The Design, Construction, and Operation of a Neutron Activation Analysis Transfer System

A Thesis

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in

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by

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Dedicated to my family

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An expression of appreciation is dedicated to my family. Without their sacrifices and help, this study would not have been possible.

Last, but most important, I thank my Lord and Savior Jesus Christ for the inner strength supplied to carry this study through to completion.

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ABSTRACT

A transfer system is necessary for the study of short-lived radioisotopes when isotopic, accelerator, or reactor sources are used for activation analysis. The objectives of this work were: (1) to design and construct a transfer system, and (2) to keep the construction costs at a minimum. The transfer system was designed to be used with the Californium-252 Demonstration Center with the option of simple modifications for accelerator use.

Most of the non-electronic components of the system were salvaged from previous transfer systems. Two electronic timers were constructed and interfaced with the relay system for control of the pneumatic system (vacuum cleaner and solenoid valves). An activation terminal was designed and built for use with underwater sources.

After assembly and testing, a variety of specimens were activated to obtain practical operating parameters. Transfer times of three seconds were consistently achieved, and isotopes with two-second half-lives were easily observed. Inexpensive modifications can be made to reduce the transfer time to less than two seconds for a twenty-five foot distance.

CHAPTER I

Introduction

Activation analysis is an important teaching tool and research method for those concerned with the study of nuclear reactions and the composition of matter. It gives valuable clues which are used for quantative and/or qualitative elemental assay of samples. The technique consists of irradiation, transfer, and measurement of the induced activity in a sample.

Whatever the purpose the analysis may serve, the irradiation portion remains essentially the same and is often performed underwater when using isotopic neutron sources. Other than the neutron activation of isotopes, some studies are conducted using isotopic gamma-ray emitting sources. A transfer system is essential when gamma-rays are used to activate samples to study the excited states of isotopes because many of the metastable states of interest have short half-lives.

Neutron activation of a sample can be performed by an accelerator, a reactor, or an isotopic source. Although these activation sources are different, the results of irradiation from each of them is the same. Activation of a sample is accomplished by placing the sample in a position where it is bombarded by a known flux of neutrons for a known period of time. After the specimen is made radioactive it emits electromagnetic and/or particulate radiation which is characteristic of the product nucleus.

The time required for irradiation is estimated by consideration of several parameters which pertain to the source and the sample. To determine the amount of activity produced by the radioactive product isotope Equation (1-1) can be evaluated.

$$A_1 = N\phi\sigma(1 - e^{-\lambda t_1}) \qquad (1\text{-}1)$$

where

A_1 = amount of induced activity at time t_1 (disintegrations per second)

$N\phi\sigma = R$ = rate of production

N = number of target atoms present

ϕ = neutron flux ($n\text{-}cm^{-2}\text{-}sec^{-1}$)

σ = reaction cross section ($*10^{-24}$ cm^2)

$(1-e^{-\lambda t_1}) = S$ = saturation factor

$\lambda = \ell n\ 2/T$ = decay constant of product nuclide

t_1 = irradiation time

T = half-life of radioisotope of interest.

The calculation of N can performed by using the following formula:

$$N = \frac{N_A\ m\ k}{M} \qquad (1\text{-}2)$$

where

N_A = Avogadro's number = $6.02 * 10^{23}$ (atoms/g-atom)

m = mass of the sample (gm)

k = fractional isotopic abundance of target nuclide

M = molecular weight of element.

If the sample is originally radioactive, the activity because of the decay of the atoms originally present is added to the new activity by changing Equation (1-1) to:

$$A = A_o e^{-\lambda t_1} + RS. \qquad (1\text{-}3)$$

With or without initial activity, the activity of the sample can be increased until the effect of the decaying atoms offsets the effect of the addition of new ones. That is, a dynamic equilibrium is reached. This equilibrium occurs when the irradiation time is large when compared to the product half-life.

Saturation is approached asymptotically as shown in Figure 1-1. After five half-lives 97% of saturation has occurred. Irradiation for six or seven half-lives each add approximately 1% increases in activity.

After a sample is removed from the irradiation source it decays exponentially as a function of time as shown in Figure 1-2. This decay of a radioactive sample is evaluated by use of the formula:

$$A = A_1 e^{-\lambda t_2} \qquad (1\text{-}4)$$

where

A = activity of sample at time t_2

A_1 = activity of sample at end of activation

t_2 = decay time.(1, 2, 3, 4)

If the decay time is large with respect to the product half-life, the exponential term of Equation (1-4) approaches zero. Sample activity

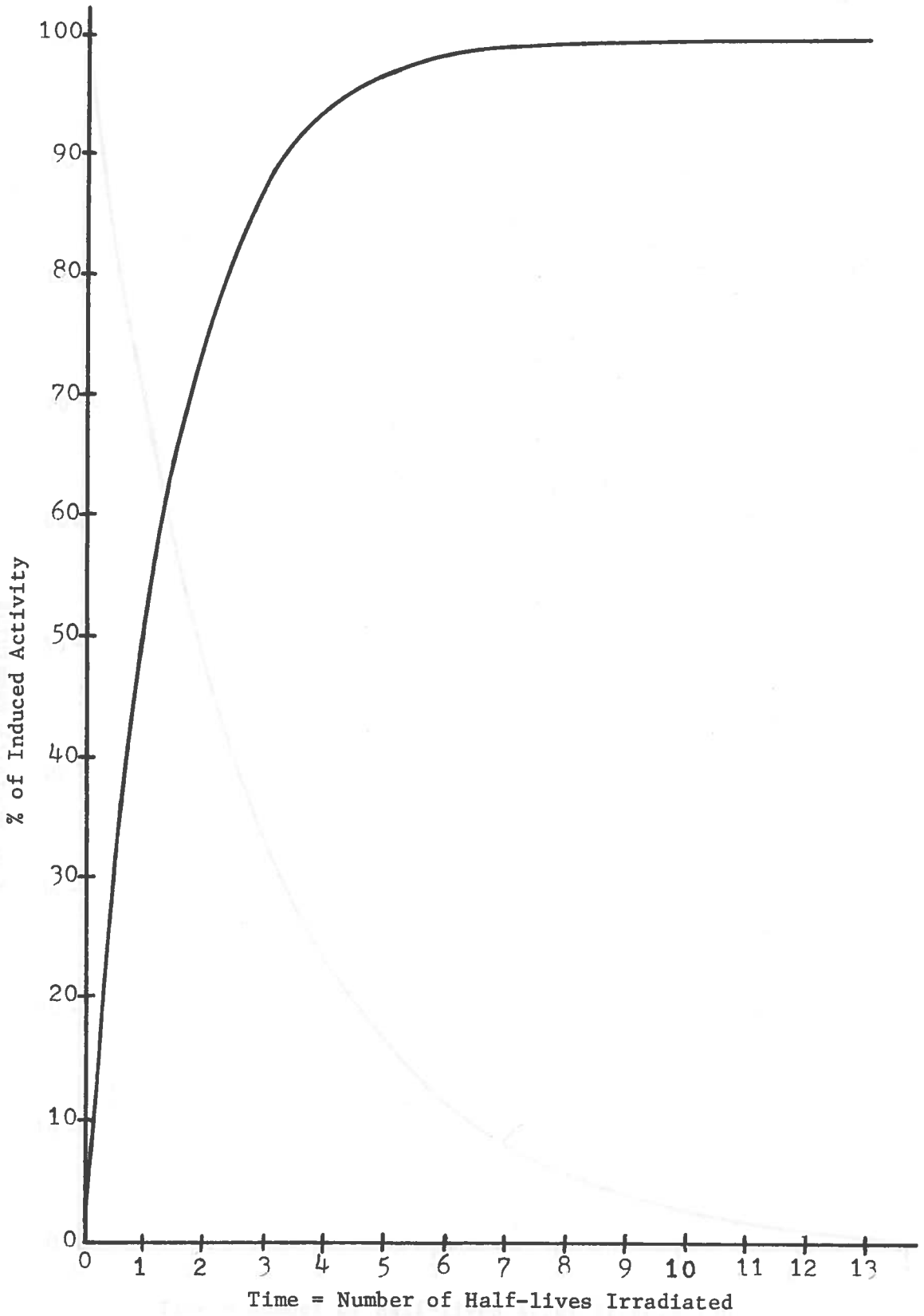

Figure 1-1

Approach to Saturation Curve

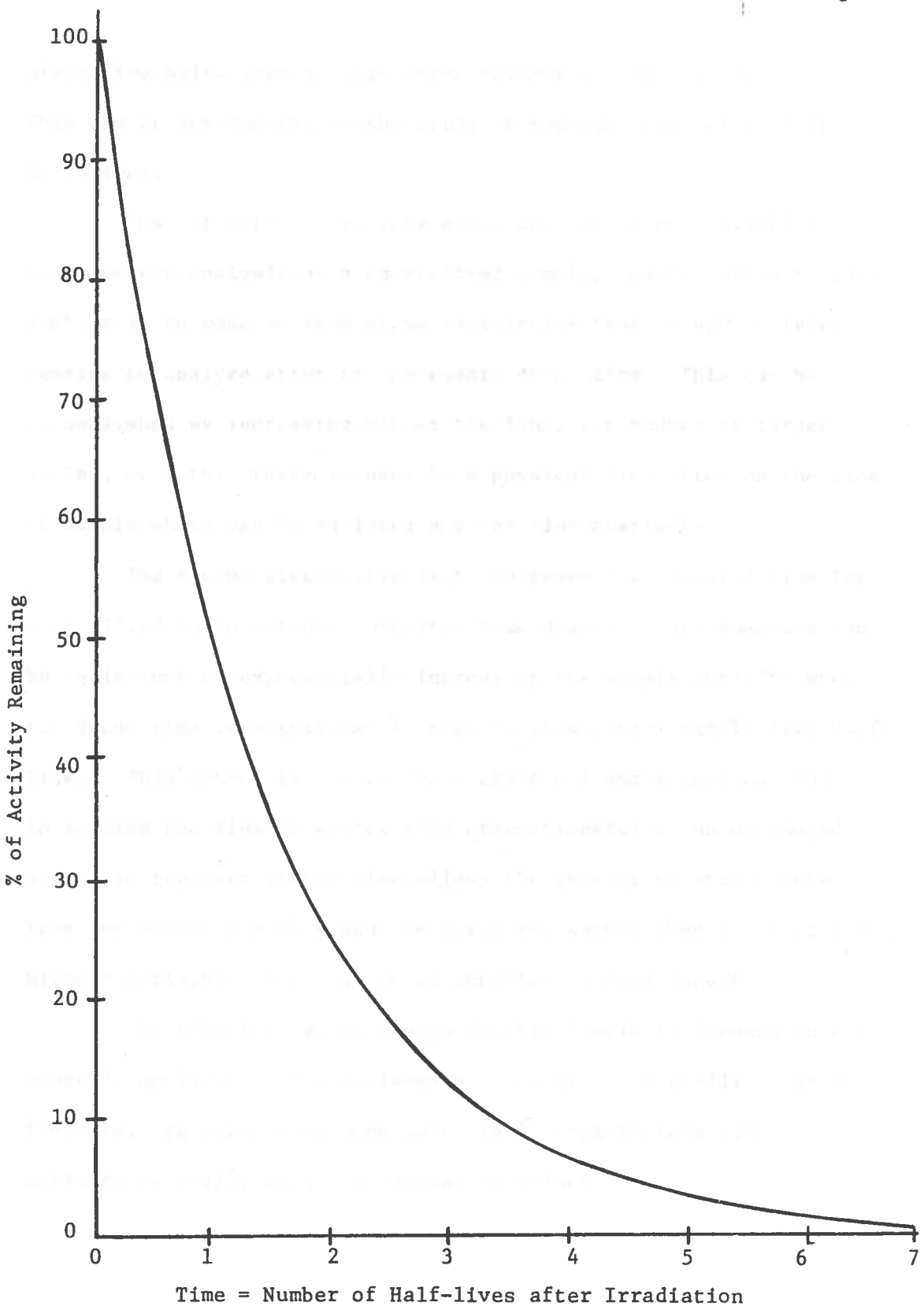

Figure 1-2

Exponential Decay Curve

after five half-lives is only three percent of the initial activity. This can be detrimental to the study of radioisotopes with short half-lives.

Loss of activity by long decay periods after activation may preclude analysis of a short-lived sample. One solution to this problem is to make so many atoms radioactive that enough activity remains to analyze after the necessary decay time. This can be accomplished by increasing either the flux, the number of target nuclei, or both. There is usually a physical limitation on the size of sample which can be analyzed and the flux available.

The second alternative is to decrease the transfer time for short-lived radioisotopes. Shorter time delays before analysis can be equivalent to exponentially increasing the sample activity when the decay time is significantly reduced from approximately five half-lives. This method is usually more practical and economical than increasing the flux or source size proportionately. An automated pneumatic transfer system also allows the analyst to stay remote from the activation flux and the activated sample when it is at its highest activity. This can be an important safety aspect.

The transfer system design in this thesis is focused on the system's application for activation analysis of short-lived radioisotopes. Features have been added to accomplish long time activations and/or decays by manual overrides.

CHAPTER II

Design Criteria

The transfer system described in this thesis is conceptually similar to most state-of-the-art pneumatic transfer systems: It provides a means of remotely transmitting a sample between a send/receive station and a radiation source, with accurately timed residence in the source. To meet the needs of the LSU Nuclear Science Center the transfer system was designed with the following considerations in mind:

- LOW COST, within budget allowances
- DEPENDABLE, must not need constant maintenance
- SERVICEABLE, must be easily repaired
- SIMPLE, must be easily operated by any user
- FLEXIBLE, must be capable of use for lab instruction and with the accelerator or isotopic sources
- SAFE, must not expose operator to unsafe radiation levels.

Major emphasis was placed on furnishing a usable system at the lowest possible cost.

Parts remaining from the activation analysis transfer system previously used in the basement of the Nuclear Science Center (in conjunction with the Texas Nuclear Corporation model 9500, 150 kV Cockcroft-Walton accelerator) were salvaged as a major cost-saving step. These components included an old vacuum cleaner, a pair of two-

way dishwasher valves, and several relays (including one with an adjustable time delay). The vacuum cleaner and dishwasher valves were connected by tubing which allowed the direction of air flow in the transfer tube to be changed by actuation of the valves.[5] This arrangement is shown in Figure 2-1. Most commercial systems use compressed air to move the samples, which makes a closed-loop system necessary.

Two-dram polyethylene vials, bunnies, were used to contain the samples during transport. The loader/receiver and the bunny stop gate (for sample placement during counting) were designed by Dr. E. L. Steele (former Manager of the Cf-252 Demonstration Center) for a commercial activation analysis facility. The bunny stop gate is solenoid actuated and is controlled from the transfer-system console. The solenoid is normally inactive to keep the gate, which is perforated to allow continuous air flow, in the "closed" position. When the bunny is in contact with the gate the sample is centered in front of one or two 5" x 5" (12.70 cm) NaI(Tl) crystals, as seen in Figure 2-2.

The loader/receiver is the first and last component that the sample encounters in this transfer system. Dual functions for the loader/receiver makes operation of the system more convenient. Some commercially available systems require a remote receiver or dual tubing runs to accomplish the same result made possible by the directional-air-flow capability of this transfer system. Figure 2-3 shows the loader/receiver.

