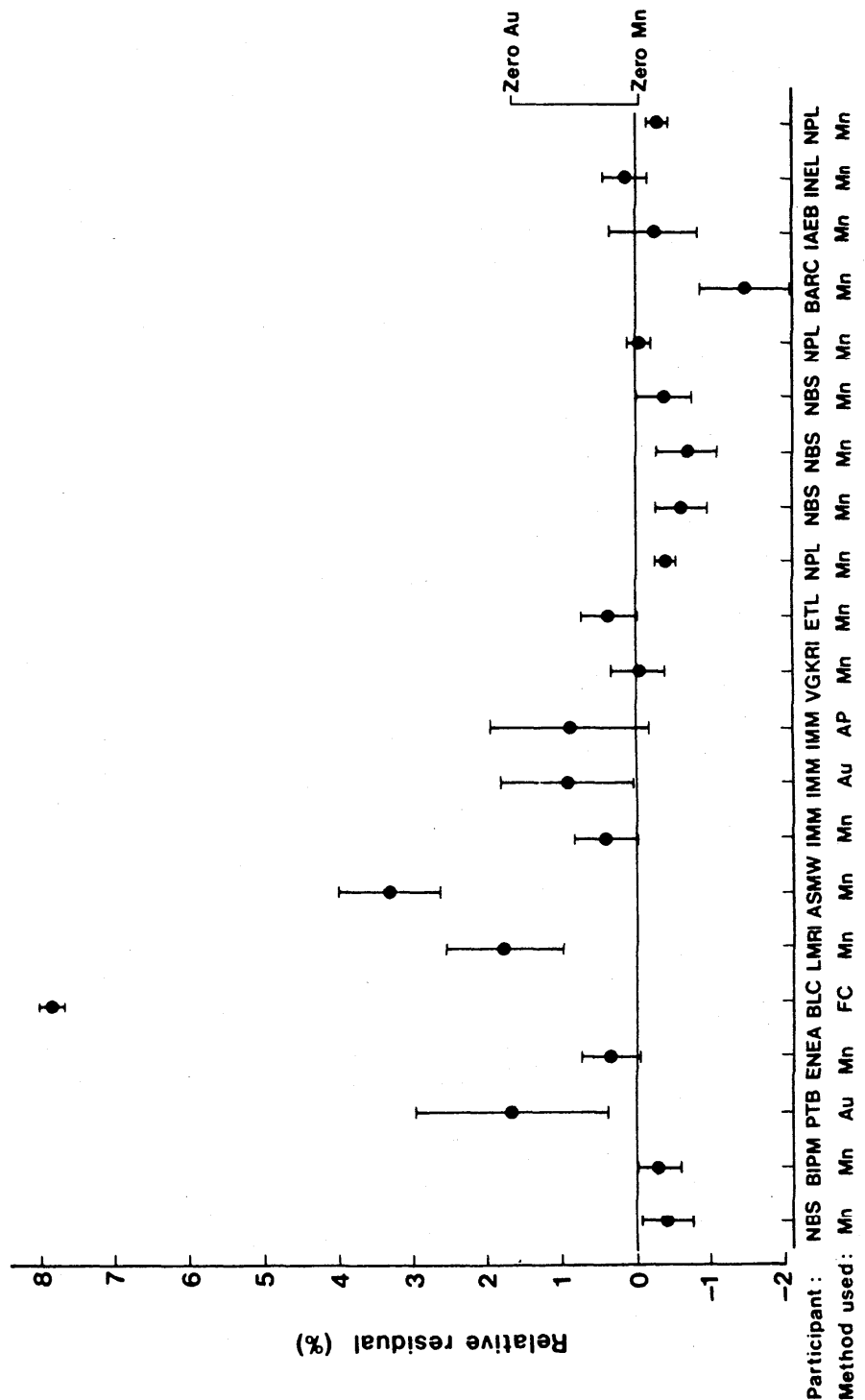
Fig. 5. Residuals obtained from least-squares fit to data as submitted by participant. BLC and ASMW were excluded from the fit, which determines the zero of the scale. Error bars represent the uncorrelated component of the uncertainties estimated by the participants. 'Zero Au' and 'zero Mn' are the respective positions of the zeros obtained when only water-bath or only Mn-bath measurements, are included.

Table 8. A Review of the Most Recent International Source Strength
Inter-Comparison (see Ref. 10).

		Result (x10⁷n/s)	Uncertainties (in percent) (at a 68% confidence level)
1	NBS (1978)	2.09557	0.945
2	BIPM	2.09814	0.322
3	ENEA	2.11161	0.404
4	LMRI	2.14190**	0.791
5	IMM	2.11347	0.423
6	VGK	2.10430	0.366
7	ETL	2.11225	0.379
8	NPL	2.09653	0.292
9	NBS* (1983)	2.09277***	0.952****

Footnotes:

*NBS (1983) value: (see Ref. 10 and 12)

2.09154 x 10⁷ n/s	0.944%
2.09016 "	0.960%
2.09662 "	0.952%

Average = 2.09277±0.00278
           (i.e., reproducibility is ±0.13%).

This average value is for an arbitrary date used in Ref. 10. When
corrected for ^{252}Cf decay, it corresponds to the source strength of
5.24 x 10⁶ n/s on 7/17/86 as referred to in Sect. 3.3.1.

**Examination of above tabulated results (x10⁷n/s)

Unweighted Average = (all values) 2.10745±0.01529 (σ_x)
                                  (±0.725%)

Unweighted Average = (excluding 2.14239) 2.10308±0.00842 (σ_x)
                                         (±0.400%)

***Comparison of world average with NBS 1978 and 1983 values

$$\frac{2.10308}{2.09277} = 1.00493 \quad \text{while} \quad \frac{2.10308}{2.09557} = 1.00349$$

****Uncertainty on NBS results versus other values

The uncertainty of the NBS measurements is due mainly to the ±0.85%
uncertainty in the value of the NBS-I, radium-beryllium, reference
source. See discussion in Section 1.2.1.

5. OPERATIONAL DESCRIPTION OF FACILITY

The manganese sulfate bath method of neutron source calibration at the NBS involves mechanical manipulations necessary to position either NBS-I or an unknown source into the bath for measurements, electronics operations necessary to obtain a comparison of the ^{56}Mn counting rates, and finally a complete description of data analyses from which a final neutron source strength is derived. The following operations begin when the source has been in the bath long enough for the ^{56}Mn to reach equilibrium. The discussion of methods will start with electronics operations.

5.1 Counting the ^{56}Mn Gamma Rays

Electronics for the main and remote crystal are identical. The following paragraphs describe the components and the settings used in normal operations.

5.1.1 Scintillators and Photomultiplier Tubes

The photomultiplier tubes are Bicron-selected 8542s and require about 1000 volts positive voltage. The scintillator and photomultiplier are in a factory-sealed container. The high voltage is supplied by a single HV unit with dual output. The dials on the high voltage unit should be set so that the meter shows 1.11 kV.

5.1.2 Preamplifiers

The preamps are ORTEC Model 113s and are set at 200 picofarad input capacitance. They feed negative input pulses less than one microsecond wide to two amplifier channels.

5.1.3 Linear Amplifiers

The amplifiers are ORTEC 485s which have been modified to have 0.25 microsecond time constants. The gains are set at about 8 coarse and 6 fine gain so that the desired ^{56}Mn peak (846.9 keV) is in channel 316 and a ^{137}Cs peak (662 keV)is in channel 247, of 512 channels. The positive unipolar output pulses are about 1.5 microseconds wide and all the negative undershoot pulses are restored to the baseline by about 3.2 microseconds.

5.1.4 Discriminators

The amplifiers are fed to constant-dead-time discriminators, built at NBS, with settings as follows: Input offset is OFF. The 2-20 microsecond dead-time scale is set at about 90 so that the dead-time output pulse is 3.4 microseconds wide on the scope screen and results in a total dead time of 3.5 microseconds. The outputs are labelled as "Dead Time Count Output". The discriminator output pulse of 0.5 microseconds width is routed to the scalers. The discriminators are set to match channel 37, which corresponds to a gamma-ray energy of about 100 keV.

5.1.5 Scalers

All scalars are contained in a single Tennelec module, which is a timer and triple scalar. The scalar channels are A,B and C. A & B are the main readout, with A being the most-significant-digit overflow from B. C is for the remote output.

5.1.6 Printout Modules

Printout is controlled by a Tennelec 588 Printout Control. See Appendix D on Interconnection of Electronics for more details on output to a microcomputer.

