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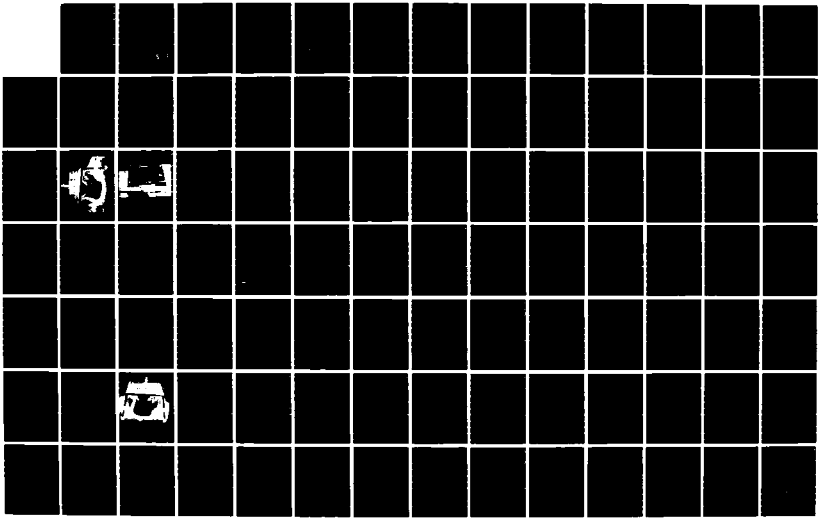

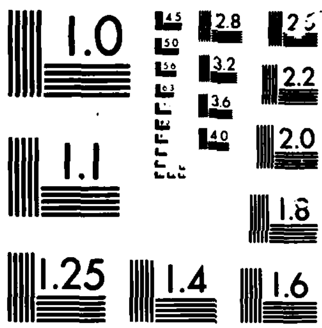


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# Final Report for Phase I
for
Contract DAAK70-85-C-0101
"Feasibility Study For Field Monitoring of Water Supplies for Radioactivity"

**Final Report for Phase I**
**for**
**Contract DAAK70-85-C-0101**
**"Feasibility Study For Field Monitoring of Water Supplies for Radioactivity"**

Submitted to:

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## Section 1.

## EXECUTIVE SUMMARY

The feasibility study for field monitoring of water supplies for radioactivity has been completed. A detailed review of commercially available charged particle detectors was completed and a "ruggedized" silicon surface barrier (SSB) detector was selected for use in the en-ineering prototype field water radioactivity monitor (FWRM). A review of the fission products and daughter products was also conducted to identify the types and energies of particles or photons present in the environment after a bomb detonation. The review identified Sr-90/Y-90 and Cs-137 as the more dangerous of the radionuclides present in the environment following an event. In the case of "seeded" bombs, it was determined that cobalt (Co-60) is a dangerous element that must be considered for analysis in the design of the FWRM. Tests were conducted with both Cs-137 and Co-60 gamma ray backgrounds. Sr-90/Y-90 was identified as the charged particle emitter that the FWRM would be designed to detect, since Sr-90/Y-90 emits betas with average energies of 0.7 and 0.93 MeV and is representative of the range of beta energies from mixed fission products.

An engineering prototype FWRM was constructed and subjected to a large number of tests to verify its ability to detect Sr-90 at concentration levels of 1000 pCi/liter. The sensitivity of the FWRM to Sr-90 of that concentration in water in a 100 mR/hr Cs-137 or Co-60 field was established. Under the condition of a 100 mR/hr Cs-137 field, the signal (Sr-90 in water) to noise (Cs-137 background) with electronic discrimination against low energy electrons created by background gamma rays was >100.[1] Because of the much higher energies of gammas from Co-60, electrons created by gamma ray interaction in the water are much more energetic. This creates a problem in achieving accurate analyses of the field water. A method of overcoming this problem is discussed in Section 8.2.

1. Practically the signal-to-noise ratio was much higher since the background-gamma-created electrons were almost completely ignored electronically by appropriately setting the lower level discriminator on the single-channel analyzer.