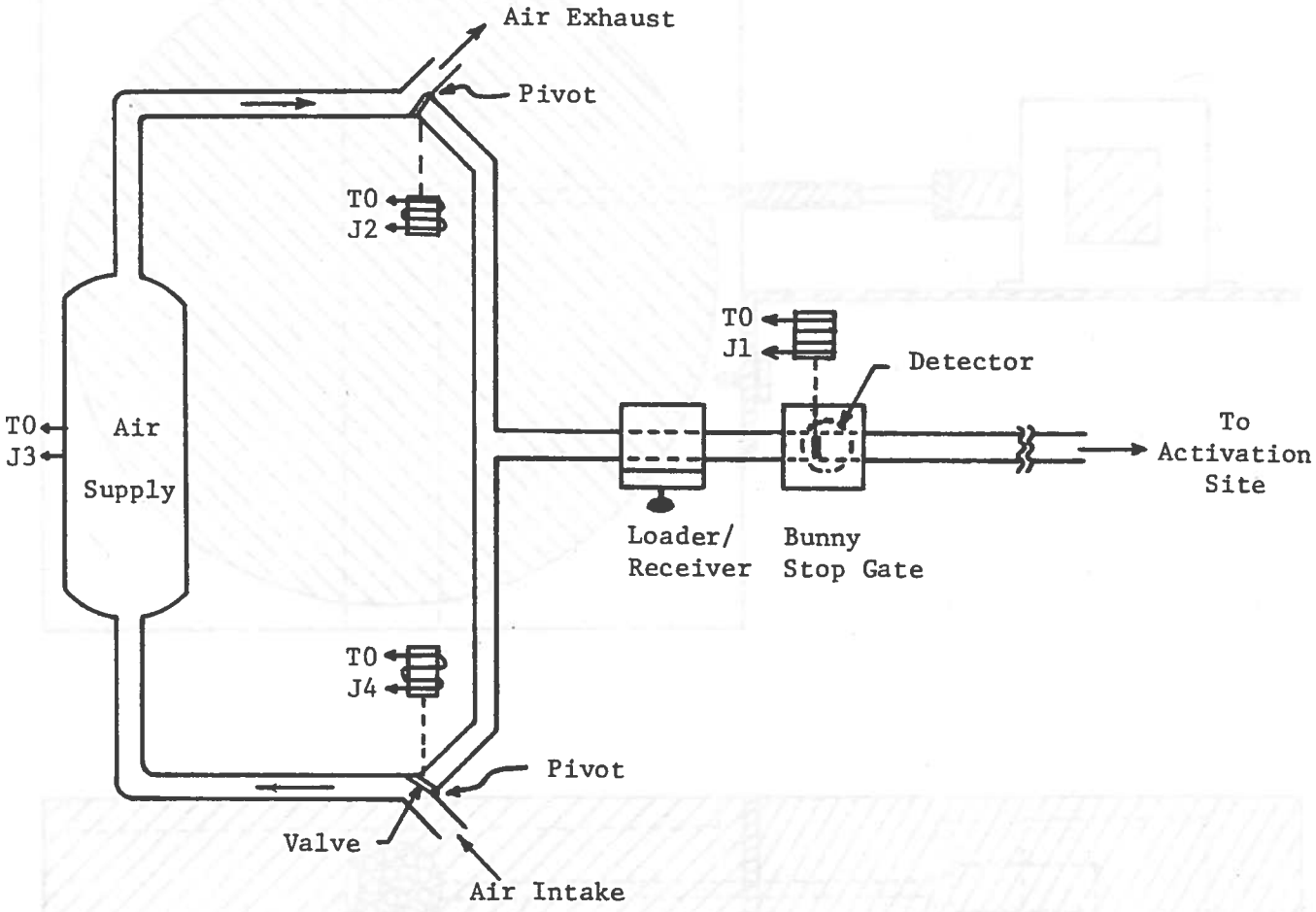

Figure 2-1

Pneumatic Transfer System

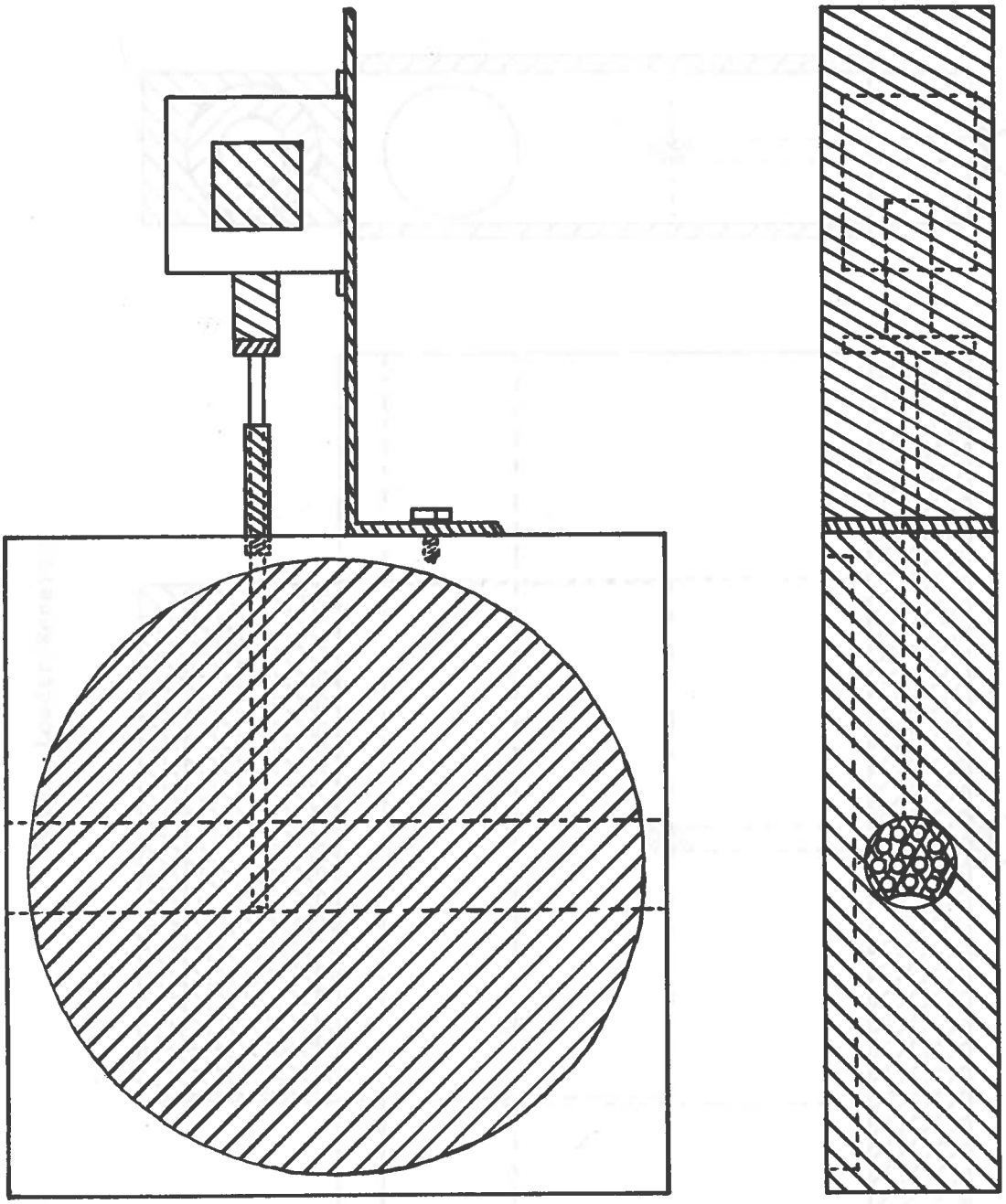

Figure 2-2

Bunny Stop Gate

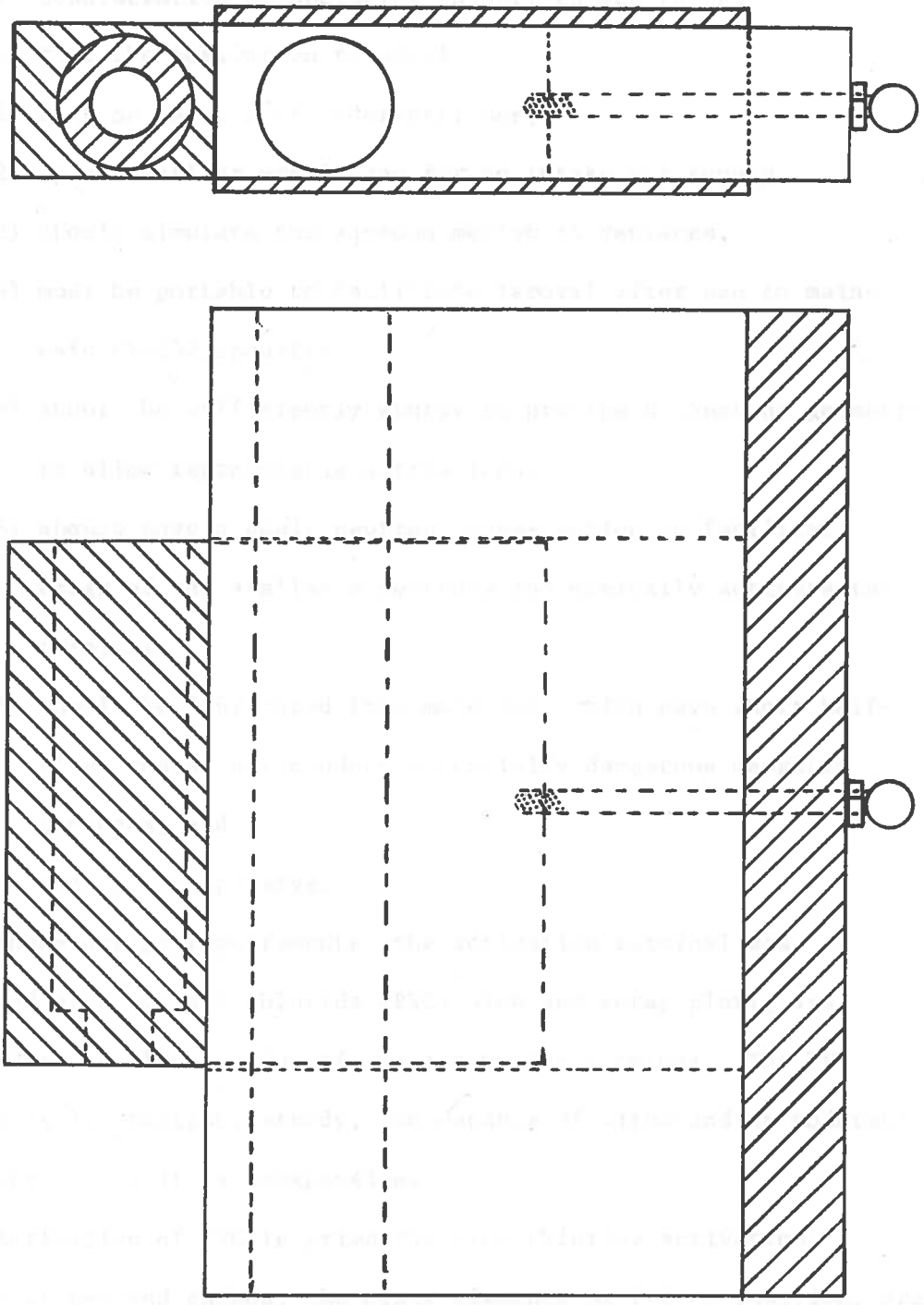

Figure 2-3

Sample Loader/Receiver

The major contributions of this thesis are the timing and control unit called the "transfer system console" and the activation terminal. Consideration of operating objectives led to the conclusion that the activation terminal:

1) must be capable of underwater use,
2) should include provisions for an intake air supply,
3) should simulate the aqueous medium it replaces,
4) must be portable to facilitate removal after use to maintain Cf-252 security,
5) should be sufficiently sturdy to provide a constant geometry to allow reproducable activations,
6) should have a small neutron cross-section to facilitate usage of the available neutrons and nominally activate the terminal,
7) should be fabricated from materials which have short half-lives and do not produce potentially dangerous daughter isotopes, and
8) must be inexpensive.

To meet these design requirements, the activation terminal was constructed of polyvinyl chloride (PVC) pipe and scrap plexiglass. Figure 2-4 is an illustration of the activation terminal. The PVC pipe used is lightweight, sturdy, and capable of withstanding moderate abuse. Above all, it is inexpensive.

Activation of PVC is primarily from chlorine activation because hydrogen and carbon, the other elements of PVC composition, are

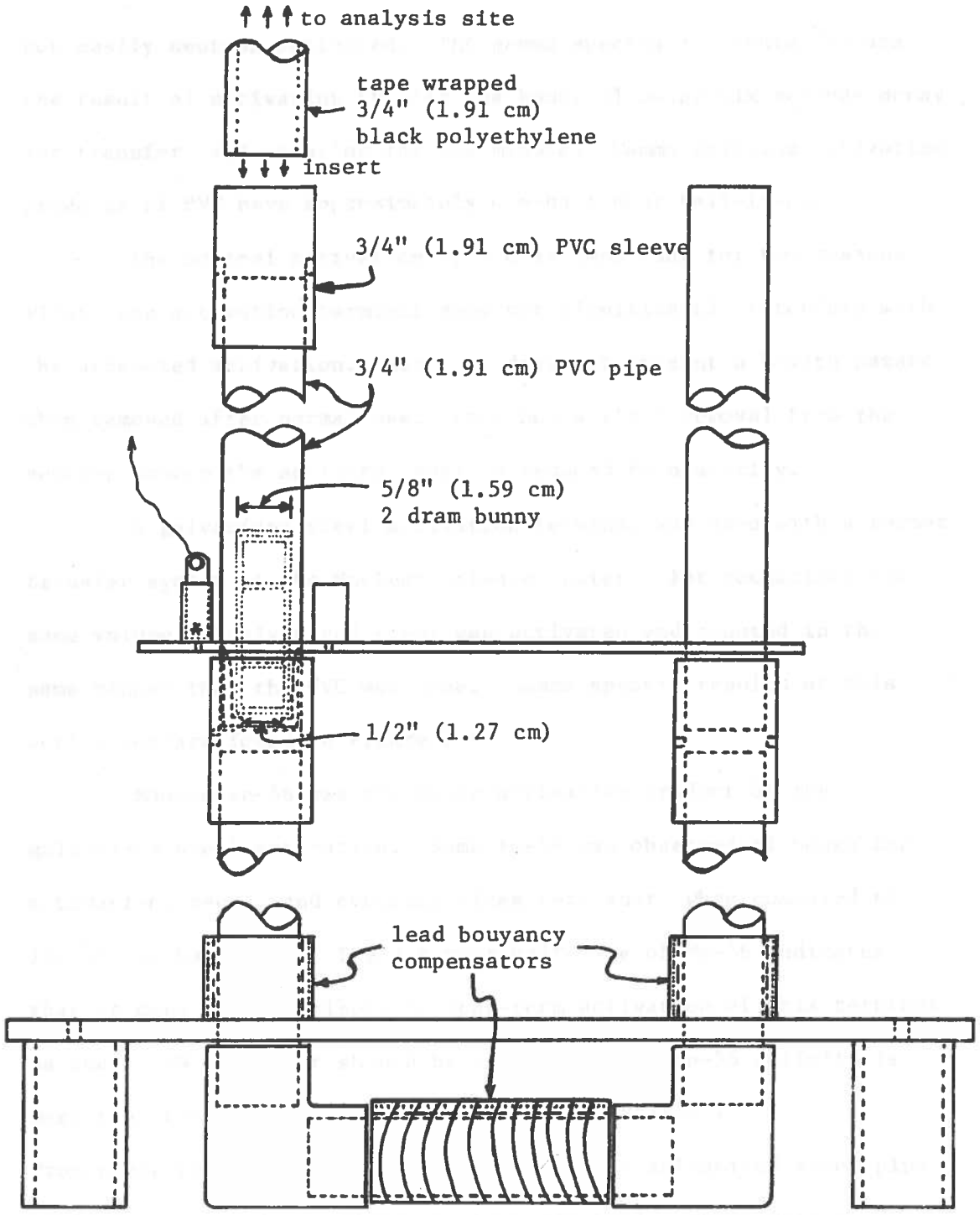

Figure 2-4

Activation Terminal

not easily neutron activated. The gamma spectra in Figure 2-5 are the result of activating PVC for one hour, allowing six seconds decay for transfer, and counting for one minute. Gamma emitting activation products of PVC have approximately one-half hour half-lives.

The nominal activation of PVC is important for two reasons. First, the activation terminal does not significantly interfere with the attempted activation. Next, it does not present a health hazard when removed after normal use. Four hours after removal from the neutron source the activity level is reduced to obscurity.

A galvanized steel activation terminal was used with a former transfer system at the Nuclear Science Center. For comparison the same volume of galvanized steel was activated and counted in the same manner that the PVC was done. Gamma spectra results of this activation are found in Figure 2-6.

Manganese-56 was the major activation product of the galvanized steel activation. Some Fe-59 was observed although the activation, decay, and counting times were short when compared to its 45 day half-life. The 2.6 hour half-life of Mn-56 indicates that it does not contribute to long-term activation of this terminal as the Fe-59 does. It should be noted that the Mn-56 activity is more than ten times greater than the Cl-38 activity.
From these results it was determined that the galvanized steel pipe would interfere with activations more and would remain activated longer than the PVC pipe. Therefore, PVC was used for construction of the activation terminal.