5.2 Response Ratio of Counters and System Dead Time

Weaker sources between 5×10^5 to 2×10^6 n/s are counted with the main crystal and larger sources with the remote crystal. The main-to-remote crystal counting ratio is dependent upon the dead time of the system. This dead time is non-extendable. That is, amplifier pulses shaped to have shorter time durations than the set discriminator time interval, and which appear during the set (or fixed) dead time, do not lengthen the set time interval.

The main-to-remote crystal counting ratio is determined by observing the counting-rate ratio of the two counters for a source strength of about 5×10^8 n/s. The counting rates are corrected for a fixed dead-time of 3.4 microseconds plus 0.1 microseconds for electronics later in the chain.

The system response for other counting rates, higher and lower, is checked by observing the decay of ^{56}Mn with a half-life of 154.71 minutes. This is accomplished by allowing a source of appropriate strength to reach equilibrium in the bath and then cutting off the flow to the counters and observing the exponential decay.

5.3 The U.S. National Standard Source Strength, NBS-I

A Ra-Be (γ,n) source was selected as the standard because of its 1600 year half life. For comparison, Ra-Be (α,n) sources do not have such simple time histories since their strength depends upon other factors than the amounts of radium and beryllium present (8). A Ra-Be (α,n) source has an initial growth of about 0.5 percent per year. In brief, the NBS Standard Ra-Be (γ,n) source, NBS-I, consists of a beryllium sphere, 4 cm in diameter, at the center of which a one curie capsule of RaBr$_2$ is placed (see Figure 1). As only gamma rays can enter the beryllium, the neutron source strength is governed by the known exponential decrease of Ra-226.

Two nearly identical radium-beryllium photo-neutron sources have been constructed to serve as standards for the Bureau. The radium in both sources was initially enclosed in platinum-iridium capsules of 0.2 mm wall thickness. One capsule developed a leak and was subsequently

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enclosed in Monel of 1-mm thickness (9). The source having the original capsule (NBS-I) has been chosen as the primary standard for the absolute calibration. It has had an aluminum protective jacket placed around it. The other source is known as NBS-II. The source strength ratio of the two sources is 0.94±0.01.

6. DATA TAKING AND ANALYSIS

The radioactivity of the ^{56}Mn is sampled at saturation by a continuous flow system at a location outside of the primary radiation shielding for the MnSO$_4$ bath. There are two sodium-iodide scintillation counters at this remote location. One, identified as the "main" counter is a 2" x 2" crystal mounted crystal-end down in a Marinelli metal beaker through which the MnSO$_4$ solution is pumped. This beaker is positioned inside of a lead cave. Attached tightly to the beaker by two large "hose" clamps is a pipe which contains a second scintillation crystal, also 2" x 2", positioned on its side at the end of the pipe. This second or "remote" counter is held in the pipe by an adjustable positioning mechanism so that the ratio of the counting rate in the two crystals can be varied by about 30%. Nominally the present ratio between them is 70. The remote crystal is also surrounded by lead.

6.1 Data Collection

The counting data are accumulated in scalars connected to permit accumulation of up to 10^8 counts. The counters are connected together with a time and date clock, and interval timer, to a read out mechanism connected by an RS-232 line to a Professional 350 (PRO-350) DEC computer. This electronics is on an uninterruptable power supply which, in event of a power failure, will keep the system in operation long enough to record the fact that a power failure occured and record the current data.

The RS-232 interface is operated in the File Transfer Mode of the normal DEC operating system during data collection. Functionally, this means that from the Main Menu of the PRO-350, the File Transfer is selected and a name is assigned by the user to an ASCII file. The PRO-350 then waits until the counter electronics sends data and then the PRO-350 places it in the file and returns to the waiting state for further data. The process can be terminated at any time by the user. The data file may be viewed with the normal File Services routines of the PRO-350 or it may be printed by the normal Print Services routines.

6.1.1 Data Collection Monitoring

The essential task of data monitoring is that of assuring that the gain of the data collection channel does not change. To monitor this gain, the signal from the channel (i.e., main or remote) is sent to a multichannel analyzer. The characteristic spectrum of the voltage pulse height distribution from the output of the linear amplifier (which is also fed to one of the discriminators) is a distribution of pulses from about 50 keV, the typical noise level, to about 1.2 MeV. The peak from the ^{56}Mn activity is at 846.9 keV. Section 5.1.4 gives

the details for setting the electronics and the discriminator. The position of the ^{56}Mn peak is periodically checked by the operator and manual adjustments to the amplifier gain are made as necessary. After acquiring some experience with the system, gain is controllable to about ±0.3% depending somewhat upon the counting rate. The effect of gain setting on the average of two measurements taken at two different times has an estimated uncertainty of ± 0.35%.

6.2 Data Analyses

The analysis of the counting data normally takes place in two separate operations. The first is analysis of the raw data to obtain a best average value of the ^{56}Mn count rate for a specific set of data. These data are corrected for resolving time loss primarily in the 3.5 microsecond fixed-dead time discriminators, source decay during data acquisition (when necessary), and background. The latter is taken after a source has been placed into the bath but before the flow to the counters is turned on. This is convenient because it requires about 25 hours for the ^{56}Mn activity level to reach saturation. Also note that, if a source with a strength of greater than 8 x 10^7 n/s has been in the bath recently, the background will be a function of time (primarily because of 14.29-day ^{32}P created by the ^{32}S(n,p) reaction). This means background measurements must be taken before and after the source measurement.

Also note that normally there are periods of several weeks between source measurements. Therefore, in addition to taking data for the source which is to be calibrated, the bath must be re-calibrated against NBS-I, for which background measurements are very important. Currently, the background is nominally 1.8% of the count rate for NBS-I.

6.2.1 Fortran Analysis Code: General Concepts

This first part of the data analyses is accomplished using FORTRAN code ANALYZE.FTN (see Appendix B for listing and example output). The code performs the following operations:

1) The code derives an "uncorrected" average value of the individual results for the preset counting-time interval. The uncorrected notation means not corrected for background.

2) From this average, the code determines what the uncertainty would be if it were based solely on Poisson statistics of the number of counts. This is the "expected standard deviation." The code then finds the observed square root of the variance about the mean value. This is the "observed standard deviation" about the mean.

3) The program provides the background corrected mean and the count rate in counts per second.

4) From the larger of the above-mentioned uncertainties and the number of observations, the code determines the uncertainty of the mean count rate.

5) The code lists the system dead-time (or counting loss) correction, and the background rate.

6) The code gives the fraction of observed counts which lie outside of both one sigma and three sigma of the mean.

7) If desired, the code will recompute a revised average and a revised standard deviation by eliminating all observations outside of three sigma. This option is primarily for use when there is trouble with the system. For example, suppose source measurement were accomplished over a weekend and in the last few hours one of the channels, say a scaler, failed. It is easy to eliminate the bad data using this option.

8) The code computes the main-to-remote counter ratio. Also as a matter of convenience, the code computes the ratio of both the main and remote count rates to an input best-estimate of the current count rate of NBS-I. Note, one does not always know the precise value for NBS-I at the time of data processing so these latter ratios are for a quick reference only.

6.2.2 Some Limitations of the Analysis Code

1) All counting time intervals must be the same. The counting time interval is assumed to be in multiples of tenths of a second and must be the first output parameter for each observation. The code computes the counting time interval as DELTA = C(1)/10.0.

2) The same FORTRAN program is used to process background measurements as well as source strength calibration data. It asks whether or not the data to be processed refer to a background measurement. If the answer is yes, the code uses the same algorithm but assumes a negligibly small "background" to be subtracted from the measured background data.

3) The user must input the dead-time in microseconds. This is the value set on the fixed dead-time discriminators. There is currently only one value for this in the code so the fixed dead times in both counting channels must be set the same.

4) The uncertainty of the mean is more complicated than alluded to above. After deciding on the larger of the Poissonian and observed deviations, the value is divided by the square root of the number of observations. This is then added in quadrature to 0.15% to form a quantity called TEMP. The 0.15% reflects the current uncertainty associated with gain instabilities.

5) Finally, the following are computed:

$$TN = (TEMP/100)*(mean\ count\ rate)$$
$$TB = 0.06*(mean\ background\ rate)$$
$$ERR = SQRT\ (TN^2 + TB^2)$$

where: TN is the absolute, as opposed to relative, uncertainty on the
average counting rate; TB is the uncertainty on a variable background,
and is taken to be 6% of the instantaneously observed background (see
discussion below); ERR is the quantity printed out as the uncertainty
of the mean counting rate.

Although counting statistics on a long background determination (3 to 4
counts per second) may be considerably less than 6% (say 0.3%), there
is frequently ^{32}P activity in the bath from the $^{32}S(n,p)^{32}P$ reaction.
During a one-day determination of background, there will be a decay of
5%. On the other hand, short-term counting of background yields
nominally 1.5% statistics, if there are no gain shifts or sources moved
in the vicinity of the equipment. Consequently, if 6% is conserative,
it is not so by more than a factor of two and this would translate to
about 0.15% uncertain in the source strength determination.