## Section 2.

## INTRODUCTION

The major objectives of the Phase I research were to develop and demonstrate an engineering prototypic instrument which can detect low-level (1000 pCi/l of water) mixed fission products in water in the presence of a 100 mR/hr gamma background field. The developed instrument was to be rugged, portable, reliable, and easy to use. The detector, mixed fission product source geometry, and shielding (against the gamma background) must always be repeatable so that the output of the detector is a reliable measure of the radioactive contamination of the water being monitored.

The tasks carried out to accomplish the primary objectives were:

1. Selection of the detector.
2. Development of the source geometry and container geometry.
3. Design and construction of an engineering prototype FWRM.
4. Test of the engineering prototype FWRM to demonstrate acceptable sensitivity to the mixed fission product contamination source in water in the presence of a 100 mR/hr background, as well as ruggedness, simplicity, and the required portability.

The activities carried out in these tasks are described in further detail in Sections 3 through 8.

The basic philosophy used in the design of the FWRM was to make the beta activity of the fission products within the water the primary observation. The detector was to be immersed in the water to: (a) maximize its sensitivity to the mixed fission product radioactivity in the water and (b) shield the detector from the background gamma field (up to 100 mR/hr). The mixed fission product source was established from the literature researched.[(1),(2),(3)] A proposal for Phase II is presented in the Appendix, in which the engineering prototype will be developed into a field-usable manufacturable prototype.

## Section 3.

### RADIOELEMENTS PRESENT IN WATER IN THE POST-BOMB DETONATION ENVIRONMENT

In a nuclear explosion, fallout is produced when material from the earth is drawn into the fireball where it is vaporized, combined with fission products and other radioactive material, and condensed into particles which then fall back to earth. Several hundred different isotopes have been identified among the fission products. These isotopes, when included with those created by neutron activation, make up an array of gamma and charged-particle emitters. Most isotopes decay rapidly following a detonation, e.g., the number of curies of fission products present in the environment 40 days after a detonation is reduced by more than three orders of magnitude.

Of the radioactive isotopes present in the environment, Strontium-90 and Cesium-137 are considered to be the most dangerous products of the detonation of a "typical" bomb.[3] This situation is different when "seeded" bombs are considered. Bombs "seeded" with cobalt result in the generation of Co-60 at levels that are an order of magnitude greater than the amounts of Sr-90 and Cs-137 (See Table 1). Table 1 shows that, in the case of a "seeded" bomb, Co-60 is dominant while, in a typical nuclear bomb, Co-60 is not found in the environment in significant quantities.

Table 1

CO-60, CS-137 AND SR-90 YIELDS OF 20 MEGATON COBALT AND NUCLEAR BOMBS

| | 20 MT "COBALT BOMB" | 20 MT "NUCLEAR BOMB" |
|---|---|---|
| Fusion Blast | 10 MT | 10 MT |
| Fission Blast | 10 MT | 10 MT |
| Megacuries Fission Products formed (one-hour after detonation) | 5,500,000 | 5,500,000 |
| Kilocuries $^{90}Sr$ formed | 1050 | 1050 |
| Kilocuries $^{137}Cs$ formed | 1580 | 1580 |
| Kilocuries $^{60}Co$ formed | 378,000 | 0 |

All of these isotopes are beta emitters. Cobalt-60 and Cesium-137, in addition to being beta emitters, are also gamma emitters (Cobalt-60 emitted gammas are 1.17 MeV and 1.31 MeV and the Cesium-137 emitted gamma is 0.662 MeV). Lindsten[3] identified Sr-90 as probably the most harmful fission product. This observation along with the fact that Sr-90 very quickly reaches a state of secular equilibrium with Y-90 makes it the ideal source for use in determining the performance of the FWRM. That is, the Sr-90/Y-90 source emits betas with average energies of 0.2 and 0.931 MeV, allowing the testing of the detector over a wide energy spectrum.