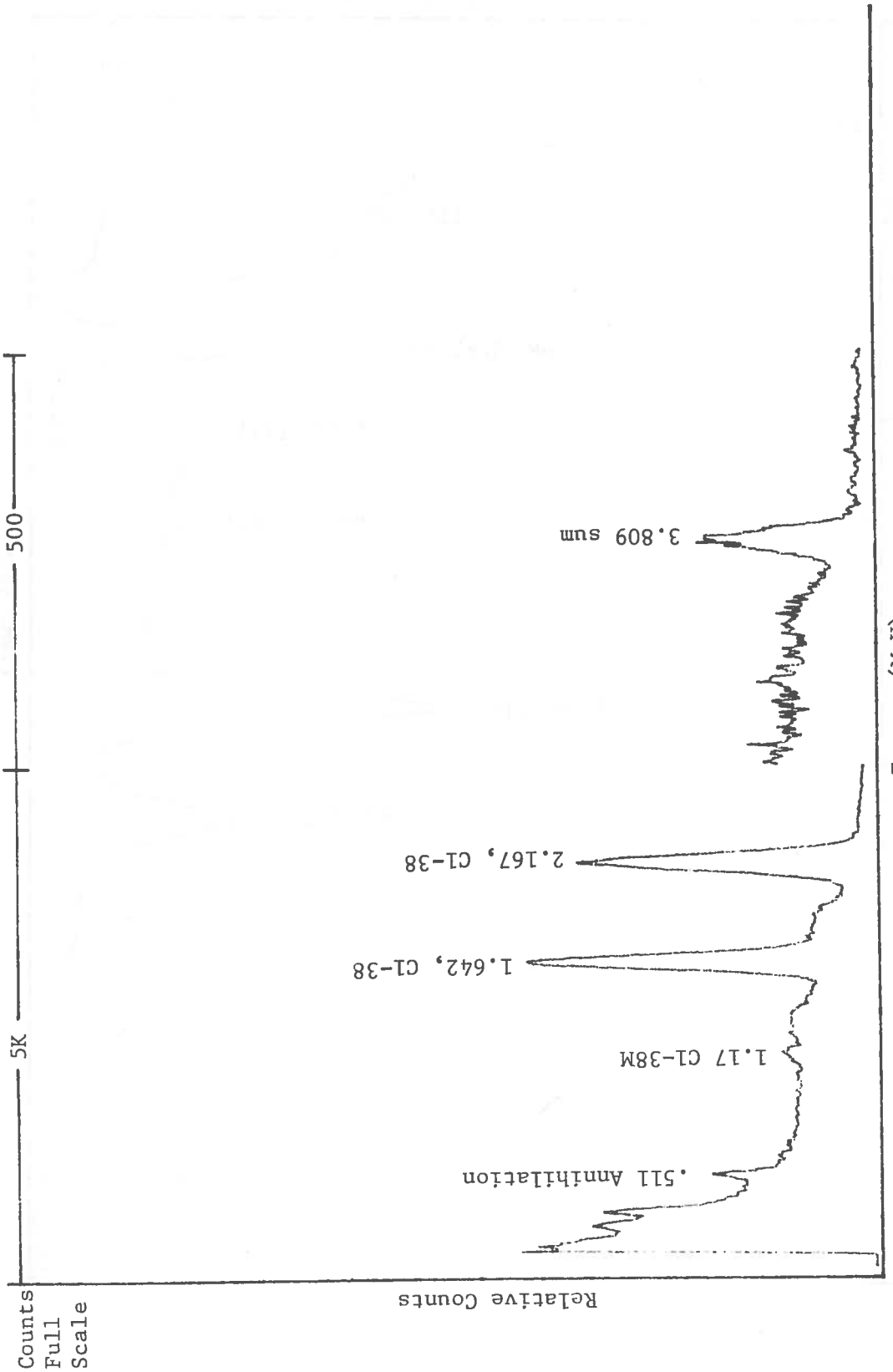

Figure 2-5. PVC Activation Spectrum

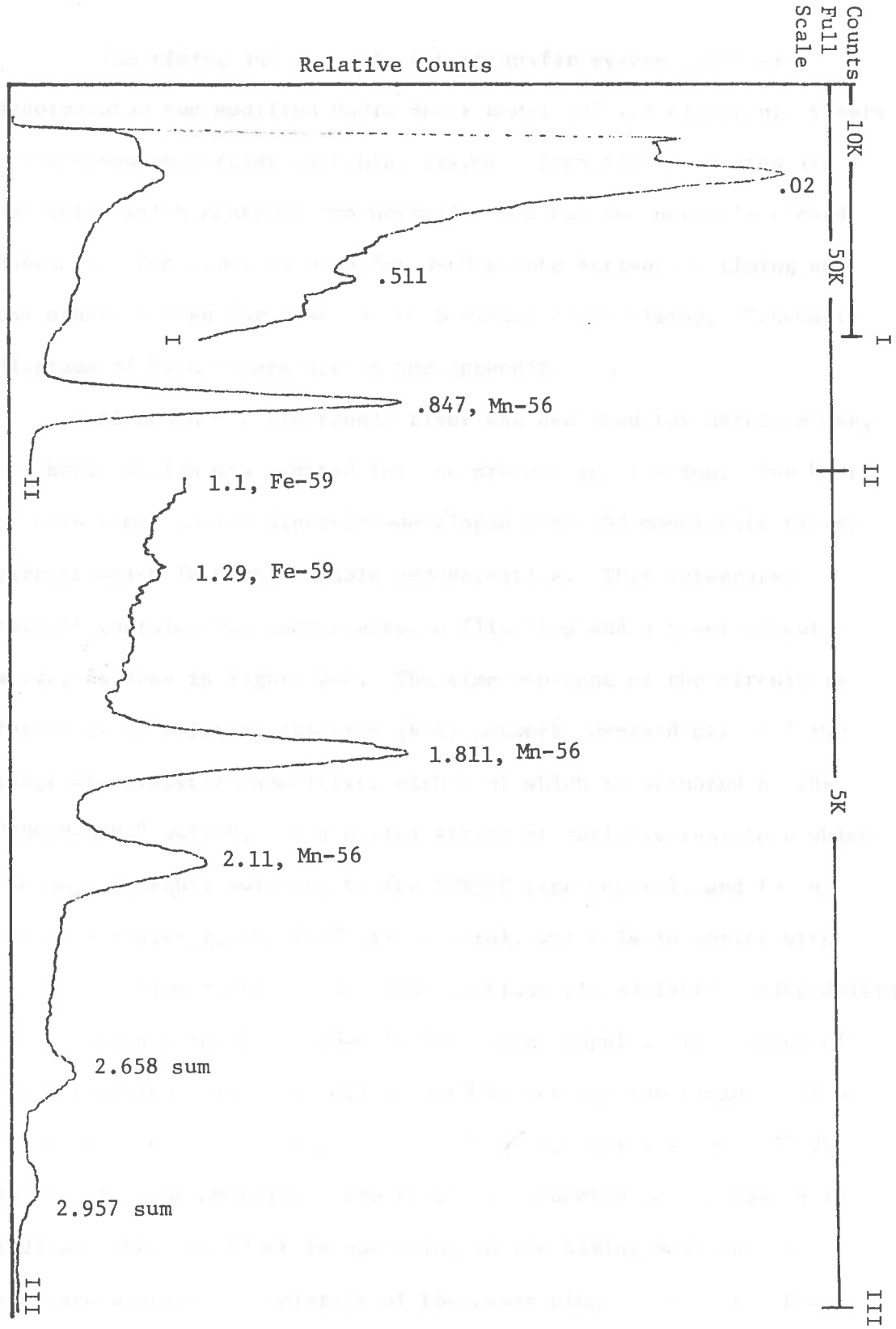

Figure 2-6. Galvanized Steel Activation Spectrum

The timing and control unit (transfer-system console) incorporates two modified Radio Shack model 277-113 electronic timers and a compatable relay switching system. Each timer actuates its own relay which controls two normally open and two normally closed contacts. One timer is used for 0-60 minute activation timing and the other is used for 6 second to 6 minute decay timing. Schematic diagrams of both timers are in the Appendix.

Although the electronic timer was designed for darkroom use, the basic design was adapted for the present application. The heart of this timer is the Signetics-developed Type 555 monolithic timing circuit which is highly stable and versatile. This integrated circuit contains two comparators, a flip-flop and a power output stage, as seen in Figure 2-7. The time constant of the circuit is formed by a resistor-capacitor (R-C) network composed of: (1) two large electrolytic capacitors, either of which is actuated by the "SHORT-LONG" switch, (2) a series string of variable resistors which can be selectably switched by the COARSE time control, and (3) a variable resistor, the FINE time control, which is in series with the COARSE time control and allows continuously variable timing delays.

Each timer has a 16-volt D.C. power supply. The output of the integrated circuit (I.C.) is used to actuate the pickup coil of Radio Shack model 275-206, double pole double throw (DPDT), 12 VDC relay. A light emitting diode (LED) is connected to the switch to indicate when the timer is operating in the timing mode and to indicate whether the polarity of the power plug is correct. Power

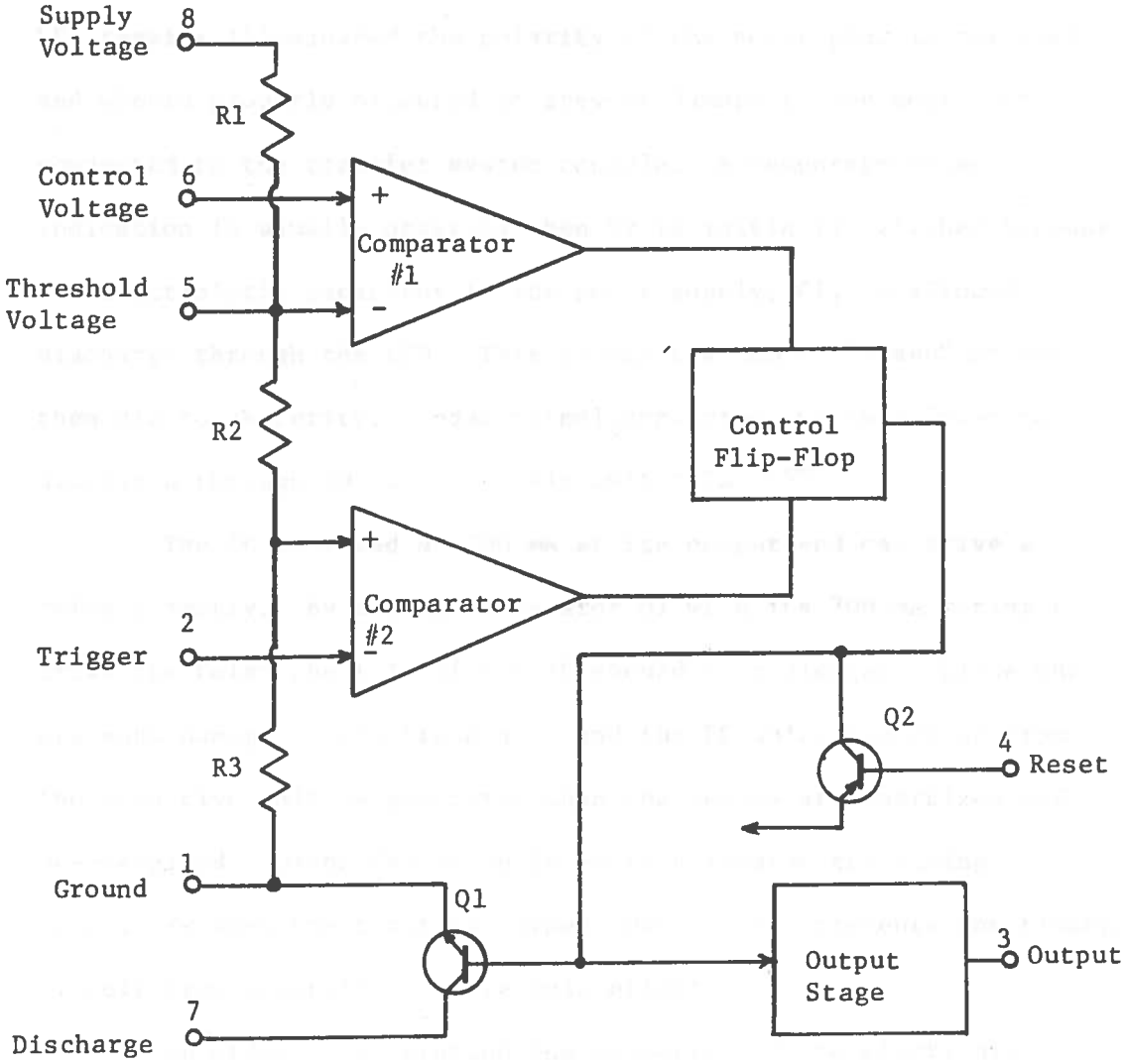

Figure 2-7

Block Diagram of 555 Timer

plug polarity can be reversed if a non-polarized adapter is improperly inserted in a receptacle. Referring to the schematic in Figure A-1, when the main switch, S1, is turned "OFF" and S2 is switched to "TIMED ACTIVATION" the LED should remain dark. If the LED remains illuminated the polarity of the power plug is reversed and should properly oriented to prevent damage to any equipment connected to the transfer system console. A temporary false indication is usually observed when S2 is initially switched because the electrolytic capacitor in the power supply, C1, is allowed to discharge through the LED. This causes the LED to "flash" on and then dim to obscurity. Under normal conditions C1 is allowed to discharge through R9 when the main switch is "OFF".

The IC is rated at 200 mA at its output and can drive a relay directly. By adding transistor Q1 with its 700 mA rating to drive the relay the life of the IC should be prolonged. Diode CR2 prevents damage to the transistor and the IC which can occur from the inductive voltage generated when the relays are energized and de-energized. Diode CR4 is included to discharge the timing capacitors when the timer is turned "OFF". This prevents the timing circuit from observing a hysteresis effect.

In order to understand the operation of the electronic timer the functions of the integrated circuit must be known. A block diagram of the contents of the 555 IC is shown in Figure 2-7. Because the switch activating the timer has positive instead of momentary closure, the discharging feature of the internal transistor

of the 555 could not be used. If pin 7 of the 555 is connected to discharge the timing capacitors, the timer will continuously recycle. That is, the timer will operate in an astable mode rather than the desired monostable mode.

Operation of the 555 starts when a negative trigger pulse of less than one-third of the supply voltage is applied to pin 2. This causes the flip-flop to set and drive the output at the level of the supply voltage. During this time the external timing capacitor (C, in farads) is charging exponentially through the selected resistance (R, in ohms) for a period (expressed in seconds) of

$$t = 1.1\ RC. \qquad (2\text{-}1)$$

At the end of the period the voltage at pin 2 equals two-thirds of the supply voltage. The comparator then resets the flip-flop, which drives the output to its low state. This completes the 555 timing cycle.[6]

When Timer #1, the activation timer, is turned "ON" the output of the 555 through the transistor energizes its DPDT relay (K1). Through the closure of the K1 normally open contacts, relay K2 and the activation timer receptable (J5) are energized. Relay K2 is cascaded with K1 because the contacts of K2 are capable of handling 10 amperes whereas the K1 contacts are low current contacts.

For servicability all relays are mounted in sockets. Other than those specified previously, the relays are Potter and Brumfield type KRP11AG, 115 v.a.c., DPDT relays, with the exceptions of K9 and

K10, which are Potter and Brumfield type CDB 38-70003, 115 v.a.c., DPDT with adjustable time delay on operate.

Figure 2-8 is the relay scheme which operates as shown in the relay sequential circuit timing chart of Figure 2-9 which is described in Table 2-1. To simplify the following discussion of relay operations the schematic alpha-numeric designations are changed to alphabetic as follows:

R1 = A
R2 = B
.
.
.
R10 = J.

Boolean algebra juxtaposition expressions for the relay outputs are in Table 2-2 and are diagrammed by the logic blocks of Figure 2-10.

Some relay cascading was required to utilize the salvaged relays and obtain enough contacts to perform the desired operations. Examples of this are the cascading of relays B and C and cascading relays E and F.

Relay C actuates the air supply, output air valve, and the bunny stop gate. When relay C is energized the bunny is pushed pneumatically from the loader/receiver to the activation site. After the adjustable time delay of relay I has elapsed, relay C is de-excited to turn off the pneumatics. Adjustable time delays for relays I and J allow various weights of samples and lengths of tubing to be used with this transfer system because the transit time varys with these two parameters.