6.3 Photoproduction

De Volpi (11) performed an experiment in his $MnSO_4$ bath with a radium
bromide pellet of about one curie (without a beryllium shell). First,
to check the shielding of his continuous flow counter, he placed the
pellet into the bath but did not turn the flow on. Basically there was
not an increase at the counter. Next he placed the radium bromide
pellet in the bath, turned the flow on and observed an apparent neutron
yield of 3.0×10^4 n/sec. Finally, he placed the pellet in a thick
beryllium shell and this, in turn, into the bath and measured 1.16×10^6 neutrons/second. Therefore, without the beryllium shell he had
seen a $(2.6 \pm 0.1\%)$ response. De Volpi asserts that very little of
that observed signal can be from photoneutrons from the deuterium
component of the bath or from structural materials. However, he
asserts that some may be due to (α,n) reactions from radium α's on the
two bromine isotopes in the pellet.

Since NBS-I (and II) both contain radium bromide $(RaBr_2)$, we must
consider what effect all this has on our calibration procedure. NBS-I
was calibrated, at least once, against a Sb-Be(γ,n) source and whether
the neutrons come from (α,n) reactions on beryllium or (α,n) reactions
on bromine only matters when it is necessary to know something about
the neutron energy spectrum from NBS-I. The (α,n) neutrons will be of
higher energy so the leakage from the bath could be larger. However,
since the fraction of these is already small, the effect is assumed to
be negligible.

The conclusion from these attempts to measure photoproduction is that
no correction for photofission or the (α,n) neutrons is necessary for
the NBS procedures.

7. IMPROVEMENTS IN OPERATIONS BECAUSE OF BETTER NEUTRON AND GAMMA-RAY SHIELDING

Two areas of improvement have resulted from the installation of better neutron and gamma shielding. Previously, scintillation counters could be activated by exposure to neutrons. The background of the 5 cm x 5 cm cylindrical NaI crystal is nominally 3 counts per second. Activation by the source increased this by a factor of four. There are two distinct components to the decay: that of 25 minute iodine-128 and that associated with 15 hour sodium-24. In roughly four hours after exposure, the background activity was reduced to about 30% more than normal. This residual then decayed with the 15 hour half-life. The improved shielding appears to have eliminated this crystal activation problem for neutron sources up to about 10^9 n/second.

The second area of improvement is that associated with gamma background from a neutron source in the bath or the handling of NBS-I which contains one gram of radium. To first establish a basis for what could be attained, measurements of background with four different size sodium iodide crystals were made in a low-background, lead-shielded environment. See Table 9.

TABLE 9

Data to Establish A Realistic But Low Level Background for Sodium Scintillation Counts at NBS $MnSO_4$ Bath

Crystal Dimension (inches)	Relative volume	Observed background (counts/s)	Ratio background per volume	Predicted background[1] (counts/s)	Ratio observed to predicted
1x1	1	0.39	0.39	0.26	1.50
1 1/2 x 1 1/2	3.38	1.04	0.31	0.87	1.20
2x2	8	2.4	0.30	2.06	1.17
4x4	64	16.5	0.25	16.5	1.0

For comparison before the recent improvements in shielding, and with NBS-I in the bath (but with no flow to the counters) and no other sources in the room, the 1 1/2" x 1 1/2" crystal had a background of about 5 cps and the 2" x 2" crystal about 11 cps. Subsequent to the new shielding, the backgrounds in the 2" x 2" crystals (now in use) are in the vicinity of 3.7 cps. This is a factor of three improvement although the background is still 50% above that of a radiation free area. The significance in the improvement, however, is seen from the fact that previously the background-to-signal ratio was 11/148 = 0.074. Now that ratio is 3.7/148 = 0.025, that is, only 2.5% of the response to NBS-I is background. It takes less effort now to accurately establish counter background when sources are in the bath.

---

[1]Based on high-quality, well-shielded 4x4 crystal background of 16.5 cps and reductions per relative volume.

8. SAFETY

The calibration of neutron sources involves several different safety aspects:

1) The radiation safety aspect emphasizes minimization of personnel exposure. Because there are no hot cells at NBS, the magnitude of neutron source strengths that can be safely handled is limited to 10^{10} n/s, or less. This means that many hours of close proximity exposure would be necessary to produce a lethal dose of radiation. Consequently, emphasis is upon as small an exposure as practical.

2) The other aspects are safe handling of neutron sources to prevent any damage and industrial safety practices when handling heavy shielding materials, shipping casks, and the removable parts of shipping containers.

With regard to radiation safety, NRC and NBS regulations require that all personnel handling neutron sources be given a radiation safety and awareness training course. This training is essentially the same as that required by the NBS reactor. Therefore, the training requirement for neutron source handling is satisified every two years by attendance at the Reactor Health Physics course.

Safe handling of neutron sources and the industrial safety aspects are taught through an apprentice-type relationship with each new handler.

All neutron-source transfer operations at NBS are accomplished by trained professionals with the cognizance of, and frequently with the help of, Health Physics personnel. Temporary, in-transit, source storage is accomplished with moveable water tanks and shielding barrels. Procedures are reviewed prior to each handling operation. Each participant must wear an albedo-type neutron dosimetry badge, a gamma badge, and pocket dosimeter. The latter serves as a device for periodically estimating doses during an operation. Frequently, in those situations where sources are to be removed from a unfamiliar surrounding, or for in-air source transfers, audiable-signal dosimeters are also used.

9. REFERENCES

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APPENDIX A - Output from the Mn-56 Data Processing Code and Example Test
Report

<div align="center">

FILENAME IS ED1.LOG
****

THE RAW COUNTING DATA WERE (time is in seconds):

</div>

1	40.	0.	187627.	101136.		92.	11. 4.48.
2	40.	0.	187429.	100295.	—	92.	11. 5.28.
3	40.	0.	187554.	100835.		92.	11. 6. 8.
4	40.	0.	183841.	98798.		92.	11. 6.48.
5	40.	0.	182512.	98406.		92.	11. 7.28.
6	40.	0.	187830.	100472.		92.	11. 8. 8.
7	40.	0.	187480.	99762.		92.	11. 8.48.

NUMBER OF COUNTS=   7

THE EXPERIMENT WAS STARTED ON APRIL   2, 1986

MAIN COUNTER RESULTS
****

The uncorrected mean of all the data is	189413.172
Its expected standard deviation (in %) is	0.230
Its observed standard deviation (in %) is	1.194
The corrected mean is	189403.172
In COUNTS PER SECOND it is	4735.079
The uncertainty on the mean (in %) is	0.476
System dead time in microseconds was	3.500
The percent counting-loss correction was	1.685
The background (in cps) was	10.000
The percent of background in the net count was	0.005
The fraction of counts outside of one std. dev. was	1.000
The fraction of counts outside of 3 std. dev. was	0.571

X	SW
190758.77	3.09
190554.09	2.62
190683.30	2.92
186846.64	-5.90
185473.99	-9.05
190968.59	3.57
190606.81	2.74

Revised average excluding counts outside 3 sigma is	190614.750
Its revised standard deviation (in %) is	0.034

REMOTE COUNTER RESULTS
****

The uncorrected mean of all the data is	100839.766
Its expected standard deviation (in %) is	0.315
Its observed standard deviation (in %) is	1.036
The corrected mean is	100834.266
In COUNTS PER SECOND it is	2520.857
The uncertainty on the mean (in %) is	0.420
System dead time in microseconds was	3.500
The percent counting-loss correction was	0.890
The background (in cps) was	5.500
The percent of background in the net count was	0.005
The fraction of counts outside of one std. dev. was	0.857
The fraction of counts outside of 3 std. dev. was	0.429

X	SW
102038.98	3.78
101182.96	1.08
101732.59	2.81
99659.54	-3.72
99260.69	-4.97
101363.12	1.65
100640.51	-0.63

Revised average excluding counts outside 3 sigma is	101229.797
Its revised standard deviation (in %) is	0.449
RATIO OF MAIN/REMOTE counter response	1.878
Reference value for NBS-I was	148.200
Main-to-NBS-I ratio is	31.951
Remote-to-NBS-I ratio is	17.010

<div align="center">

A1

</div>

REPORT OF CALIBRATION

Test No. 536-98765-4   Date: 13 May 1985

SUBMITTED BY: ABCDE Corporation

FOR: John P. Doe
      9999 S. South Avenue
      Anywhere, US 66666

DESCRIPTION OF NEUTRON SOURCE:

Nominally a 50 microgram Cf-252 source.
Assumed source encapsulation equivalent to source
NBS-108. Isotopic composition as follows:

Cf-250	12.750%
Cf-252	77.410%
Cf-254	0.001%

CALIBRATION: The source described above has been calibrated by
comparing its strength to that of the NBS primary Ra-Be photoneutron
standard source, "NBS-1." The neutron emission rate of the submitted
source was found to be 1.088×10^8 neutrons/sec. The error is
estimated as 1.3% standard error. September 16, 1984 is the reference
calibration date.