## Section 4.

## SELECTION OF DETECTOR

### 4.1 Review of Commercially Available Detectors

A review of the commercial and technical literature[(4),(5),(6)] was conducted to determine the most appropriate detector for use in the FWRM. The detectors considered are presented in Table 2. Characteristics that were considered are: (1) ruggedness of design, (2) sensitivity to the predominate beta energies anticipated for detection, (3) detector noise, (4) capability for light-tight encapsulation, (5) cost, (6) area and thickness of the sensitive region, (7) power and amplification requirements, and (8) reliability. The complete set of characteristics was compared against the characteristics of commercially available semiconductor detector devices in order to select the best available device for this application.

### 4.2 Discussion of Selected Detector

Based on the review of the detectors given in Table 1 and the characteristics set forth above, TEC selected a "Ruggedized"™ silicon surface barrier (SSB) detector produced by EG&G ORTEC called a DIAD II

Table 2

CHARACTERISTICS OF POTENTIAL DETECTORS

| | Advantages | Disadvantages |
|---|---|---|
| Ionization Chambers | Rugged; can be made sensitive to betas or gammas. | Limited sensitivity given size constraints. Device cannot be made insensitive to gammas while retaining beta sensitivity. |
| Proportional Counters | Extremely sensitive to charge particles. | Typical configuration requires that samples be placed inside the chamber. Limited sensitivity given size constraints. Device cannot be made insensitive to gammas while retaining beta sensitivity. |
| Geiger-Mueller | Rugged; can be made sensitive to gamma or betas. | Requires large electric fields in sensitive volume. Responds to betas created by gamma interactions in the detectors walls and to betas incident on thin window. Limited sensitivity given size constraints. Device cannot be made insensitive to gamma while retaining beta sensitivity. |
| $S_I$(Li) | Small; high efficiency for electron (.15-5.MeV energy) | Cannot be operated at room temperature. Poor efficiency for photon with energy >150 keV. Light sensitive. |

Table 2 (Continued)

| | Advantages | Disadvantages |
|---|---|---|
| Cadmium Telluride | Room temperature operation; can be made very small. | Poor efficiency for all betas and gammas with energies >.661 MeV. Requires high voltage to operate. High Z material makes device sensitive to gammas. |
| Diffused Junction Detectors | Small; rugged when compared to surface barrier detectors. Sensitive to betas and less sensitive to gammas. | Contains dead layer through which the incident particles must penetrate before reaching depletion zone. Light sensitive. |
| Surface Barrier | Small; very sensitive to charge particles; can have depletion depth adjusted for beta detector; relatively insensitive to gammas; low voltage operation. | Light sensitive. |
| Ruggedized Surface Barrier | Small; very sensitive to charge particles; can have depletion depth adjusted for beta detector; relatively insensitive to gammas; low voltage operation. Is not sensitive to light. | Must be made water tight for this application (i.e., for use in FWRM). |

Table 2 (Continued)

| | Advantages | Disadvantages |
|---|---|---|
| Ion Implanted Sr Detectors | Very sensitive to charge particles; can be made with thin entrance window. Relatively insensitive to gamma rays. | Light sensitive. |
| Scintillation Detector | Can be made, by choice of crystal, sensitive to betas and gammas. | High voltage requirement; fragile photomultiplier and crystals. Temperature stability. |
| Hyper-pure Germanium Detector | Very sensitive to low energy gammas. | Must be operated at cryogenic temperature. Complicated system for field use. |

for the initial feasibility studies. This detector is extremely sensitive to betas, relatively insensitive to gammas, and is designed for field use. Thus, it would require minimum modification to make it usable for this application.

The DIAD II incorporates a hybridized preamplifier, shaping amplifier, single-channel analyzer, along with the SSB in a package that is shown schematically in Figure 1. The actual detector surface area is 600 $mm^2$ with a 3.96 cm outside diameter and a height of 1.57 cm.