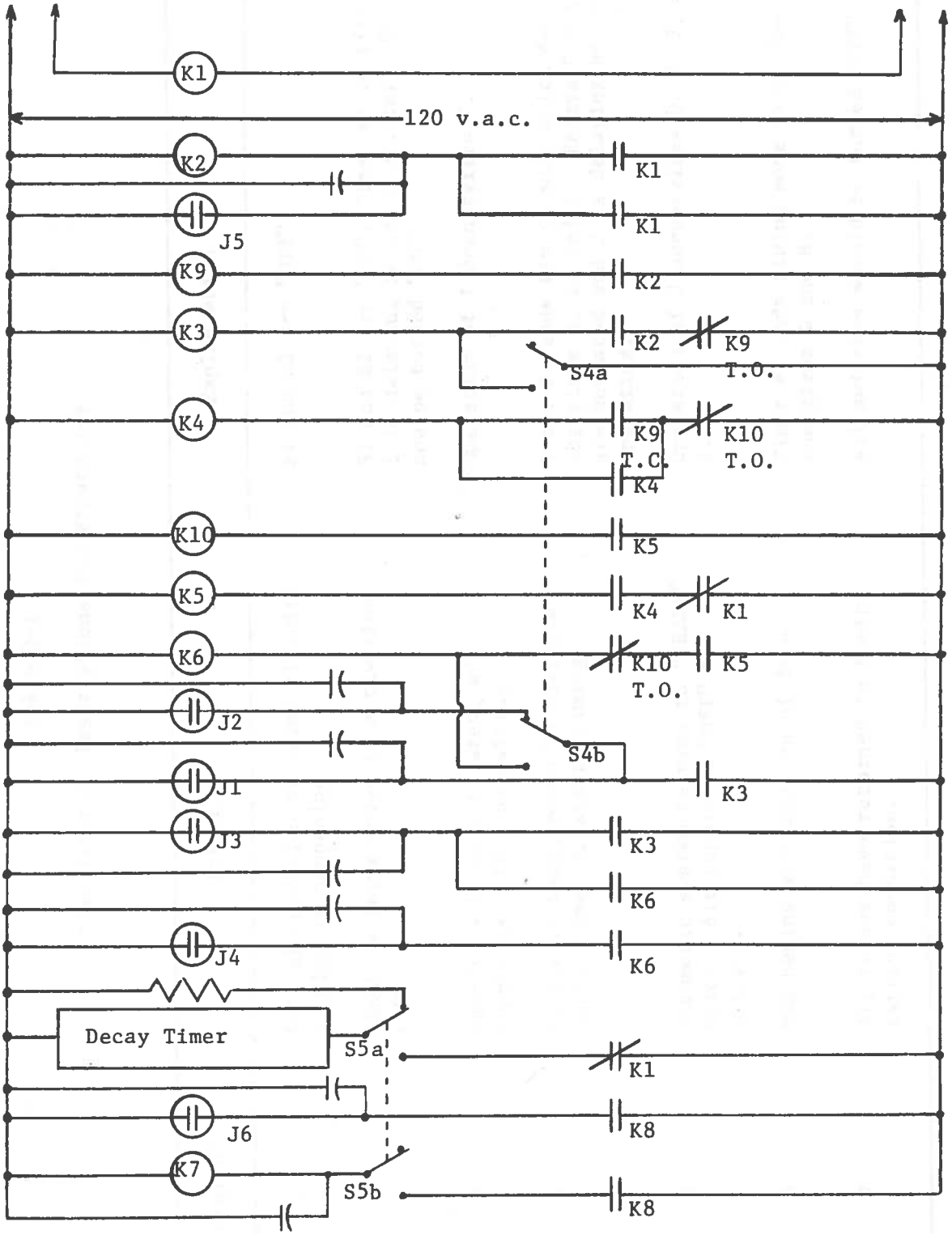

Figure 2-8

Relay Scheme

Table 2-1

Time Interval Descriptions for Figure 2-9

Interval	Action	Explantation
1	Initial condition of relay circuit; nothing is happening.	S1 and S2 are "OFF".
2	Bunny is being moved to activation site.	S1 and S2 are "ON", Timer #1 is timing, I is delaying before operating. S5 can now be turned "ON".
3	Sample is being activated, air supply is "OFF" and waiting.	Operation of I deenergizes C.
4	Sample is being moved to analysis site. Timer #2 starts timing.	Timer #1 ends timing mode which de-energizes A, B, and I. Relays E and F are actuated and J is delaying before operating.
5	Pneumatic system returns to "READY" state. Air supply is "OFF" and waiting.	Operation of J deenergizes D, E. F, and J.
6	MCA begins accumulation of data.	Timer #2 ends timing mode which de-energizes G and H.
7	All relays have returned to their initial condition.	All switches should be turned "OFF".

Table 2-2

Relay Logic

Desired Action	Input	Output	Function
PUSH BUNNY	activation timer	A	sensory power to relays during activation cycle
PUSH BUNNY	A	B	sensory power to relays during activation cycle
PUSH BUNNY	$B\bar{I}$	C	power for air supply, output air valve, and bunny stop gate
STOP PUSHING	delay B	I	stops pneumatics after bunny is delivered
ACTIVATION WAIT + RETURN BUNNY	IJ + D	D	power to relays after activation cycle
RETURN BUNNY	$\bar{A}D$	E	energizes relays to return bunny
RETURN BUNNY	$E\bar{J}$	F	power for air supply and intake air valve
STOP RETURN AIR	delay E	J	stops pneumatics after bunny returns by de-energizing relays
BUNNY RETURNING AND/OR DECAYING	$\bar{A}$ decay timer	G	sensory power to MCA control relay
BUNNY RETURNING AND/OR DECAYING	G	H	start pulse for MCA when de-energized

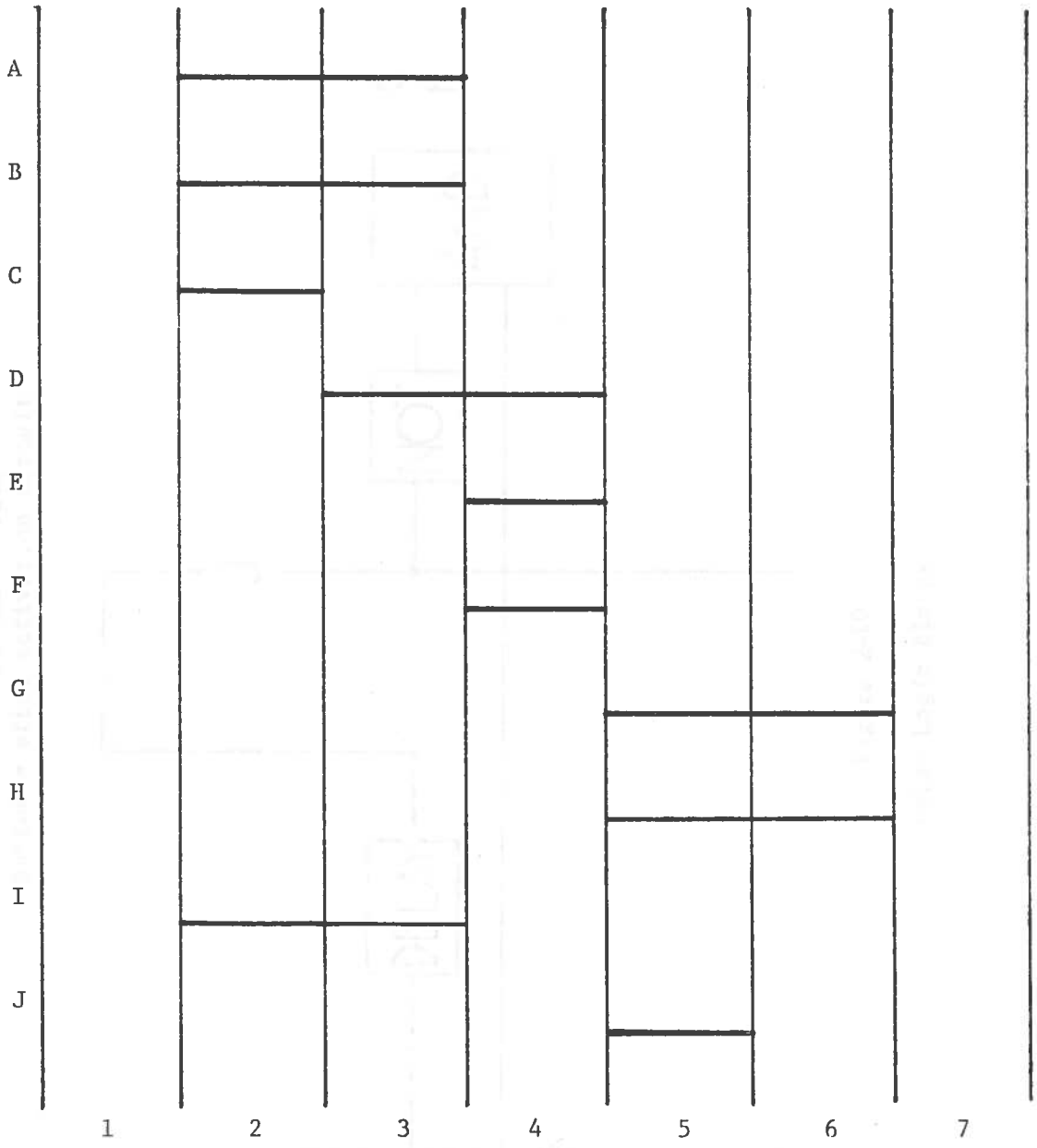

Figure 2-9

Relay Sequential Timing Chart

Top = to activate circuit
Bottom = after activation circuit

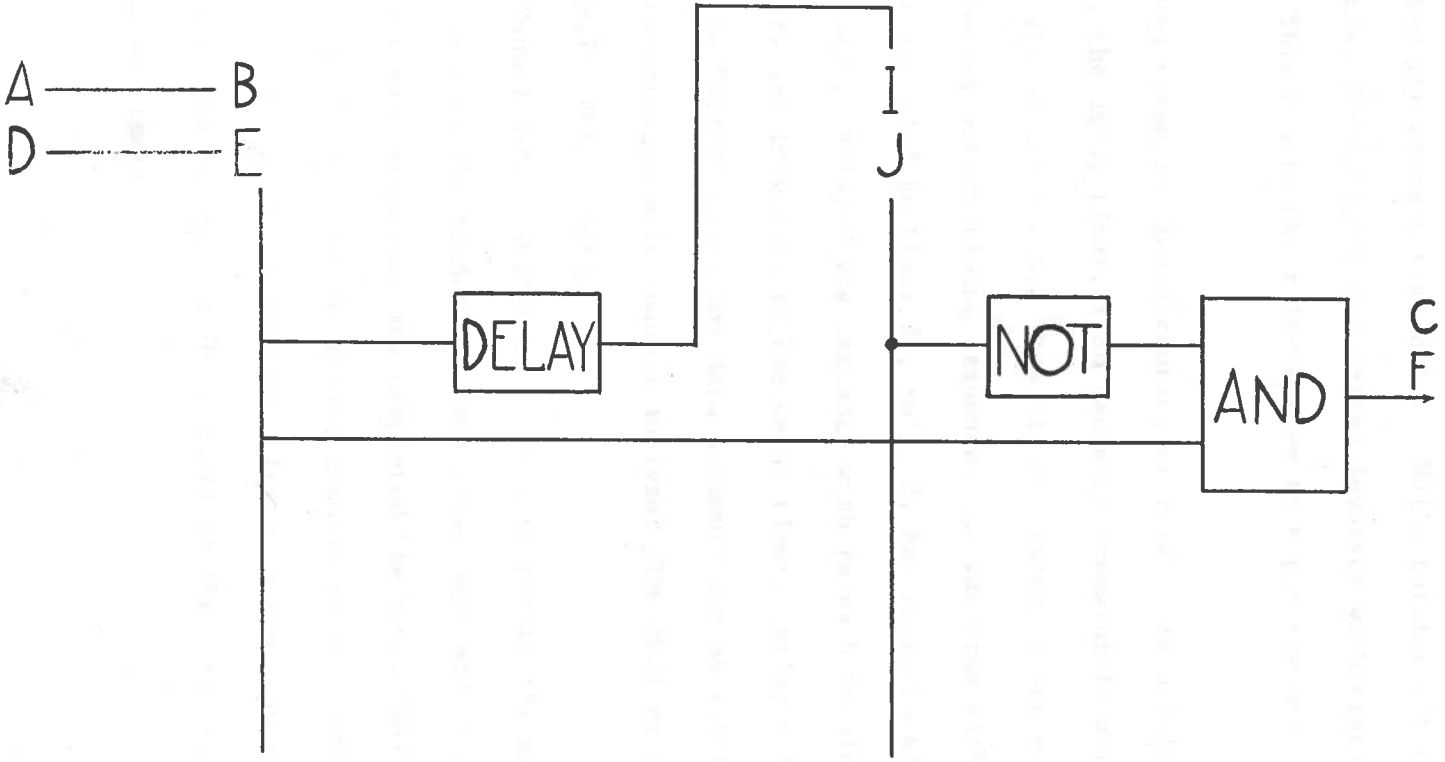

Figure 2-10

Relay Logic Blocks

Interruptable power to the relay circuitry is supplied by relay D after the activation timer completes its timing cycle. The air supply and intake air valve are actuated by relay F until relay J completes its pre-set time delay. While turning off the pneumatics, relay J also de-energizes all relays involved with transfer of the sample. This resets the relay system to begin the next activation transfer.

One normally closed contact of relay A is utilized to prevent Timer #2, the decay timer, from becoming prematurely actuated and starting its adjustable 0.1 to 6 minute timing sequence before the end of the activation timing sequence. As was true with Timer #1, the relay included in Timer #2, relay H, has contacts which are low-current rated. Relay G was cascaded with relay H to provide more reliability and longevity to the decay timer. Relay G is used to deliver the "START" pulse for data accumulation by either the Texas Nuclear Corporation multichannel analyzer (TMC-MCA) or the Northern model TN-1705 MCA or both.

Manual detent switch S4 is used to return the sample pneumatically to the loader/receiver after analysis is complete. After the timing sequences are completed the power switches should be turned "OFF" to allow the timing capacitors to discharge and return to their initial condition. The main power switch, S1, turns off power to the relays and the primary of the activation timer power supply transformer.

The transfer tubing is approximately 40 feet (9.1 m) of black polyethylene which has an inside diameter of 3/4 inches (19 mm). The tubing was shipped and stored in a roll which has caused most of its length to assume an elliptical cross section shape because of flattening. The two-dram bunny used to contain the sample for activation has an outside diameter of 5/8 inch (1.6 cm). Adequate air flows were achieved for rapid transfer through the tubing without having to add gaskets to the bunny. This alleviated the "could-have-been" problem of flat transfer tubing. Black tubing was used in lieu of translucent tubing because of the cost. Translucent tubing would facilitate detection of a sample if it would become lodged in the transfer tubing.

Another major contribution of this thesis is the design and construction of the activation terminal. The activation site was elevated to allow a one foot (30.5 cm) clearance from the stainless steel bottom of the Californium-252 Demonstration Center tank to avoid interactions from neutron albedo from the tank. Figure 2-4 is an illustration of the activation terminal. A polyethylene liner was constructed and inserted into the PVC pipe to keep the 2 dram bunny in a constant geometry for reproducable activations.

CHAPTER III

Preliminary Studies

Pneumatic transfer systems have been commercially available for many years. Previously, a system for activation analysis using the Cockcroft-Walton accelerator was in use at the Nuclear Science Center.[5] The prohibitive cost of the commercial systems made this thesis a viable option for the acquisition of a transfer system for activation analysis.

Initial investigations of the requirements of this transfer system partially consisted of the salvaging of the previous system. Other transfer systems described in available literature were then examined in detail to establish which features were feasible for incorporation into the new system.[7]

One of the most important qualifications for this transfer system was to provide accurate timing for the activation of samples. First, a salvaged Mostek model MK-50395 six-decade counter/display totalizer integrated circuit was tried. After breadboard wiring was completed the circuit was found defective.

Next a clock timer was constructed. This timer could control a relay, had digital readouts, and kept very accurate time. Because of the design of the integrated circuit the shortest time interval at which the relay could be operated was in the minutes range. This was not adequate for the required fractional-minute activations of short-lived isotopes.

Further investigations suggested that the Radio Shack 277-113 darkroom timer could be adapted for use as the time control of this transfer system for a reasonable cost. Some frills like the digital readout were sacrificed.