EXPERIMENTAL METHOD: The comparison of source strengths was made by
activating a manganese sulfate bath and continuously counting the
induced, saturated manganese-56 activity with a scintillatin counter.
The source was located at the center of a 1.2 m diameter spherical bath
in a small teflon cavity. The bath was circulated to the scintillation
counter, which was located in a shielded, stainless-steel beaker. The
following corrections have been applied: 0.63% for fast neutron
capture by oxygen and sulfur in the bath, 0.13% for neutron capture by
fluorine in the teflon source holder, 0.05% for escape from the bath,
and 0.29% for thermal neutron absorption in the source. The
calibration data is recored on 259 in data book No. 15. The present
emission rate of NBS-1, which is absolutely determined, is 1.245×10^6
neutrons/second with an assigned uncertainty of ± 0.85%.

This calibration was performed by

_____   For the Director:

                                        _____
                                        Chief, Ionizing Radiation Division

Ionizing Radiation Division   A2

PROGRAM ANALYZE.FTN

```
         CHARACTER AN1,AN2,AN3,AN4,AN5,INFILE*12,OUFILE*12,MONTH*9
         REAL C(8),CMAIN(100),CREMOT(100),NB,DTIME(100),SECOND(100)
         REAL X(100),LAMBDA,SW(100),TX(100),COUT(2),NBS1,RNBS(2)
         INTEGER DAY,YEAR,PASS

         WRITE (5,*) 'What is the name of the input file?'
         READ (6,'(A)') INFILE
         WRITE (5,*) 'What is the name of the output file?'
         READ (6,'(A)') OUFILE
         OPEN(UNIT=3,FILE=INFILE,STATUS='OLD')
         OPEN(UNIT=4,FILE=OUFILE,STATUS='NEW')

         WRITE(4,1000) INFILE
1000     FORMAT(47X,'FILENAME IS ',12A)
         WRITE(4,1001)
1001     FORMAT(45X,'*****************************')
         WRITE(4,1002)
1002     FORMAT(17X,'THE RAW COUNTING DATA WERE (time is in seconds):')
         WRITE(4,*)
         WRITE(4,*)

         NO=0
         READ(3,*)
         READ(3,1003)
1003     FORMAT(18X)
10       READ (3,1004,END=20) (C(I),I=1,8)
1004     FORMAT(4(F7.0,3X),F6.0,3X,3F2.0)
         NO= NO + 1
         WRITE(4,1005) NO,C(1)/10.,(C(I),I=2,8)
1005     FORMAT(11X,I3,5X,F7.0,4X,F2.0,4X,F8.0,4X,F8.0,4X,F4.0,4X,3F3.0)
         CMAIN(NO)=C(3) + C(2) * 1.0E07
         CREMOT(NO)=C(4)
         IF (NO .EQ. 1) THEN
            DAY= ININT(C(5))
            DELTAT=C(1)/10.
         END IF
         SECOND(NO)=C(8) + 3600. * C(6) + 60. * C(7)
         GO TO 10
20       WRITE(4,*)
         WRITE(4,*)
         WRITE(4,1006) NO
1006     FORMAT(22X,'NUMBER OF COUNTS= ',I4)

         WRITE(5,*) 'Is this a Cf-252 source (Y or N)?'
         READ(6,'(A)') AN1
         IF (AN1 .EQ. 'Y') THEN
            CF2=1.
         ELSE
            CF2=0.
         END IF
         WRITE(5,*) 'Is this a saturation measurement of NBS-1 (Y or N)?'
```

```
      READ (6,'(A)') AN2
      IF (AN2 .EQ. 'Y') THEN
        NB=1.
      ELSE
        NB=0.
      END IF
      WRITE(5,*) 'What is the current value of NBS-I in CPS?'
      READ(6,*) NBS1
      WRITE(5,*) 'Input the deadtime in microseconds:'
      READ(6,*) TAU
      TAU= TAU * 1.0E-6
      WRITE(5,*) 'What is the current year?'
      READ(6,*) YEAR
      CALL CHANGE(DAY,MONTH,IDAY,YEAR)
      WRITE(4,*)
      WRITE(4,1007) MONTH,IDAY,YEAR
1007  FORMAT(22X,'THE EXPERIMENT WAS STARTED ON ',A9,1X,I2,', ',I4)

      TINC=0.
      DO 30 I=1,NO
        IF (I .EQ. 1) THEN
          DTIME(I)= 0.
        ELSE
          IF (SECOND(I) .LT. SECOND(I-1)) TINC= TINC + 86400.
          DTIME(I)= SECOND(I) + TINC - SECOND(1)
        END IF
30    CONTINUE

      DO 90 PASS=1,2
        WRITE(5,*) 'Is this a background measurement (Y or N)?'
        READ(6,'(A)') AN3
        IF (AN3 .EQ. 'Y') THEN
          IF (PASS .EQ. 1) THEN
            BKG= 0.003
          ELSE
            BKG= 0.001
          ENDIF
        ELSE
          WRITE(5,*) 'Input the background in ''CPS'':'
          READ(6,*) BKG
        END IF

        DO 40 I=1,NO
          IF (PASS .EQ. 1) THEN
            X(I)= CMAIN(I)
          ELSE
            X(I)= CREMOT(I)
          END IF
40      CONTINUE
```

```
         BAK= BKG * DELTAT
         DTZ= TAU / DELTAT
         DO 50 I=1,NO
           X(I)= X(I) / (1 - X(I) * DTZ)
50       CONTINUE

         LAMBDA= ALOG(2.) / (2.645 * 365.25 * 8.64E4)
         IF (CF2 .EQ. 1) THEN
           DO 60 I=1,NO
             X(I)= X(I) - BAK
             X(I) = X(I) * EXP(LAMBDA * DTIME(I))
             X(I) = X(I) + BAK
60         CONTINUE
         END IF

         CALL ECALC(NO,X,AVE,SIG,STD)
         NX= 1
         CALL OTSIDE(NO,NX,AVE,X,SW,TX,KOUT1,JT1)
         NX = 3
         CALL OTSIDE(NO,NX,AVE,X,SW,TX,KOUT3,JT3)

         CZERO= AVE / DELTAT
         CTLOSS= 100. * ((1. / (1. - CZERO * TAU)) - 1.)
         CAVE= AVE - BAK
         COUT(PASS)= CAVE
         CPS= CAVE / DELTAT
         RNBS(PASS)= CPS/NBS1
         FRACT1= KOUT1 / FLOAT(NO)
         FRACT3= KOUT3 / FLOAT(NO)

         IF (STD .GT. SIG) THEN
           EX=STD
         ELSE
           EX=SIG
         END IF
         TEMP= EX / SQRT(FLOAT(NO))
         TEMP= SQRT(TEMP ** 2 + 0.15 ** 2)
         TN= (TEMP / 100.) * CPS
         TB= 0.06 * BKG
         ERR= SQRT(TN ** 2 + TB ** 2)
         ERR= (ERR / CPS) * 100.
         PBKG= (BKG * 100.) / AVE

         WRITE(4,*)
         WRITE(5,*)
         WRITE(4,*)
         WRITE(5,*)
```

```
        IF (PASS .EQ. 1) THEN
           WRITE(4,1008)
           WRITE(4,1009)
           WRITE(5,1008)
           WRITE(5,1009)
        ELSE
           WRITE(4,1010)
           WRITE(4,1011)
           WRITE(5,1010)
           WRITE(5,1011)
        END IF


1008    FORMAT(22X,'MAIN COUNTER RESULTS')
1009    FORMAT(22X,'********************')
1010    FORMAT(22X,'REMOTE COUNTER RESULTS')
1011    FORMAT(22X,'**********************')

        WRITE(4,1012) AVE
        WRITE(4,1013) SIG
        WRITE(4,1014) STD
        WRITE(4,*)
        WRITE(4,1015) CAVE
        WRITE(4,1016) CPS
        WRITE(4,1017) ERR
        WRITE(4,1018) TAU * 1.0E6
        WRITE(4,1019) CTLOSS
        WRITE(4,1020) BKG
        WRITE(4,1021) PBKG
        WRITE(4,1022) FRACT1
        WRITE(4,1023) FRACT3

        WRITE(5,1012) AVE
        WRITE(5,1013) SIG
        WRITE(5,1014) STD
        WRITE(5,*)
        WRITE(5,1015) CAVE
        WRITE(5,1016) CPS
        WRITE(5,1017) ERR
        WRITE(5,1018) TAU * 1.0E6
        WRITE(5,1019) CTLOSS
        WRITE(5,1020) BKG
        WRITE(5,1021) PBKG
        WRITE(5,1022) FRACT1
        WRITE(5,1023) FRACT3
```

```
1012        FORMAT(12X,'The uncorrected mean of all the data is ',F25.3)
1013        FORMAT(12X,'Its expected standard deviation (in %) is ',F23.3)
1014        FORMAT(12X,'Its observed standard deviation (in %) is ',F23.3)
1015        FORMAT(12X,'The corrected mean is ',F43.3)
1016        FORMAT(12X,'In COUNTS PER SECOND it is ',F38.3)
1017        FORMAT(12X,'The uncertainty on the mean (in %) is ',F27.3)
1018        FORMAT(12X,'System dead time in microseconds was ',F28.3)
1019        FORMAT(12X,'The percent counting-loss correction was ',F24.3)
1020        FORMAT(12X,'The background (in cps) was ',F37.3)
1021        FORMAT(12X,'The percent of background in the net count was '
      &            ,F18.3)
1022        FORMAT(12X,'The fraction of counts outside of one std. dev. was '
      &            ,F13.3)
1023        FORMAT(12X,'The fraction of counts outside of 3 std. dev. was '
      &            ,F15.3)

            WRITE(5,*)
            WRITE(5,*)
            WRITE(5,*) 'Do you want a listing of the corrected counts and ',
      &               'their distribution'
            WRITE(5,*) 'relative to the average (Y or N)?'
            READ(6,'(A)') AN4
            IF (AN4 .EQ. 'Y') CALL PEXTRA(NO,X,SW)

            WRITE(5,*) 'Do you want a revised average of the data excluding'
            WRITE(5,*) 'points outside of 3 sigma (Y or N)?'
            READ(6,'(A)') AN5
            IF (AN5 .EQ. 'Y') THEN
              CALL ECALC(JT3,TX,AVE,SIG,STD)
              WRITE(4,*)
              WRITE(4,1024) AVE
              WRITE(4,1025) STD
1024        FORMAT(12X,'Revised average excluding counts outside 3 ',
      &               'sigma is ',F13.3)
1025        FORMAT(12X,'Its revised standard deviation (in %) is ',F24.3)

            END IF
90      CONTINUE

            WRITE(4,*)
            WRITE(4,1026) COUT(1) / COUT(2)
1026        FORMAT(12X,'RATIO OF MAIN/REMOTE counter response ',F27.3)
            WRITE(4,*)
            WRITE(4,1027) NBS1
            WRITE(4,1028) RNBS(1)
            WRITE(4,1029) RNBS(2)
1027        FORMAT(12X,'Reference value for NBS-I was ',F35.3)
1028        FORMAT(12X,'Main-to-NBS-I ratio is ',F42.3)
1029        FORMAT(12X,'Remote-to-NBS-I ratio is ',F40.3)
            END
```

```
      SUBROUTINE CHANGE(DAY,MONTH,IDAY,YEAR)
C DETERMINE MONTH AND DAY OF THE MONTH WHEN GIVEN THE DAY OF THE YEAR
      CHARACTER*9 MONTH
      INTEGER DAY,YEAR
      IF (DAY .LE. 31) THEN
        MONTH= 'JANUARY'
        IDAY= DAY
      END IF
      IF (IMOD(YEAR,4) .NE. 0) THEN
        IF (DAY .GT. 31 .AND. DAY .LE. 59) THEN
          MONTH= 'FEBRUARY'
          IDAY= DAY-31
        END IF
        IF (DAY .GT. 59 .AND. DAY .LE. 90) THEN
          MONTH= 'MARCH'
          IDAY= DAY-59
        END IF
        IF (DAY .GT. 90 .AND. DAY .LE. 120) THEN
          MONTH= 'APRIL'
          IDAY= DAY-90
        END IF
        IF (DAY .GT. 120 .AND. DAY .LE. 151) THEN
          MONTH= 'MAY'
          IDAY= DAY-120
        END IF
        IF (DAY .GT. 151 .AND. DAY .LE. 181) THEN
          MONTH= 'JUNE'
          IDAY= DAY-151
        END IF
        IF (DAY .GT. 181 .AND. DAY .LE. 212) THEN
          MONTH= 'JULY'
          IDAY= DAY-181
        END IF
        IF (DAY .GT. 212 .AND. DAY .LE. 243) THEN
          MONTH= 'AUGUST'
          IDAY= DAY-212
        END IF
        IF (DAY .GT. 243 .AND. DAY .LE. 273) THEN
          MONTH= 'SEPTEMBER'
          IDAY= DAY-243
        END IF
        IF (DAY .GT. 273 .AND. DAY .LE. 304) THEN
          MONTH= 'OCTOBER'
          IDAY= DAY-273
        END IF
        IF (DAY .GT. 304 .AND. DAY .LE. 334) THEN
          MONTH= 'NOVEMBER'
          IDAY= DAY-304
        END IF
        IF (DAY .GT. 334) THEN
          MONTH= 'DECEMBER'
          IDAY= DAY-334
        END IF
```

```
C LEAP YEAR
      ELSE
        IF (DAY .GT. 31 .AND. DAY .LE. 60) THEN
          MONTH= 'FEBRUARY'
          IDAY= DAY-31
        END IF
        IF (DAY .GT. 60 .AND. DAY .LE. 91) THEN
          MONTH= 'MARCH'
          IDAY= DAY-60
        END IF
        IF (DAY .GT. 91 .AND. DAY .LE. 121) THEN
          MONTH= 'APRIL'
          IDAY= DAY-91
        END IF
        IF (DAY .GT. 121 .AND. DAY .LE. 152) THEN
          MONTH= 'MAY'
          IDAY= DAY-121
        END IF
        IF (DAY .GT. 152 .AND. DAY .LE. 182) THEN
          MONTH= 'JUNE'
          IDAY= DAY-152
        END IF
        IF (DAY .GT. 182 .AND. DAY .LE. 213) THEN
          MONTH= 'JULY'
          IDAY= DAY-182
        END IF
        IF (DAY .GT. 213 .AND. DAY .LE. 244) THEN
          MONTH= 'AUGUST'
          IDAY= DAY-213
        END IF
        IF (DAY .GT. 244 .AND. DAY .LE. 274) THEN
          MONTH= 'SEPTEMBER'
          IDAY= DAY-244
        END IF
        IF (DAY .GT. 274 .AND. DAY .LE. 305) THEN
          MONTH= 'OCTOBER'
          IDAY= DAY-274
        END IF
        IF (DAY .GT. 305 .AND. DAY .LE. 335) THEN
          MONTH= 'NOVEMBER'
          IDAY= DAY-305
        END IF
        IF (DAY .GT. 335) THEN
          MONTH= 'DECEMBER'
          IDAY= DAY-335
        END IF
      END IF
      RETURN
      END
```

```
        SUBROUTINE ECALC(NO,X,AVE,SIG,STD)
        REAL X(100)
        SMW= 0.
        S= 0.
        AMT= FLOAT(NO) - 1
        DO 10 I=1,NO
          S= S + X(I)
10      CONTINUE
        AVE= S/FLOAT(NO)
        SIG= SQRT(AVE)
        DO 20 I=1,NO
          SMW= SMW + (X(I) - AVE) ** 2
20      CONTINUE
        STD= SQRT(SMW/AMT)
        SIG= (SIG / AVE) * 100.
        STD= (STD / AVE) * 100.
        RETURN
        END




        SUBROUTINE OTSIDE(N,NX,XBAR,X,SW,TX,KOUT,JT)
C DETERMINE HOW MANY X'S FALL OUTSIDE NX STANDARD DERIVATIVES OF THE MEAN
        REAL X(100),SW(100),TX(100)
        KOUT= 0
        JT= 0
        DO 10 I=1,N
          SW(I)= (X(I) - XBAR) / SQRT(XBAR)
          DIFF = ABS(SW(I))
          IF (DIFF .GT. NX) THEN
            KOUT= KOUT + 1
          ELSE
            JT= JT + 1
            TX(JT)= X(I)
          END IF
10      CONTINUE
        RETURN
        END




        SUBROUTINE PEXTRA(NO,X,SW)
        REAL X(100),SW(100)
        WRITE(4,*)
        WRITE(4,1000)
1000    FORMAT(22X,'X',13X,'SW')
        DO 10 I=1,NO
          WRITE(4,1001) X(I),SW(I)
1001      FORMAT(17X,F11.2,5X,F6.2)
10      CONTINUE
        RETURN
        END
```

```
C     CFYLD--CALIFORNIUM YIELD 6/26/82.
      DIMENSION KCOM(66)
      CHARACTER*1 REP
      CHARACTER*4 A
C      THIS PROGRAM USES 2.645 YR HALFLIFE FOR 252CF AND NU=3.766.
C      FOR 250CF IT USES 13.2 YRS AND 3.53. FOR 254CF IT USES 61.9 DAYS
C      AND 3.93. NU RATIOS ARE FROM N. SC. AND ENGIN. 43,54(1971).
C      RATIO OF ALPHA PARTICLE TO SPONTANEOUS FISSION RATE IS FROM
C      J. INORG. NUCL CHEM 27,33(1965)., IE., 31.3 AND 1260.
C      LAMBDA ALPHA/(LAMBDA SP FISSION) = 1/(1260+1) AND 1/(31.3+1)
C      SP FISSION/ALPHA FOR 254 IS 0.997
C
      DATA CFOHF/13.2/, CF2HF/2.645/, CF4HF/61.9/, CFONU/3.53/,
     &CF2NU/3.766/, CF4NU/3.93/
      A='XXXX'
 1 FORMAT(F14.0)
 2 FORMAT(6X,A4,I2,',',I4,1P4E12.4)
 3 FORMAT(I5)
 4 FORMAT(/7X,
     &'GIVE THE DAY,MONTH, AND YEAR OF ISOTOPIC ANALYSIS ')
 5 FORMAT(7X,'IN F FORMAT THE ATOM PERCENT COMPOSITION OF CF250,
     & 252, AND 254 =')
 6 FORMAT(7X,'GIVE THE DAY, MONTH, AND YEAR OF CALIBRATION ')
 7 FORMAT(/7X'   DATE  '3X'250/TOTAL'3X'254/TOTAL'3X
     &'DECAY'7X'N/SEC'/)
 8 FORMAT(7X'GIVE THE DAY, MONTH, AND YEAR FOR THE END OF THE '
     &/7X'TABULATION '/)