After the construction of the mechanism which could control the pneumatics through the transfer system console, it was necessary to find a convenient means to load and remove the samples. One means which was previously used was a plexiglass box which was spliced into the transfer tubing. Samples were loaded by opening the lid of the box and inserting the bunny directly into the tubing. To remove the sample the bunny "fell" to the bottom of the box when it returned from the activation, the lid was opened, and the sample was removed. Advantages of this unit were: (1) it was existing and operable, (2) it required no additional construction, and (3) the sample could be visually detected when it arrived. Disadvantages included: (1) it decreased the pressure of the system which slowed the transfer time, (2) it required too much time to unload the sample to be used for analysis of short lived radioisotopes, and, (3) was not very durable.

A loader/receiver unit which was designed by Dr. E. L. Steele (Chapter II, p. 8) for commercial use was incorporated into the transfer system. This unit is discussed in Chapter II and illustrated in Figure 2-3. Although the sample can not be visually observed when it returns, impact in the receiver is clearly audible. This unit has all of the other advantages of the plastic box without the disadvantages.

Opaque polyethylene tubing was used to connect the activation terminal to the pneumatic supply. Translucent tubing was considered but, as mentioned in Chapter II, the cost was the deciding factor. The convenience of visually locating a sample that possibly could get lodged in the tubing did not compensate for the additional cost.

The activation terminal which was previously used in the Californium-252 Demonstration Center was constructed from galvanized pipe. This terminal was readily activated and provided unwanted shielding of the sample. An alternative terminal was considered which consisted of two lengths of PVC pipe, one inside the other. The outside pipe was to be used for return air and the inside pipe was for sample transfer. Disadvantages of this design were: (1) greater source to sample distance which diminishes the flux as shown in Figure 3-1,[8] (2) air surrounding the sample instead of a consistent hydrogeneous media, and (3) the difficulty of providing unrestricted air flow between the two pipes.

The U-shaped design of an activation terminal was the only inexpensive alternative which did not possess the drawbacks of the other activation terminals. Interface of the PVC pipe with the polyethylene tubing was accomplished by adding a sleeve to the PVC pipe and wrapping tape around the tubing to act as a gasket when it is inserted into the PVC sleeve.

A solenoid-actuated device which could stop the sample in front of one or two 5 inch (12.7 cm) NaI(Tl) crystals, the bunny stop

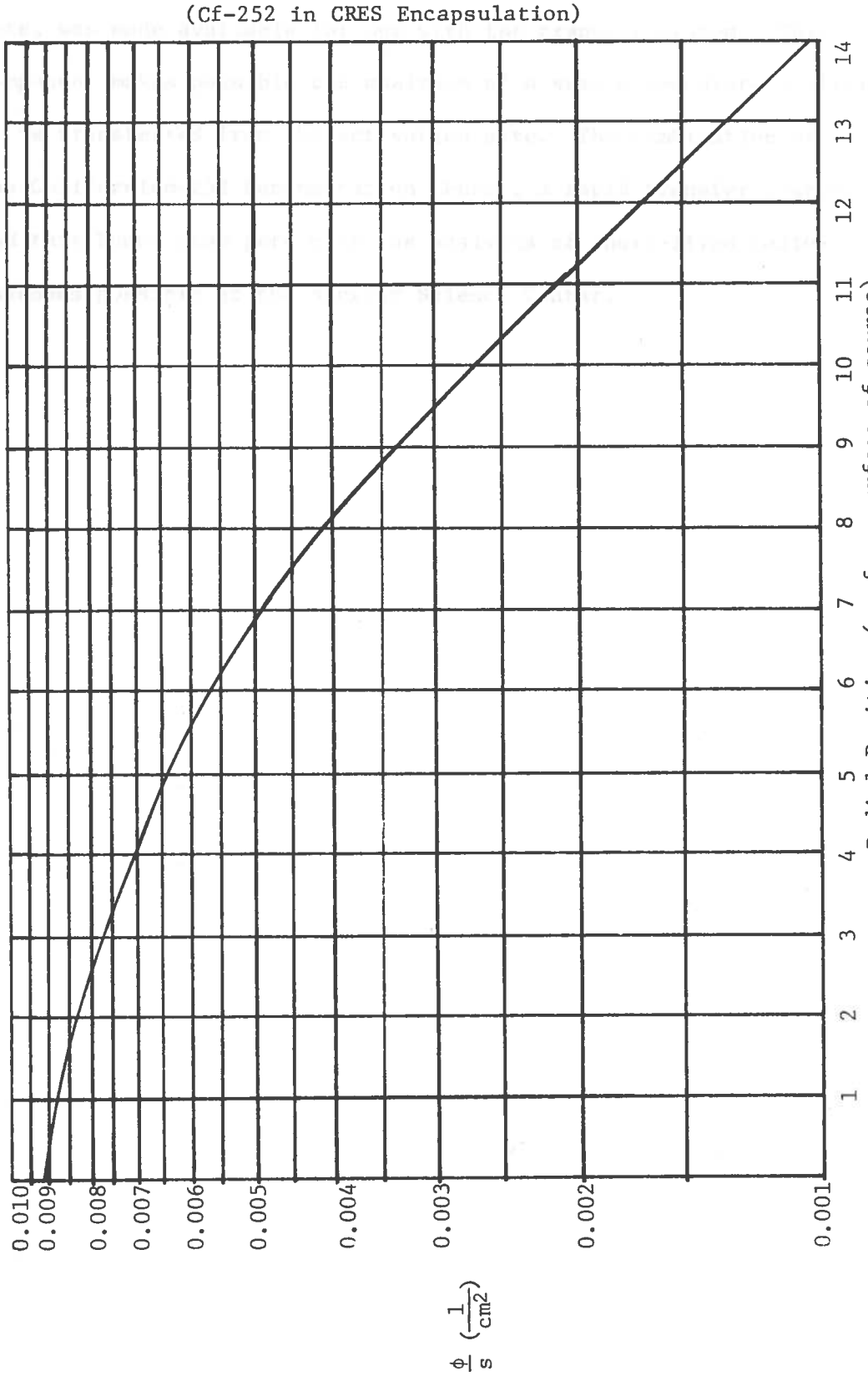

Figure 3-1

Subcadmium Flux vs Distance in Water (8)

gate, was made available for use with the transfer system. This component makes possible the analysis of a sample immediately after it is transferred from the activation site. The combination of the Californium-252 Demonstration Center, a rapid transfer system, and this bunny stop gate make the analysis of short-lived radioisotopes possible at the Nuclear Science Center.

CHAPTER IV

Results

After constructing the transfer system console and the activation terminal, the site for the analysis instruments was selected close to the californium storage tank. Survey meter readings indicated that the gamma background for the area above the classroom and behind the air conditioning unit was usually less than 0.5 mR/hr. The other site surveyed was at the top of the stairs to the graduate student offices and normally read greater than 1.5 mR/hr.

The transfer system was assembled and 2 dram polyethylene bunnies containing approximately 10 grams of lead were transferred to establish the time required to return a sample after activation. Initial tests indicated that one-way transfer time was approximately six seconds. The time delay relays (K9 and K10) were adjusted to operate at the same time that the sample arrived at its destination.

Next, the transfer system was used in conjunction with activation analysis. The transfer time was observed to be significantly reduced because the ten and sometimes fifteen grams of lead used to calibrate the transfer time represented an unrealistically heavy sample weight. The light-weight samples usually used in activation analysis were transferred in approximately three seconds. The time delay relays were reset and activation analysis commenced.

Nine isotopes were selected to test the activation analysis system when used in conjunction with the transfer system. The choice of these isotopes was based on their: (1) availability, (2) cross-section, (3) activation product(s), (4) half-life of product, and (5) gamma spectrum of the product.

The photopeak from the 2.2 second metastable state of In-116M2 could easily be observed when the transfer system was used. Observation of this photopeak was not previously possible when using the facilities of the Nuclear Science Center. Three other radio-isotopes whose activities diminish below detectable levels within one minute were observed. Appendix B contains the spectra observed and the activation, decay, and count times required to duplicate these results.

CHAPTER V

Conclusions and Recommendations

The design objective for a transfer system (presented in Chapter III) were attained; especially the reduced cost aspect. The transfer system and activation terminal has been used in conjunction with current Nuclear Science facilities to complement laboratory and classroom instruction. Operation has been satisfactory in terms of simplicity of handling and dependability. Because the time required to prepare the system for activation analysis is minimal and characteristic of short-lived radioisotopes can now be observed, this system makes quick demonstrations possible. Using a short-lived sample, radioactive decay can be demonstrated in less time than was formerly possible at the Nuclear Science Center. The control system should be applicable to operation of the Cockcroft-Walton accelerator as well as the Cf-252 Demonstration Center.

Several features can be added to the transfer system to improve convenience, versatility, and timing accuracy. First, counters that drive visual displays can be included so that the activation and decay times can be constantly monitored and accurately recorded. If the counters are accurately calibrated, they can replace the current electronic timers. A single clock-type elapsed time monitor is used at this time. This dictates that both the activation and the decay times cannot be monitored, although the system has the

designed capability of doing so. An alternative to the two counters with digital displays would be to add a second elapsed time indicator.

A second design change could possibly reduce the sample transfer time. This change would start the air supply prior to the actuation of the directional air flow valves. By having the motor at full speed the pneumatic pressures required for sample deliveries could be reached more rapidly. Reduction of the transfer time to approximately one second by this improvement could increase the number of short-lived radioisotopes that can be observed (e.g., Pb-207M and Cl-38M).

Another change can be made which would expand the capability of the decay timer to a shorter time range. This can be done in two ways: First, if the existing time range is too long, the capacitor and/or resistor values can be decreased to reduce the upper limit of the time range. To reduce the lower limit of the time range, the capacitor value must be lowered. Second, if the existing time range is needed and an additional time range is required, this timer can easily be modified to duplicate the activation timer which has two time ranges. Because the lower limit of time is 0.1 minute, this modification should be made to fully utilize the existing and future rapid transfer capabilities of this system.

The installation and simultaneous use of a second five-inch NaI(Tl) crystal should improve the counting statistics of the present system. For most of the samples usually activated (not short-lived)

this addition is not necessary. In the study of short-lived radioisotopes which decay with the emission of high energy gamma rays, the additional crystal would expand the analysis capability of the system by allowing gamma-gamma coincidence counting. This is a helpful, and sometimes necessary, feature.

An intercom system or labled sound detection device can be installed to listen for the sound of the impact when the sample arrives in the activation terminal and activation actually begins. The audible indicator currently used--the increased pitch of the motor speed lags behind the actual event. An alternative method of detection could consist of a remotely monitored air flow indicator on the intake/exhaust pipe of the activation terminal. Accurate flux determinations require that the residence time of the sample in the source be accurately known. To perform reliable flux measurements with this transfer system, an accurate sample residence indicator must be added.

Any forseeable changes to the transfer system and activation terminal described in this thesis are minor and can be incorporated when necessary with simple modifications.

The study of radioisotopes with half-lives of approximately two seconds is now possible at the LSU Nuclear Science Center by using the Californium-252 Demonstration Center, this transfer system, and the readily available analysis instruments.

BIBLIOGRAPHY

1. Lamarsh, John R., Introduction to Nuclear Engr., 1975. pp. 21-23.

2. Lapp, Ralph E., and Andrews, Howard L., Nuclear Radiation Physics, 4th edition, 1972. p. 341.

3. Ross, Harley H., "Basic Nuclear Properties and Activition Analysis," Guide to Activation Analysis, edited by Lyon, William S., Jr., 1964. pp. 8-12.

4. Price, William J., Nuclear Radiation Detection, 2nd edition, 1964. p. 333.

5. Decell, Robert F., and Iddings, Frank A., Activation Analysis System at the Nuclear Science Center Louisiana State University: Installation, Use, and Operating Procedures, Aug. 2, 1965.

6. Mims, Forrest, M., III, Integrated Circuit Projects, Volume 2, 2nd edition, 1977.

7. Reactor Experiments, Inc. General Catalog 1977-78, et al., "Flexo-Rabbit Pneumatic Transfer Systems."

8. "Subcadmium Fluxes in Water Near Californium Sources," J. E. Morel and J. C. Courtney, to be published in Health Physics.

APPENDIX I

Transfer Console Description

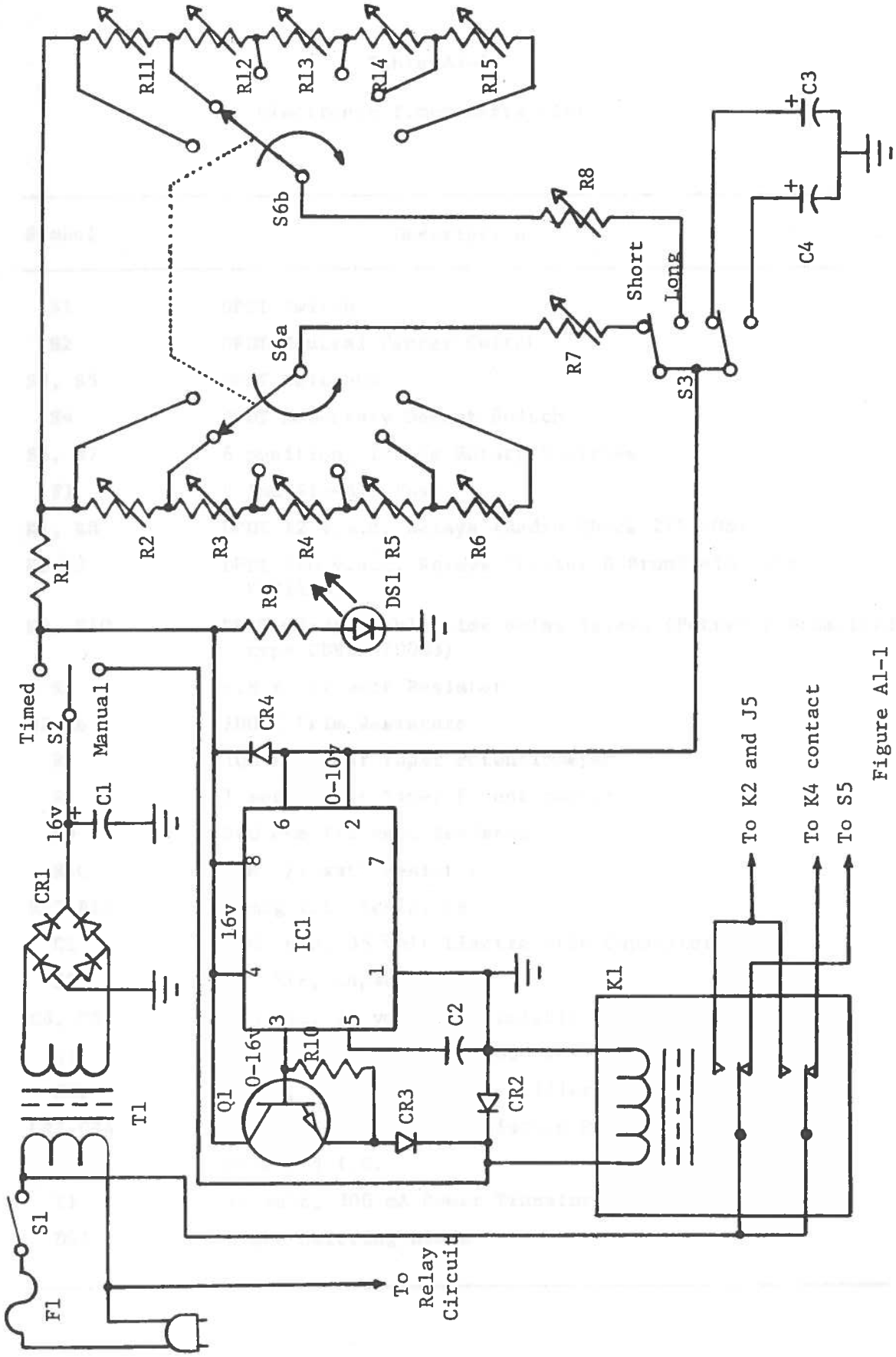

Figure A1-1

Modified Electronic Darkroom Timer

Table A1-1

Electronic Timer Parts List

Symbol	Description
S1	DPST Switch
S2	DPDT Neutral Center Switch
S3, S5	DPDT Switches
S4	DPDT Momentary Detent Switch
S6, S7	6 position, 2 pole Rotary Switches
F1	5 Amp Slo-Blo Fuse
K1, K8	DPDT 12 v.a.c. Relays (Radio Shack 275-206)
K2-K7	DPDT 120 v.a.c. Relays (Potter & Brumfield type KRP11AG)
K9, K10	DPDT w/adjustable time delay Relays (Potter & Brumfield type CDB38-70003)
R1	6.8 K 1/2 watt Resistor
R2-R6	100 K Trim Resistors
R7	100 K Linear Taper Potentiometer
R8	1 meg Linear Taper Potentiometer
R9	560 ohm 1/2 watt Resistor
R10	1 K 1/2 watt Resistor
R11-R15	1 meg Trim Resistors
C1	1000 Mfd, 35 volt Electrolytic Capacitor
C2	0.1 Mfd, Capacitor
C3, C4	470 Mfd, 16 volt Electrolytic Capacitors
Q1	SK3024, 2N1479, or RS2030 NPN Transistor
CR1	2 Amp, 50 PIV Bridge Rectifier
CR2-CR4	1 Amp, 50 PIV Microminiature Diodes
IC1	Type 555 I.C.
T1	12 volt, 300 mA Power Transformer
DS1	Light Emitting Diode