 9 FORMAT(7X'IN F OR G FORMAT WHAT IS THE CALIBRATION
     &ON THAT DATE ?')
10 FORMAT(7X'GIVE THE DAY, MONTH, AND YEAR FOR THE START OF THE '
     &/7X'TABULATION IN I FORMAT'/)
11 FORMAT(/7X,
     &'THE HALF LIVES USED IN YEARS FOR CF250 AND CF252,',/
     &7X,'          AND IN DAYS FOR CF254 = '/)
12 FORMAT(7X'TYPE THE TITLE INFORMATION '/)
13 FORMAT(66A1)
14 FORMAT(7X,66A1)
15 FORMAT(7X,3F14.6)
16 FORMAT(/7X,'THE VALUES USED FOR NUBAR = '/)
18 FORMAT(/7X'GIVE A CARRIAGE RETURN AFTER EACH DATA ENTRY')
19 FORMAT(7X'THE ATOM PERCENT COMPOSITION OF CF250,
     & 252 AND 254 =')
20 FORMAT(7X'WHENEVER YOU REQUIRE NO FURTHER OUTPUT, ANSWER THE NEXT'
     &/7X'REQUEST FOR DAY, MONTH, AND YEAR WITH THREE CARRIAGE RETURNS.'
     &' '/)
21 FORMAT(/7X'THE OUTPUT WILL BE ON FOR002.DAT.')
22 FORMAT(A1)
23 FORMAT(7X'GIVE THE DAY, MONTH, AND YEAR '/)
24 FORMAT(7X'DO YOU WISH TO INPUT A SPECIFIC DATE (Y/N) ? '/)
      OPEN(2,STATUS='NEW')

      WRITE(7,18)
```

```
      WRITE(7,4)
      READ(5,3)ID,M,IYRO
      CALL IDAYS(ID,M,IYRO,IDAYO)
      WRITE(7,5)
      READ(5,1)X050,X052,X054
C     NORMALIZE THE NEUTRON EMMITTERS TO 1.
      SN=X050+X052+X054
      X50=X050/SN
      X52=X052/SN
      X54=X054/SN
      WRITE(7,6)
      READ(5,3)ID,M,IYR1
      CALL IDAYS(ID,M,IYR1,IDAY1)
      CALL LPDAYS(IYR1,IYRO,ITL)
      WRITE(7,9)
      READ(5,1)CA
      IT=(IYR1-IYRO)*365+(IDAY1-IDAYO)+ITL
C *   DEBUG OPTIONS FOLLOW
C     WRITE(7,400)IDAYO,IYRO,IDAY1,IYR1,ITL,IT
C 400 FORMAT(7X,'IDAYO,IYRO,IDAY1,IYR1,ITL,IT',/7X,8I6)
      T=FLOAT(IT)
      A500=0.693147*CFONU*X50/(CFOHF*365.25*1261.)
      A520=0.693147*CF2NU*X52/(CF2HF*365.25*32.3)
      A540=0.693147*CF4NU*0.997*X54/CF4HF
      AAT=A520+A500+A540
      ATO=1.
      FOO=A500/AAT
      F40=A540/AAT
      A50=A500*EXP(-0.693147*T/(CFOHF*365.25))
      A52=A520*EXP(-0.693147*T/(CF2HF*365.25))
      A54=A540*EXP(-0.693147*T/CF4HF)
      ATT=A50+A52+A54
      AT1=ATT/AAT
      FO1=A50/ATT
      F41=A54/ATT
      AT=AT1
      CNO=CA/AT1
      WRITE(7,12)
      READ(5,13)KCOM
      WRITE(2,14)KCOM
      WRITE(2,19)
      WRITE(2,15)X050,X052,X054
      WRITE(2,11)
      WRITE(2,15) CFOHF, CF2HF, CF4HF
      WRITE(2,16)
      WRITE(2,15) CFONU, CF2NU, CF4NU
      WRITE(2,7)
      CALL MODAY(IYRO,IDAYO,A,ID)
      WRITE(2,2)A,ID,IYRO,FOO,F40,ATO,CNO
      CN1=CNO*AT1
      CALL MODAY(IYR1,IDAY1,A,ID)
      WRITE(2,2)A,ID,IYR1,FO1,F41,AT1,CN1
      WRITE(7,20)
   60 WRITE(7,24)
```

```
      ACCEPT 22,REP
      IF ( (REP.EQ.'Y').OR.(REP.EQ.'y') ) GO TO 70
      WRITE(7,10)
      READ(5,3)ID,M,IYR2
      IF(ID.EQ.0)GO TO 200
      CALL IDAYS(ID,M,IYR2,IDAY2)
      WRITE(7,8)
      READ(5,3)ID,M,IYR3
      CALL IDAYS(ID,M,IYR3,IDAY3)
      CALL LPDAYS(IYR3,IYR2,ITL)
      N=(IYR3-IYR2)*365+IDAY3-IDAY2+ITL+1
      GO TO 80
   70 N=1
      WRITE(7,23)
      READ(5,3)ID,M,IYR2
      IF(ID.EQ.0)GO TO 200
      CALL IDAYS(ID,M,IYR2,IDAY2)
   80 CALL LPDAYS(IYR2,IYR0,ITL)
      IT2=(IYR2-IYR0)*365+IDAY2-IDAY0+ITL
C *   DEBUG OPTIONS FOLLOW
C       WRITE(7,500)IDAY0,IYR0,IDAY1,IYR1,IDAY2,IYR2,ITL,IT2
C  500 FORMAT(7X,'IDAY0,IYR0,IDAY1,IYR1,IDAY2,IYR2,ITL,IT2',/7X,8I6)
      T=FLOAT(IT2)
      DO 100 I=1,N
      A50=A500*EXP(-0.693147*T/(CF0HF*365.25))
      A52=A520*EXP(-0.693147*T/(CF2HF*365.25))
      A54=A540*EXP(-0.693147*T/CF4HF)
      ATT=A50+A52+A54
      AT1=ATT/AAT
      F01=A50/ATT
      F41=A54/ATT
      CN1=CN0*AT1
      CALL MODAY(IYR2,IDAY2,A,ID)
      IF ( (REP.EQ.'Y').OR.(REP.EQ.'y') ) THEN
         WRITE(7,2)A,ID,IYR2,F01,F41,AT1,CN1
      END IF
      WRITE(2,2)A,ID,IYR2,F01,F41,AT1,CN1
      IDAY2=IDAY2+1
      IF(IDAY2.LT.366)GO TO 100
      IF(IDAY2.GT.366)GO TO 95
      IMOD=MOD(IYR2,4)
      IF(IMOD.NE.0)GO TO 95
      GO TO 100
   95 IDAY2=1
      IYR2=IYR2+1
  100 T=T+1.
      GO TO 60
  200 CLOSE(2)
      WRITE(7,21)
      STOP
      END
C
```

```
      SUBROUTINE IDAYS(ID,M,IYR,IDAY)
C      THIS SUBROUTINE CALCULATES THE JULIAN CALENDAR DAY OF THE YEAR
C
    1 FORMAT(7X'YOU TYPED MONTH AND DAY. TYPE DAY AND MONTH '/)
    3 FORMAT(I5)
      IF(IYR.LT.1900)IYR=IYR+1900
      IF(M.GT.12)WRITE(7,1)
      IF(M.GT.12)READ(5,3)ID,M
      IY=MOD(IYR,4)
C      FOR MONTHS AFTER FEBRUARY
      X=2.0
C      FOR JANUARY AND FEBRUARY
      IF(M.LE.2)X=0.0
C     FOR MONTHS AFTER FEBRUARY IN LEAP YEARS
      IF(M.GT.2.AND.IY.EQ.0)X=1.0
      Y=(M-1)*30.57+0.5+ID-X
      IDAY=INT(Y)
      RETURN
      END
C


      SUBROUTINE LPDAYS(I2YR,I1YR,ITL)
C
C     THIS SUBROUTINE CALCULATES THE LEAP YEAR DAYS BETWEEN I1YR
C     AND THE YEAR PRECEDING I2YR.
C
      ITL=0
      IF(I1YR.GE.I2YR)GO TO 60
      DO 50 I=I1YR,I2YR-1
      IMOD=MOD(I,4)
C *     DEBUG OPTIONS FOLLOW
C    3 FORMAT(7X,'ITL,I, AND IMOD ARE ',3I8)
C      WRITE(7,3)ITL,I,IMOD
   50 IF(IMOD.EQ.0)ITL=ITL+1
   60 RETURN
      END
C
      SUBROUTINE MODAY(IYR,IDY,A,ID)
C
C     MODAY--THIS SUBROUTINE CALCULATES THE MONTH AND DAY OF THE YEAR
C     FROM THE JULIAN CALENDAR DAY.                    9/11/81
C
      CHARACTER*4 AO,AJAN,AFEB,AMAR,AAPR,AMAY,AJUN,AJUL,AAUG,ASEP,AOCT,
    1             ANOV,ADEC,A
      DATA AO/'****'/,AJAN/'JAN '/,AFEB/'FEB '/,AMAR/'MAR '/,
     &AAPR/'APR '/,AMAY/'MAY '/,AJUN/'JUN '/,AJUL/'JUL '/,AAUG/'AUG '/,
     &ASEP/'SEP '/,AOCT/'OCT '/,ANOV/'NOV '/,ADEC/'DEC '/
C
      IF(IDY.EQ.0) GO TO 1000
      A=AO
      J=1
```

```
C      IDY MUST NOT BE CHANGED BECAUSE IT IS RETURNED TO MAIN PGM
C
       IDAY=IDY
       IMOD=MOD(IYR,4)
       IF(IDAY-31)10,10,20
    10 A=AJAN
       ID=IDAY
       GO TO 1000
    20 IF(IDAY-59)30,30,40
    30 A=AFEB
       ID=IDAY-31
       GO TO 1000
    40 IF(IDAY.EQ.60.AND.IMOD.EQ.0)J=0
       IF(J-1)50,60,60
    50 A=AFEB
       ID=IDAY-31
       GO TO 1000
    60 IF(IMOD.EQ.0)IDAY=IDAY-1
C   *********************************************************
C      IDAY AT THIS LINE OF THE PROGRAM MUST BE 60 OR GREATER.
C      THIS SECTION OF THE PROGRAM DECIDES WHERE THE PROGRAM
C      SHOULD CONTINE IN ORDER TO AVOID MOST OF THE FOLLOWING 'IF'
C      STATEMENTS.
C
       K=(IDAY-6)/30
       GO TO (65,65,80,100,120,140,160,180,200,220,240,240) K
C
C   *********************************************************
    65 IF(IDAY-90)70,70,80
    70 A=AMAR
       ID=IDAY-59
       GO TO 1000
    80 IF(IDAY-120)90,90,100
    90 A=AAPR
       ID=IDAY-90
       GO TO 1000
   100 IF(IDAY-151)110,110,120
   110 A=AMAY
       ID=IDAY-120
       GO TO 1000
   120 IF(IDAY-181)130,130,140
   130 A=AJUN
       ID=IDAY-151
       GO TO 1000
   140 IF(IDAY-212)150,150,160
   150 A=AJUL
       ID=IDAY-181
       GO TO 1000
   160 IF(IDAY-243)170,170,180
   170 A=AAUG
       ID=IDAY-212
       GO TO 1000
   180 IF(IDAY-273)190,190,200
```

```
 190 A=ASEP
     ID=IDAY-243
     GO TO 1000
 200 IF(IDAY-304)210,210,220
 210 A=AOCT
     ID=IDAY-273
     GO TO 1000
 220 IF(IDAY-334)230,230,240
 230 A=ANOV
     ID=IDAY-304
     GO TO 1000
 240 A=ADEC
     ID=IDAY-334
     GO TO 1000
1000 RETURN
     END
```

EXAMPLE OUTPUT

NBS 118 (TYPE III) SOURCE STRENGTH PER 14 FEB 1985 CALIBRATION
THE ATOM PERCENT COMPOSITION OF CF250, 252 AND 254 =
        8.160000   86.260002   0.021000

THE HALF LIVES USED IN YEARS FOR CF250 AND CF252,
        AND IN DAYS FOR CF254 =

        13.200000   2.645000   61.900002

THE VALUES USED FOR NUBAR =

        3.530000   3.766000   3.930000

DATE	250/TOTAL	254/TOTAL	DECAY	N/SEC
DEC 13,1983	4.0341E-04	1.1318E-01	1.0000E+00	7.6676E+09
FEB 14,1985	5.8094E-04	1.4212E-03	6.5288E-01	5.0060E+09
JUL 21,1985	6.3639E-04	2.7449E-04	5.8269E-01	4.4678E+09
JUL 22,1985	6.3676E-04	2.7163E-04	5.8227E-01	4.4646E+09
JUL 23,1985	6.3713E-04	2.6880E-04	5.8185E-01	4.4614E+09
JUL 24,1985	6.3750E-04	2.6600E-04	5.8143E-01	4.4582E+09
JUL 25,1985	6.3786E-04	2.6323E-04	5.8101E-01	4.4550E+09
JUL 26,1985	6.3823E-04	2.6048E-04	5.8059E-01	4.4518E+09
JUL 27,1985	6.3860E-04	2.5777E-04	5.8018E-01	4.4486E+09
JUL 28,1985	6.3897E-04	2.5508E-04	5.7976E-01	4.4454E+09
JUL 29,1985	6.3933E-04	2.5242E-04	5.7934E-01	4.4422E+09
JUL 30,1985	6.3970E-04	2.4979E-04	5.7893E-01	4.4390E+09
JUL 31,1985	6.4007E-04	2.4719E-04	5.7851E-01	4.4358E+09
AUG 1,1985	6.4044E-04	2.4461E-04	5.7809E-01	4.4326E+09
AUG 2,1985	6.4081E-04	2.4206E-04	5.7768E-01	4.4294E+09
AUG 3,1985	6.4118E-04	2.3954E-04	5.7726E-01	4.4262E+09
AUG 4,1985	6.4155E-04	2.3704E-04	5.7685E-01	4.4230E+09
AUG 5,1985	6.4192E-04	2.3457E-04	5.7643E-01	4.4198E+09
AUG 6,1985	6.4229E-04	2.3212E-04	5.7602E-01	4.4167E+09
AUG 7,1985	6.4266E-04	2.2971E-04	5.7560E-01	4.4135E+09
AUG 8,1985	6.4303E-04	2.2731E-04	5.7519E-01	4.4103E+09
AUG 9,1985	6.4340E-04	2.2494E-04	5.7477E-01	4.4071E+09
AUG 10,1985	6.4377E-04	2.2260E-04	5.7436E-01	4.4040E+09
AUG 11,1985	6.4414E-04	2.2028E-04	5.7395E-01	4.4008E+09
AUG 12,1985	6.4451E-04	2.1798E-04	5.7354E-01	4.3976E+09
AUG 13,1985	6.4488E-04	2.1571E-04	5.7312E-01	4.3945E+09
AUG 14,1985	6.4525E-04	2.1346E-04	5.7271E-01	4.3913E+09
AUG 15,1985	6.4562E-04	2.1123E-04	5.7230E-01	4.3882E+09
AUG 16,1985	6.4599E-04	2.0903E-04	5.7189E-01	4.3850E+09
AUG 17,1985	6.4637E-04	2.0685E-04	5.7148E-01	4.3818E+09
AUG 18,1985	6.4674E-04	2.0470E-04	5.7107E-01	4.3787E+09
AUG 19,1985	6.4711E-04	2.0256E-04	5.7065E-01	4.3755E+09
AUG 20,1985	6.4748E-04	2.0045E-04	5.7024E-01	4.3724E+09
AUG 21,1985	6.4786E-04	1.9836E-04	5.6983E-01	4.3693E+09
AUG 22,1985	6.4823E-04	1.9630E-04	5.6942E-01	4.3661E+09
AUG 23,1985	6.4860E-04	1.9425E-04	5.6902E-01	4.3630E+09
AUG 24,1985	6.4897E-04	1.9222E-04	5.6861E-01	4.3598E+09
AUG 25,1985	6.4935E-04	1.9022E-04	5.6820E-01	4.3567E+09