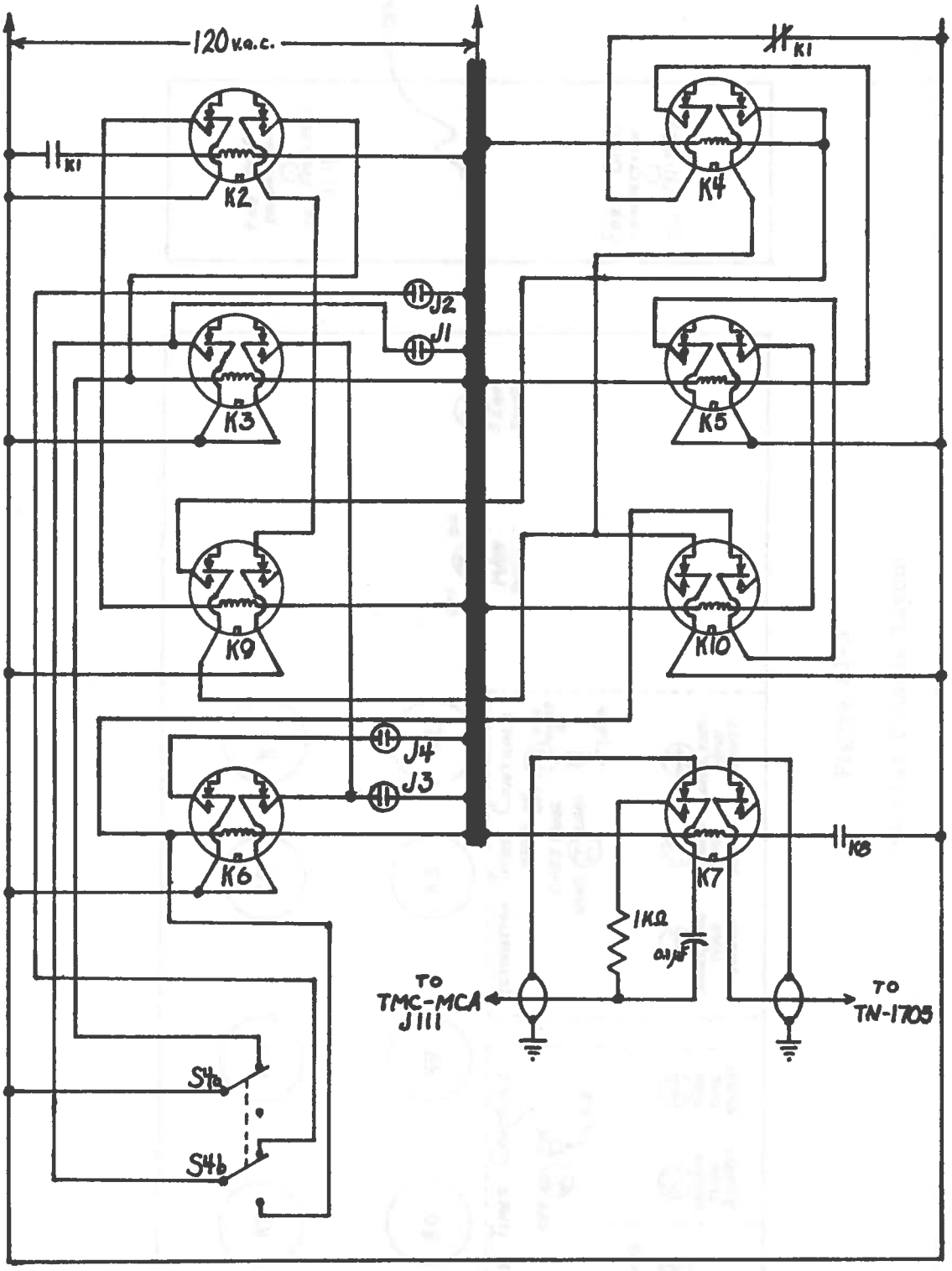

Figure A1-2

Relay Wiring Diagram

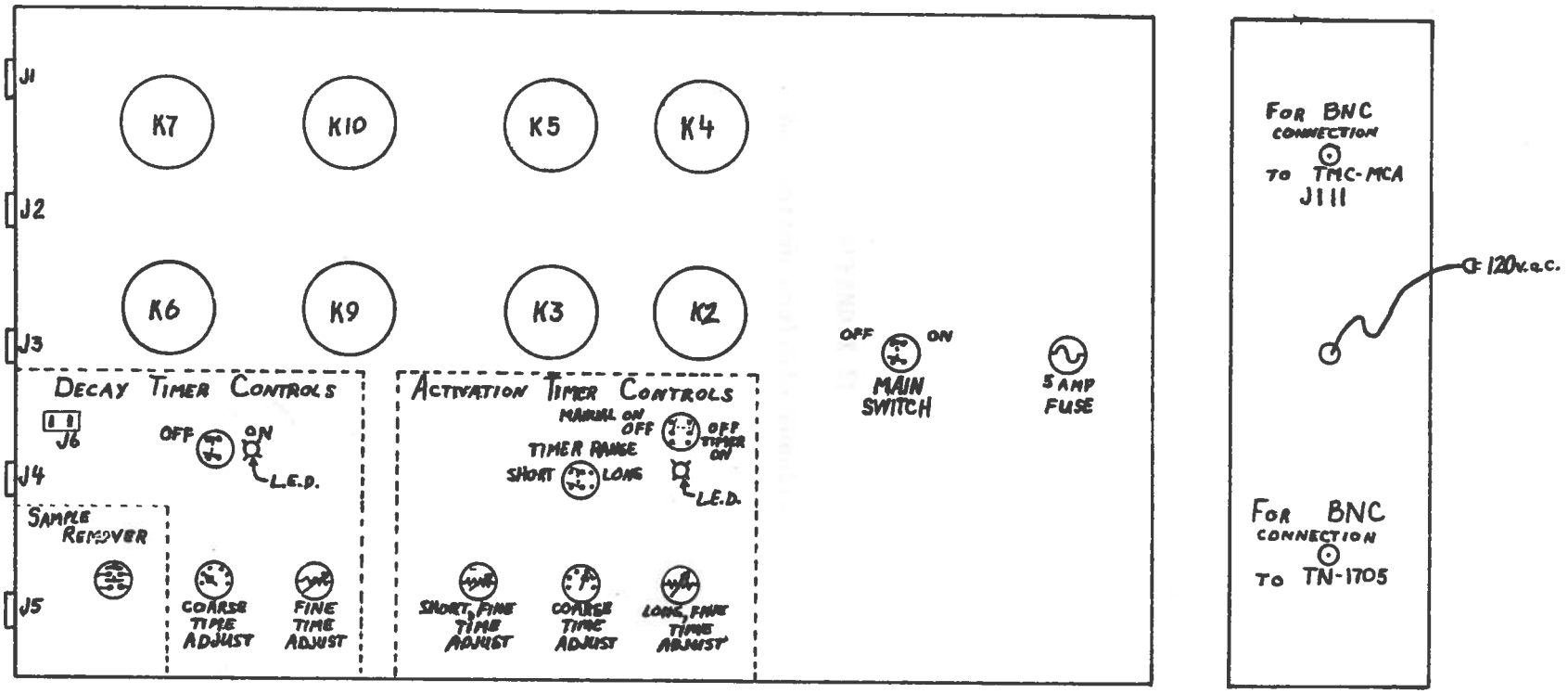

Figure A1-3

Transfer Console Layout

APPENDIX II

Activation Analysis Results

Table A2-1

Activation Analysis Data[1/]

Activation	σ(b)	$T_{1/2}$	Activation Time	Decay Time	Live Count Time	E_γ (MeV)
$^{19}F(n,\gamma)^{20}F$	$9.6 * 10^{-3}$	11.1s	1m	6s	1m	1.63
$^{19}F(n,p)^{19}O$		26.8s	1m	6s	1m	0.20, 1.36
$^{19}F(n,2n)^{18}F$		109.8m	1m	6s	1m	0.511
$^{19}F(n,\alpha)^{16}N$		7.1s	1m	6s	1m	6.13
$^{23}Na(n,\gamma)^{24}Na$	0.43	15h	10m	5m	1m	1.369, 2.754
$^{23}Na(n,p)^{23}Ne$		37.5s	10m	6s	1m	0.439
$^{37}Cl(n,\gamma)^{38m}Cl$	0.005	0.8s	20s	3s	20s	0.66
$^{37}Cl(n,\gamma)^{38}Cl$		37.2m	10m	6s	1m	1.60, 2.17
$^{51}V(n,\gamma)^{52}V$	4.88	3.76m	1m	6s	1m	1.43
$^{55}Mn(n,\gamma)^{56}Mn$	13.3	2.58h	30s	6s	1m	0.847, 1.811, 2.11
$^{75}As(n,\gamma)^{76}As$	4.4	26.3h	10m	6s	1m	0.559, 0.657, 1.22, 1.44
$^{79}Br(n,\gamma)^{80}Br$	2.4	17.4m	2m	6s	1m	0.511, 0.618, 0.666
$^{115}In(n,\gamma)^{116ml}In$	65	54.2m	1m	15s	1m	0.138, 0.417, 0.819, 1.09, 1.293, 1.508, 2.111

Table A2-1 (continued)

Activation	σ(b)	$T_{1/2}$	Activation Time	Decay Time	Live Count Time	E_γ (MeV)
$^{115}In(n,\gamma)^{116m2}In$	90	2.2s	15s	3s	10s	0.164
$^{197}Au(n,\gamma)^{198}Au$	98.8	2.695d	5m	1m	1m	0.412
$^{197}Au(n,n')^{197m}Au$		7.2s	45s	3s	40s	0.26

1/ 5000 μg of Cf-252 sources.