Appendix D

1. INTERFACE OF COUNTING ELECTRONICS TO MICROCOMPUTER

The counter electronics are connected to a microcomputer for data storage and analyses. The principal interface component is the Tennelec "TC-588" Buffered Printout Control Interface. This module collects data from various NIM modules such as scalars, timers, etc. by a Daisy Chain interconnection cabling system. The data is first swept into a buffer in the TC-588 and then made available to a PRO-350 microcomputer by an RS-232 line.

1.1 Line Characteristics

The LINE CHARACTERISTICS presently set in the PRO-350 are given in Table D-1.

TABLE D-1

Line Characteristics of the PRO-350 which must be compatible with the output from the TC-588

Receive Baud Rate	1200
Transmit Baud Rate	1200
Number of Data Bits	8
Number of Stop Bits	1
Parity	OFF
XON/XOFF control	Enabled
7-bit character codes	Enabled
Connection Type	Handwired

1.2 Communications Line Compatability

To make the TC-588 output compatible with the above conditions, two DIP switches, SW1 and SW2, inside of the TC-588 must be set as shown in Table D-2.

TABLE D-2

Switch Settings In The TC-588

Switch Name	Function	Switch Number	On or Off
SW1	TTY or RS-232	1	"ON" = RS232
SW1	(Not used)	2	
SW1	Parity	3	"OFF" = No parity
SW1	Stop Bits	4	"ON" = one stop bit
SW1	Number of Bits	5	"OFF" (means 8
SW1	" " "	6	"OFF" bits)
SW1	(doesn't matter)	7	
SW2	Band Rate	1,2,3,4	"ON,OFF,OFF,OFF"=9600 band

1.3 Switch Settings on Print Out Control

The only other requirement for the TC-588 is to assure that operation is carried out with the two switches on the front face of the unit set as follows: the READOUT MODE Switch should be in the "AUTO RECYCLE" position; the OUTPUT FORMAT switch should be in the "NORMAL" position.

1.4 Malfunction of the Readout System

The two red push buttons normally do not require activation in the autocycle mode. However, occasionally the Daisy Chain system hangs up and this is identified by one of two conditions as seen on the readout lights of the TC-588 and the Time-of-Day/Year Clock. These conditions are either: (1) no visible lights; (2) or lights on the TC-588 rapidly flash as if unit is performing readout operation. These hangup conditions are usually eliminated by pushing the RESET button, the PRINT button and then the RESET button a second time.

2. DATA COLLECTION

The following is the procedure for collecting data from the $MNSO_4$ activity counting electronics, using a Digital Equipment Corporation (DEC) Pro-350 computer.

2.1 To Start Data Taking

2.1.1 On the PRO-350:

1) Select "PRO TOOL KIT" from the Main Menu
2) Run DTE
3) Push "ADDITIONAL OPTIONS" key
4) Select "START HOST OUTPUT LOGGING"
5) Specify the output log name (XXXXXX.LOG)
6) Push "RESUME" key

2.1.2 Start Data Taking on the TC-535P Timer/Scaler:

1) Push "RESERT" button
2) Push in "START/STOP" button

2.2 To Stop Data Taking

2.2.1 ON THE TC-353P:

1) Release "START/STOP" button

2.2.2 On the PRO-350:

1) Push "ADDITIONAL OPTIONS" key
2) Select "STOP HOST OUTPUT LOGGING"
3) Push "RESUME" key
4) Push "EXIT" key (only once)

At this point, there are a variety of things which can be done. For example, the file can be viewed on the CRT of the PRO-350, it can be printed out, it can be saved to a floppy diskette (remember, it is already on the hard disk), it could be edited, but most importantly, it can be analyzed to get final results. Since the latter is the normal mode of operation, we will conclude this sequence with the analysis procedure and that to obtain a printout of the analyzed results. the other options are covered in Appendix A.

#### 2.2.3 On the PRO-350 (in PRO Tool Kit):

1) Type RUN ANALYZE

Answer the questions and provide the requested input. See discussion on the "ANALYZE" Program for details about the input required for the various program options (background counts, calibration counts of NBS-I, counts of source to be calibrated, etc.).

2) Type "COPY" (to get the printout of the output file)
   FROM: Filename.ext
   TO: LP:

3. 110 VOLT SUPPLY AND THE UNINTERRUPTABLE POWER SUPPLY

Part of the system is on an uninterruptable power supply which will
keep the system (main electronics and microcomputer) alive sufficiently
long to log the last result and close the data files. See Fig. D-1.

FIGURE D.1
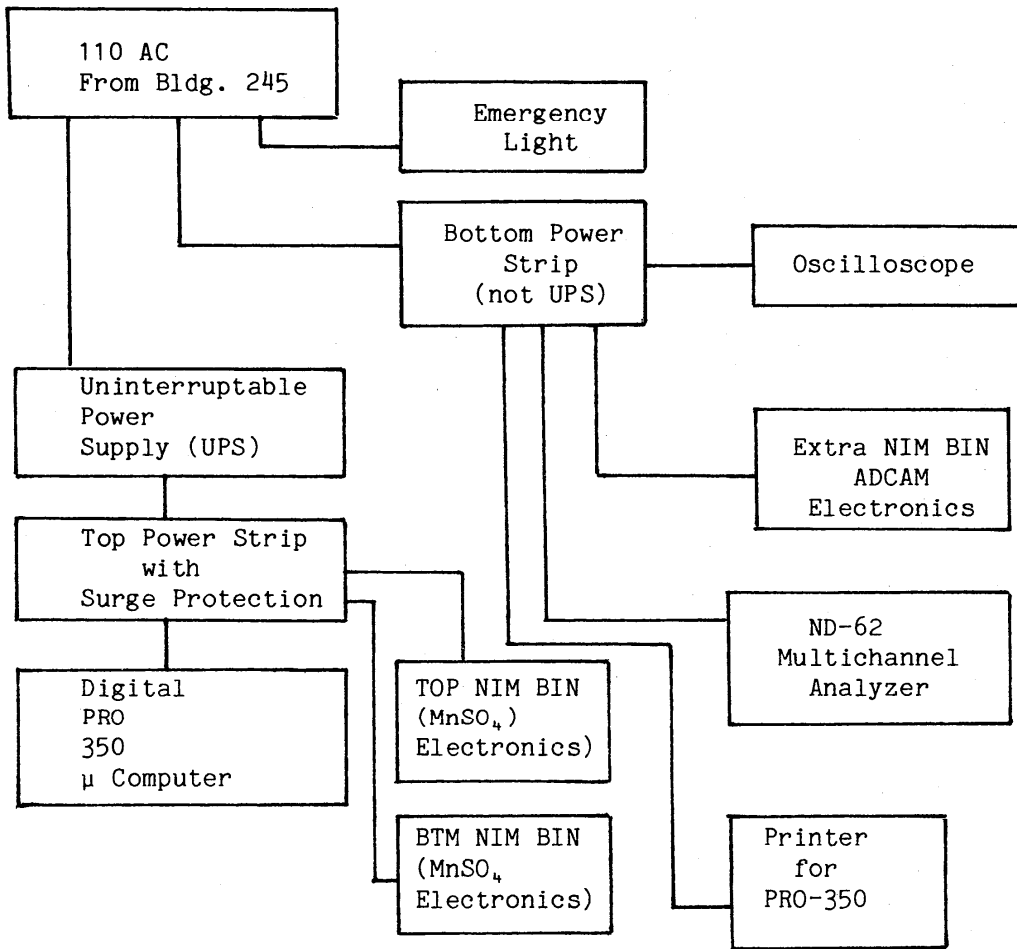
Electrical Connections to Unfiltered Building Power and Filtered Power
from an Uninterruptable Power Supply (UPS).