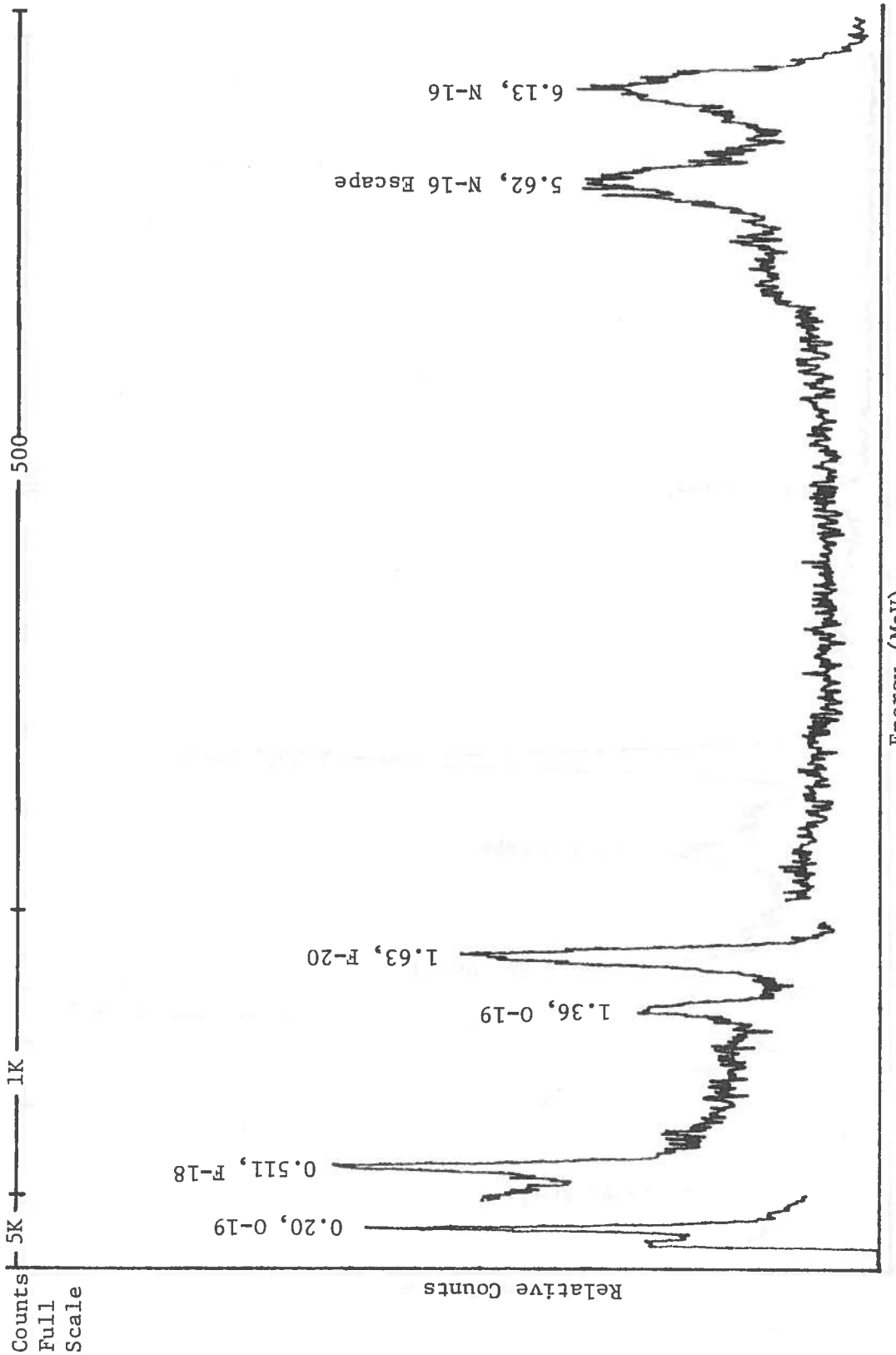

Figure A2-1. Ammonium Bifluoride Activation Spectrum

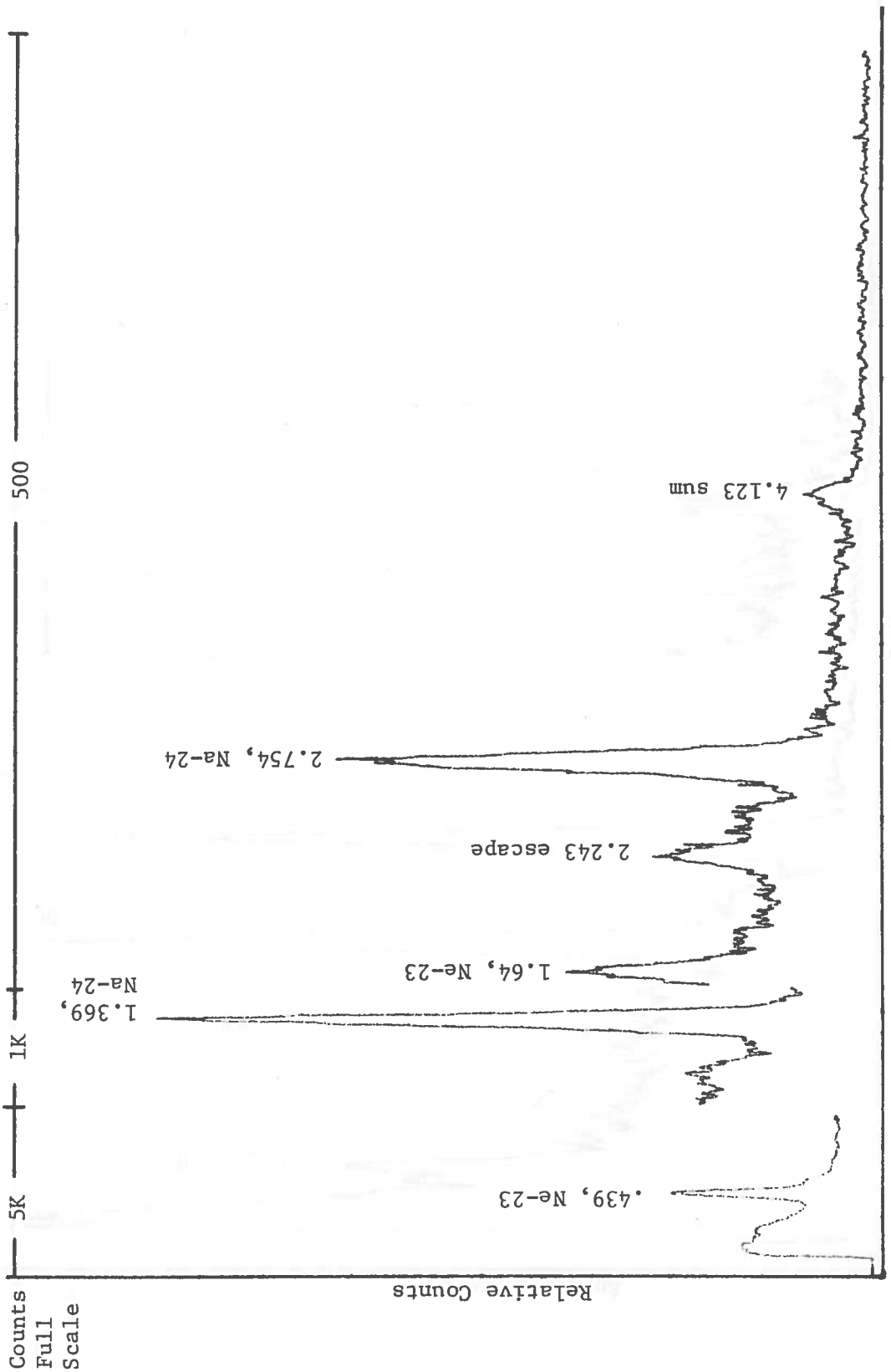

Figure A2-2. Sodium Activation Spectrum

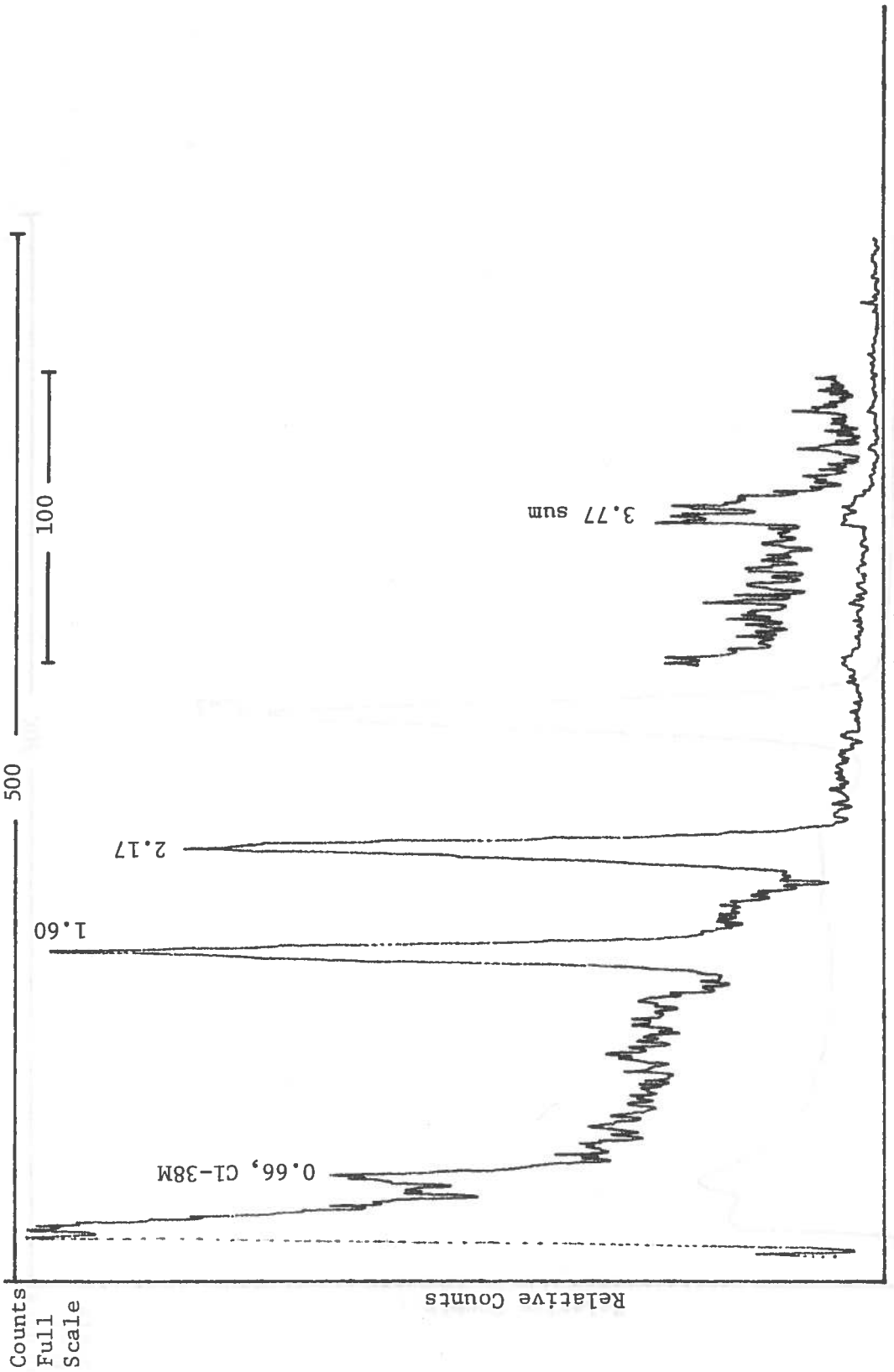

Figure A2-3. Chlorine Activation Spectrum

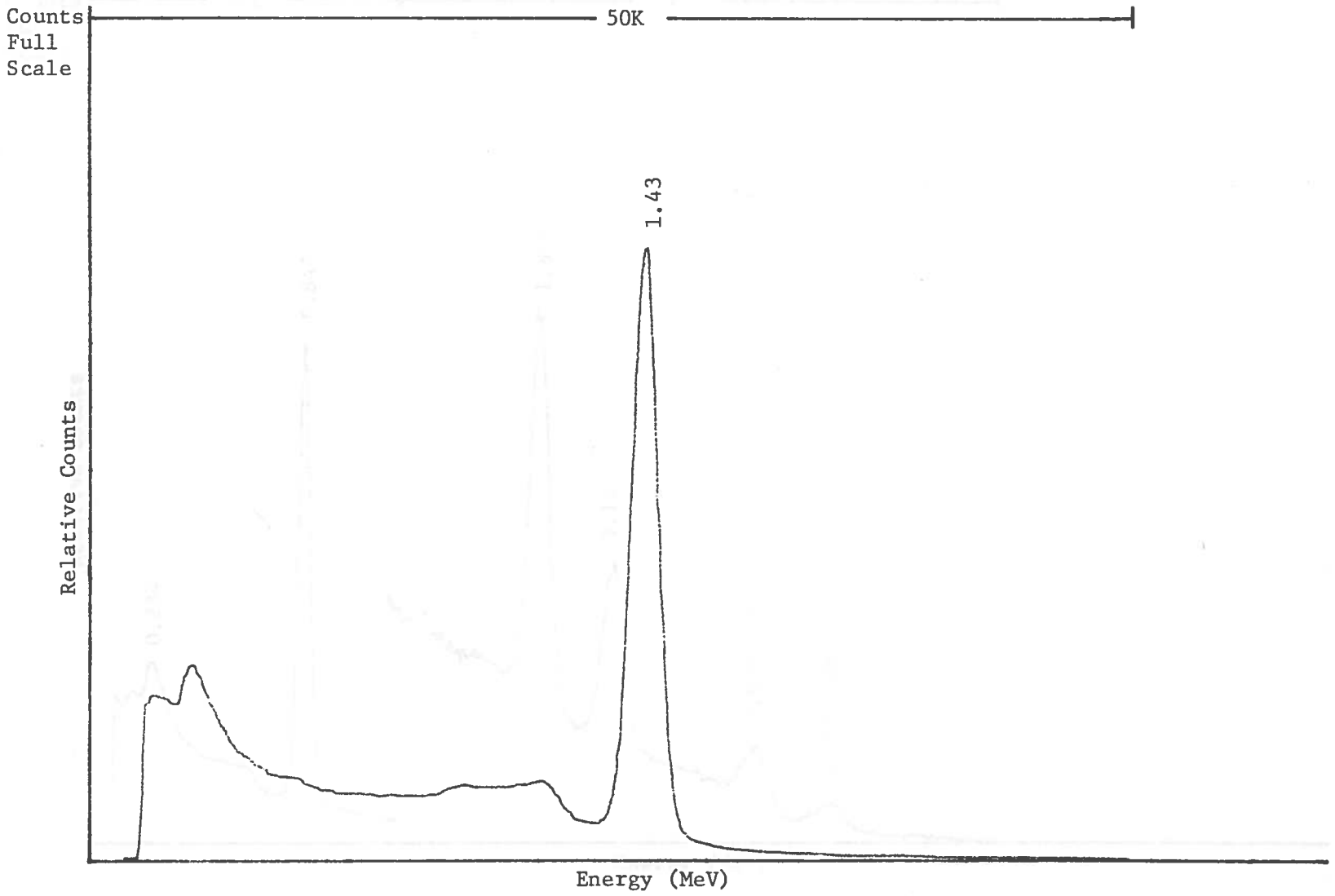

Figure A2-4. Vanadium Activation Spectrum

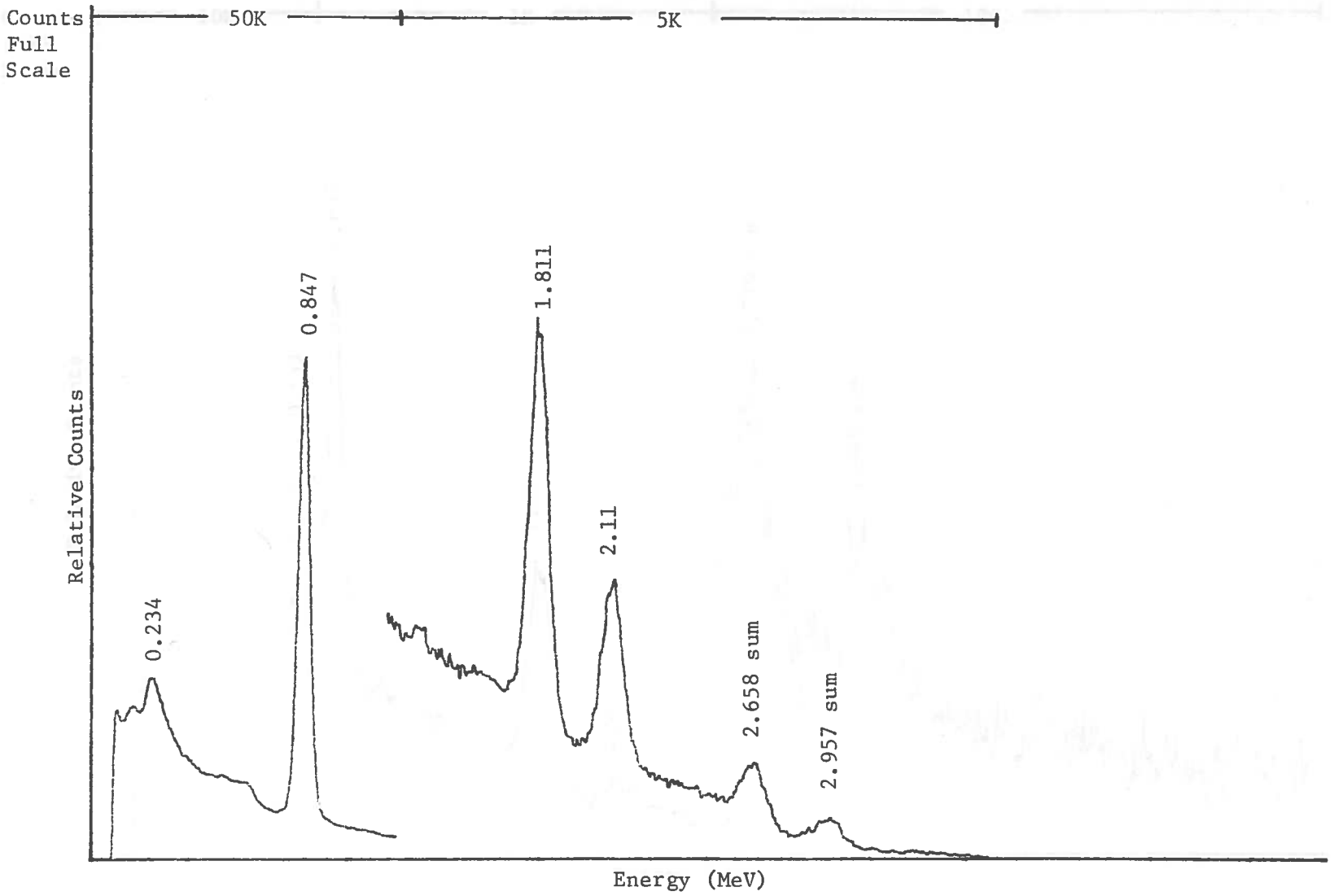

Figure A2-5. Manganese Activation Spectrum

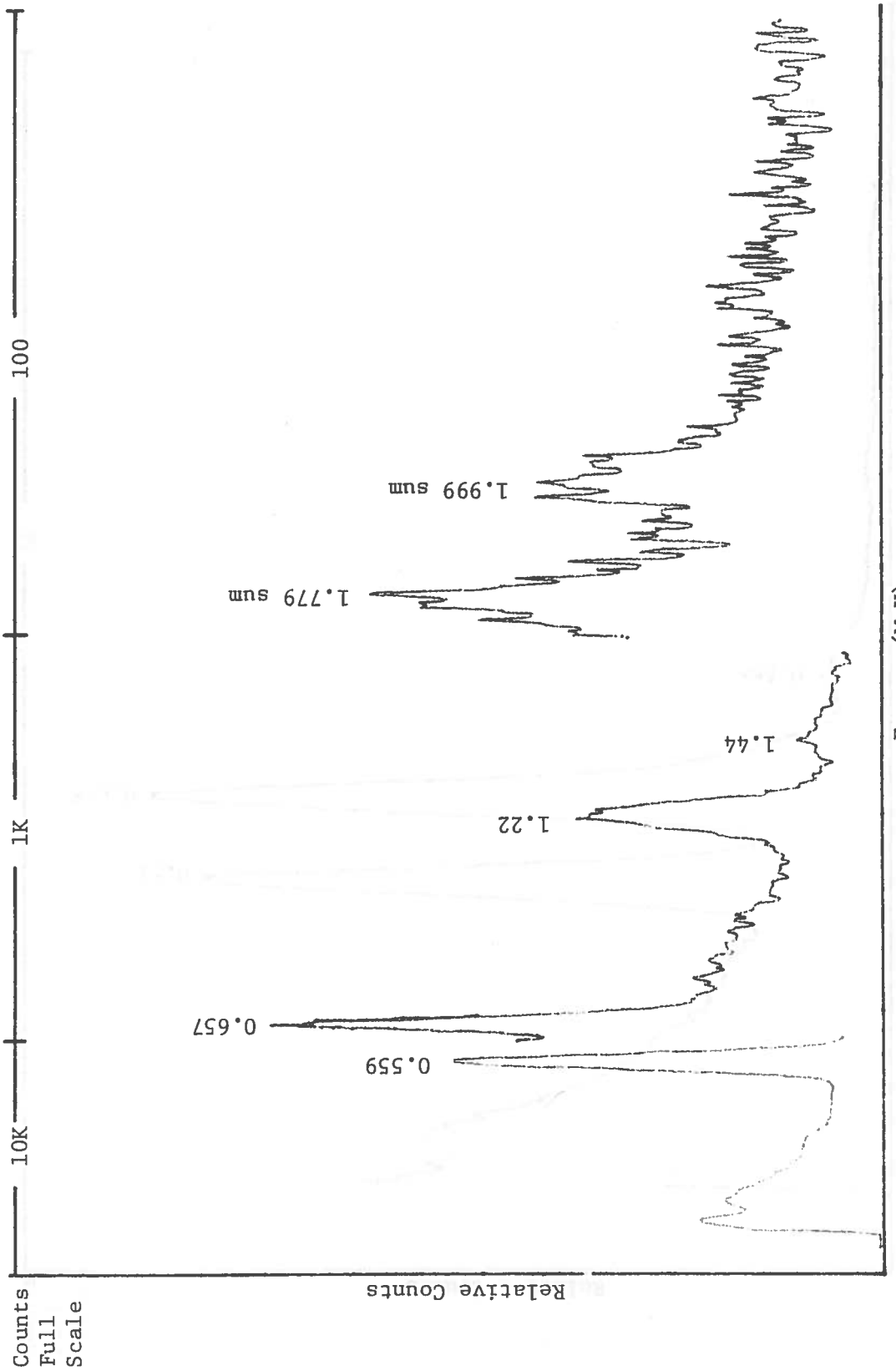

Figure A2-6. Arsenic Activation Spectrum

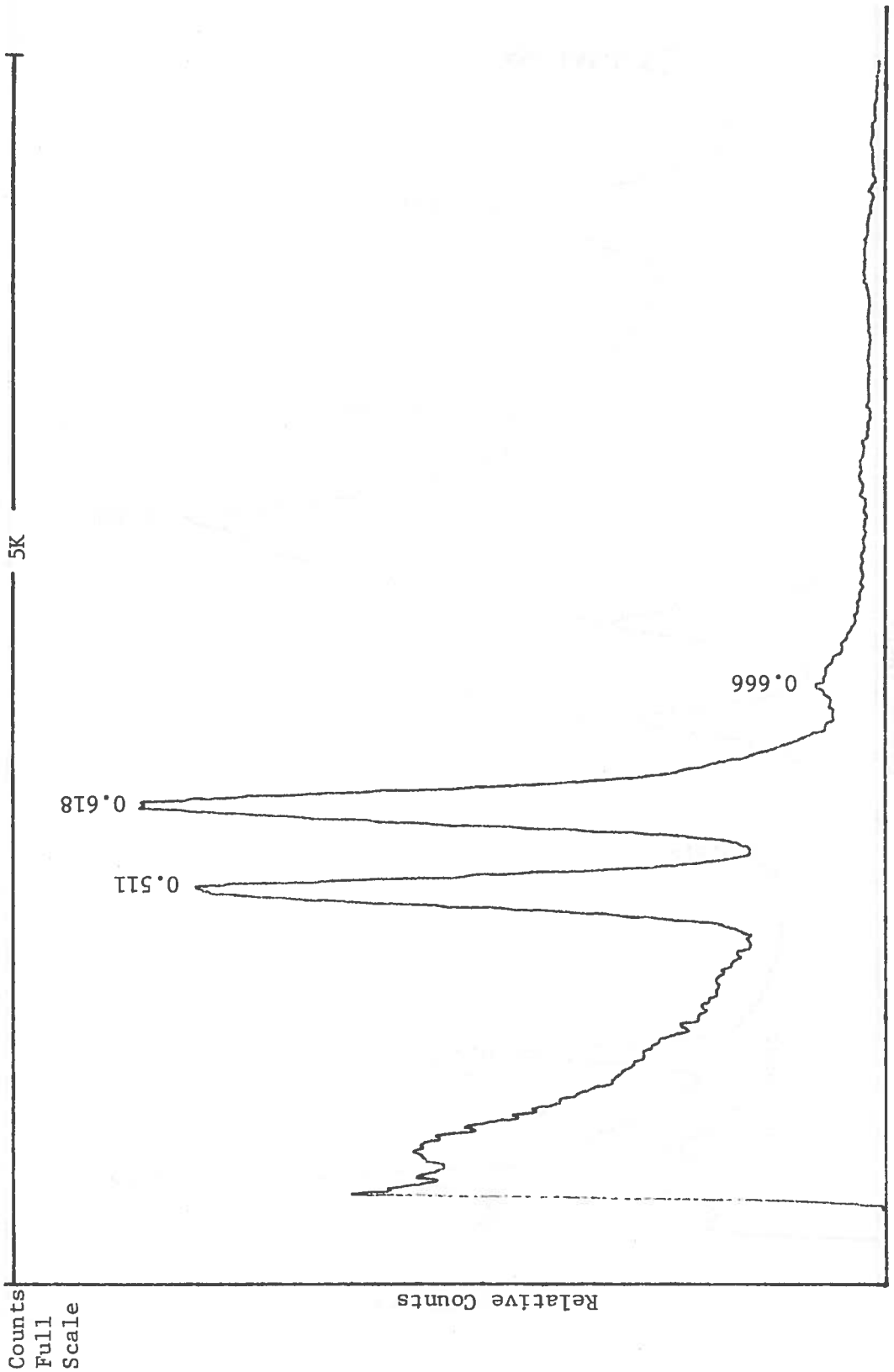

Figure A2-7. Bromine Activation Spectrum

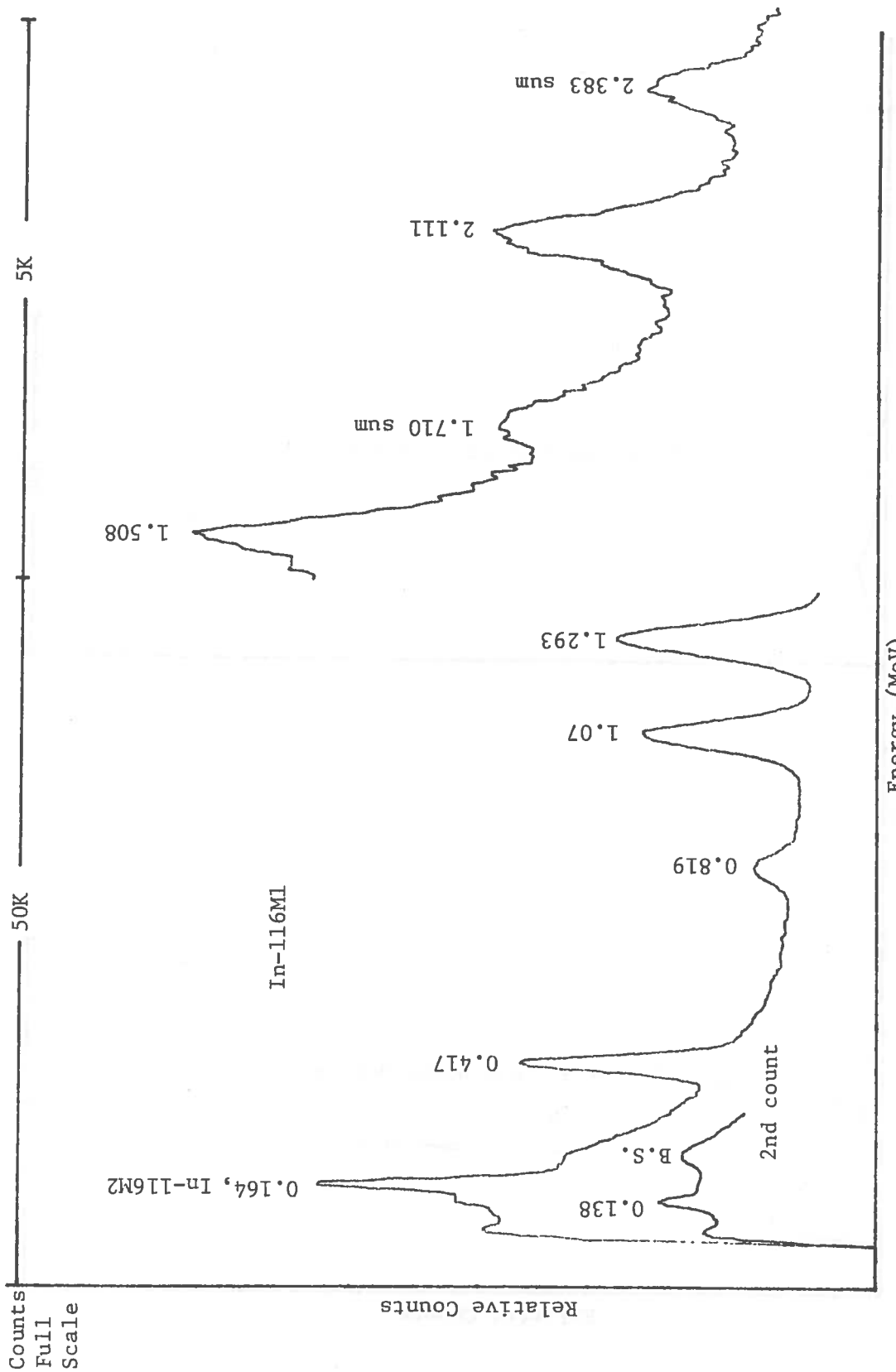

Figure A2-8. Indium Activation Spectrum

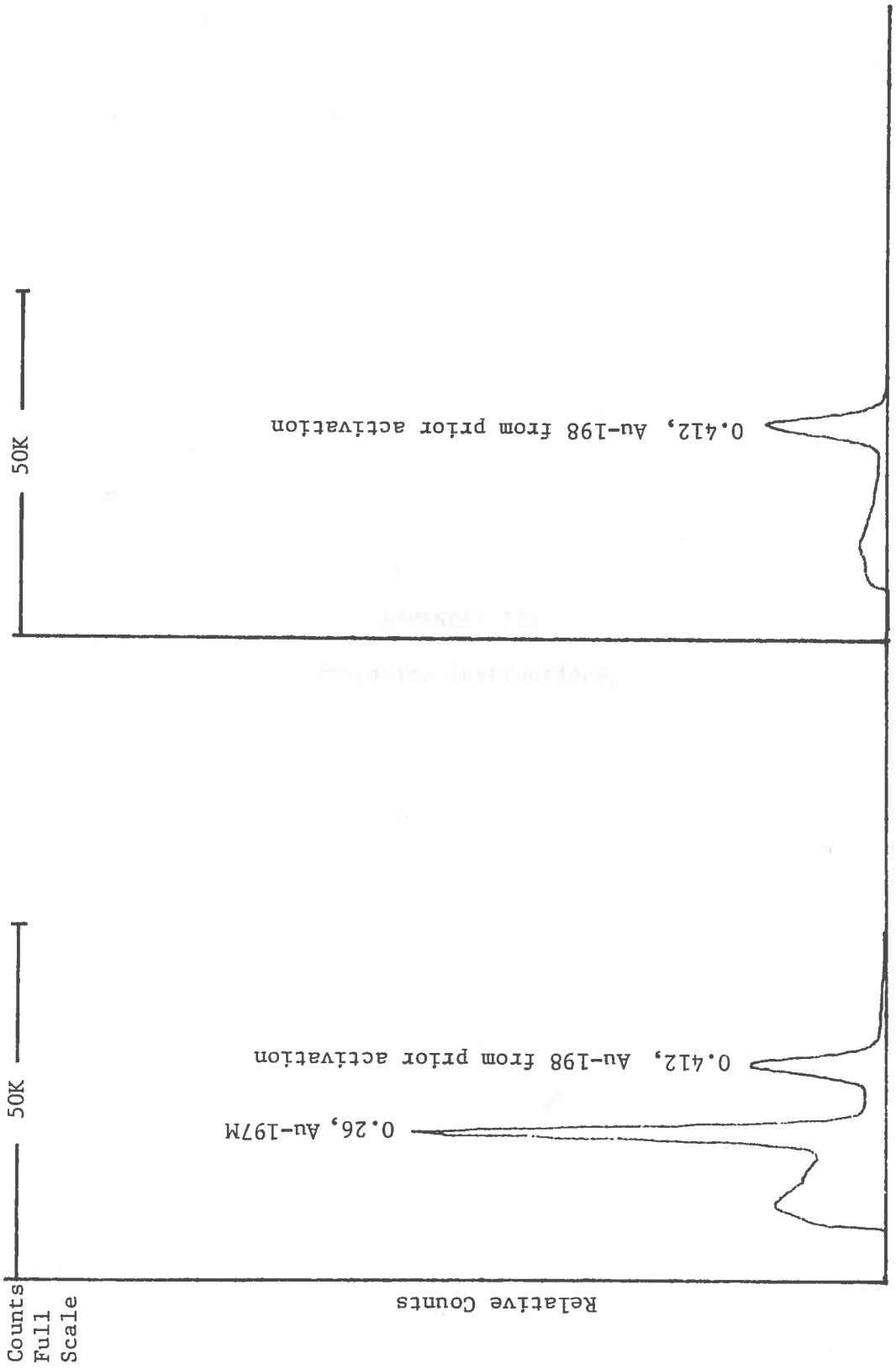

Figure A2-9. Gold Activation Spectra

APPENDIX III

Operating Instructions

APPENDIX III

Operating Instructions

I. Installing the Transfer System

A. Plug in the transfer system console and check for proper plug orientation as described in Chapter II.

B. Plug the air supply valves (solenoids), and clocks into their designated receptacles.

II. Operating the Transfer System

A. Choose the SHORT or LONG activation time range by switching the range switch (S5) to the proper position.

B. Add the setting of the COARSE control to the proper FINE control setting.

C. If decay timing is desired, set the decay time controls. (Add the COARSE and FINE control settings).

NOTE: Zero settings on both the COARSE and FINE controls require approximately six seconds for the decay timer and approximately five seconds for the activation timer.

D. Prepare the sample.

1. IMPORTANT. Cut off the rim on the bottom of the bunny so that the bottom is flat.

2. Place the bunny in the loader/receiver in the orientation that the cap is toward the air supply and the bottom is toward the activation terminal.

E. Turn the SYSTEM MAIN switch "ON".

F. Turn the ACTIVATE switch to "TIMED ACTIVATION".

G. Turn the DECAY TIMER switch "ON". (Optional).

H. Wait.

I. After the bunny returns, turn "OFF" the DECAY TIMER and TIMED ACTIVATION switches.

J. After counting is complete the bunny is removed from the system by depressing the SAMPLE REMOVER button until the impact of the bunny striking the LOADER/RECEIVER and push the bunny out with a pencil or other convenient device.

K. Turn <u>ALL</u> switches "OFF" to allow the capacitors to return to their ready status.

APPENDIX IV

Transfer System Cost

APPENDIX IV

Table A4-1

Transfer System Cost

Part Description	Quantity Used	Quantity Purchased	Unit Cost	NSC Cost
DPDT 120 vac relay	6	1	9.80	9.80
DTDT 120 vac time delay relay	2	1	67.00	67.00
DPDT 12 VDC relay	2	2	1.99	3.98
Type 555 IC	2	4	.79	3.16
12 volt power transformer	2	2	1.89	3.78
1000 µfd, 35 volt capacitor	2	2	1.49	2.98
500 µfd, 16 volt capacitor	3	3	1.49	4.47
0.1 µfd capacitor	2	0	.69	0
NPN transistor	2	3	.89	2.67
2 amp, 50 PlV bridge rectifier	2	2	1.29	2.58
1 amp, 50 PlV microminiature diode	6	15	.13	1.95
DPDT switch	2	2	1.59	3.18
DPDT neutral center switch	1	1	1.49	1.49
DPST switch	1	1	1.49	1.49
DPDT momentary switch	1	0	2.49	0
6 position, 2 pole rotary switch	2	2	1.89	3.78
100 K trim resistor	10	10	.49	4.90
1 Meg trim resistor	5	5	.49	2.45
100 K linear taper potentiometer	2	2	.99	1.98
1 Meg linear taper potentiometer	1	1	.99	.99
1/2 watt resistors	6	0	.29	0
PVC and polyethylene pipe	20'+100'	all	$20	20.00
handy box	1	1	11.35	11.35
miscellaneous (sockets, etc.)				20.00
				174.18

VITA

Craig Henry Greene, son of Mr. and Mrs. George H. Greene, was born on April 26, 1950, in Fenton, Louisiana. He graduated as Valedictorian from Fenton High School in May, 1968. In the fall of the same year, he entered Louisiana State University and graduated from that institution in December, 1973, with a Bachelor of Science degree in Electrical Engineering. After graduation, his part-time employment at Barbay Engineers, Inc. of Baton Rouge changed to a full-time job. In August, 1974, he moved west to work for Los Angeles Department of Water and Power. Fifteen months later, in November, 1975, he returned to Louisiana and shortly thereafter began his graduate study in Nuclear Engineering at Louisiana State University. At present, he is a candidate for a degree of Master of Science in the Department of Nuclear Engineering.