An SSB detector(4)(7) consists of a piece of hyper-pure silicon with an electrode on each side, e.g., gold on one and aluminum on the other. The proper processing creates a Schottky or surface barrier to be formed on the silicon surface. The device becomes a large area diode. The width of the diode is an intrinsic region in which an interacting alpha, beta, or gamma particle creates electron-hole pairs. The number of electron-hole pairs are directly proportional to the energy deposited in the intrinsic region. The reverse bias causes the electrons and holes to be swept to the appropriate electrode generating a measurable charge.

The SSB is designed to detect beta particles and be transparent to gamma rays. Gamma rays interact by photoelectric effect and Compton scattering in the range of energies generally encountered with fission product radioelements. Both of these interaction probabilities are low in silicon when compared with the interaction probability of beta particles. However, even with a low probability of interaction, the

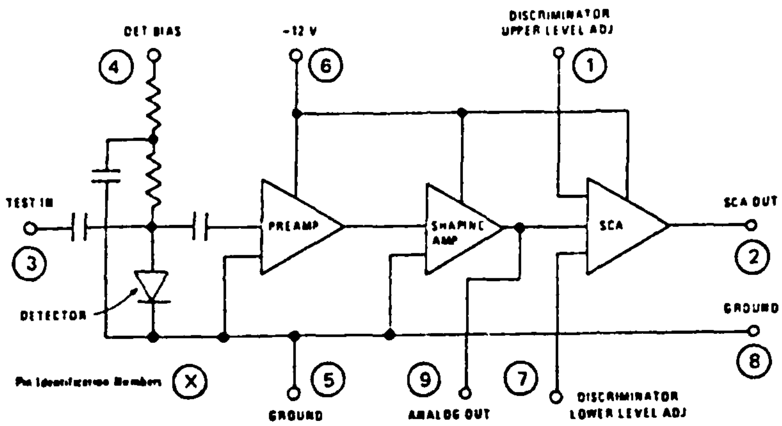


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Figure 1. Block Diagram of the Miniaturized Hybridized Preamplifier, Shaping Amplifier, Single Channel Analyzer and SSB System.

incidence of a large gamma flux on the surface of the detector results in a large, gamma-induced pulse rate in the detector.

The charge collected at the SSB electrodes is directly proportional to the energy deposited by the beta particles or gamma rays. By the proper choice of electronics, it is possible to discriminate against the Compton electrons generated by gamma interactions in surrounding materials and direct gamma interactions in the SSB since these both generally will result in much lower energy than the beta particles impinging on the SSB.

**4.3 Preliminary Test of Ruggedized SSB with Different Beta Sources**

TEC conducted several experimental tests with the selected SSB (DIAD II) detector to examine its sensitivity to beta particles of several different energies (see Table 3). A 100 mR/hr gamma background field was created with a Cesium-137 source. The output pulse from the DIAD II was fed to a single-channel analyzer.

A plot of the average energy of betas emitted by several beta sources (See Table 1) versus the lower level discriminatory setting of a single-channel analyzer is shown in Figure 2. The output response of the DIAD II detector to betas emitted by these sources varied almost linearly with the energy of the incident betas. In these experiments, the sources were positioned directly above the detector and the bias on the detector set to -20 volts. The depletion depth of the detector with a -20 volt bias applied to it is approximately 120 microns. The results

Table 3

BETA SOURCES USED TO TEST THE ENERGY
RESPONSE OF THE DIAD II DETECTOR

| ISOTOPE | AVERAGE ENERGY OF BETAS MeV | MAXIMUM ENERGY OF BETAS MeV |
|---|---|---|
| CARBON-14 | .049 | .158 |
| PROMETHIUM-147 | .062 | .225 |
| TECHNETIUM-99 | .085 | .295 |
| CHLORINE-36 | .252 | .714 |
| BISMUTH-210 | .390 | 1.161 |
| STRONTIUM-90 | .200 | .544 |
| YTTRIUM-90 | .931 | 2.24 |

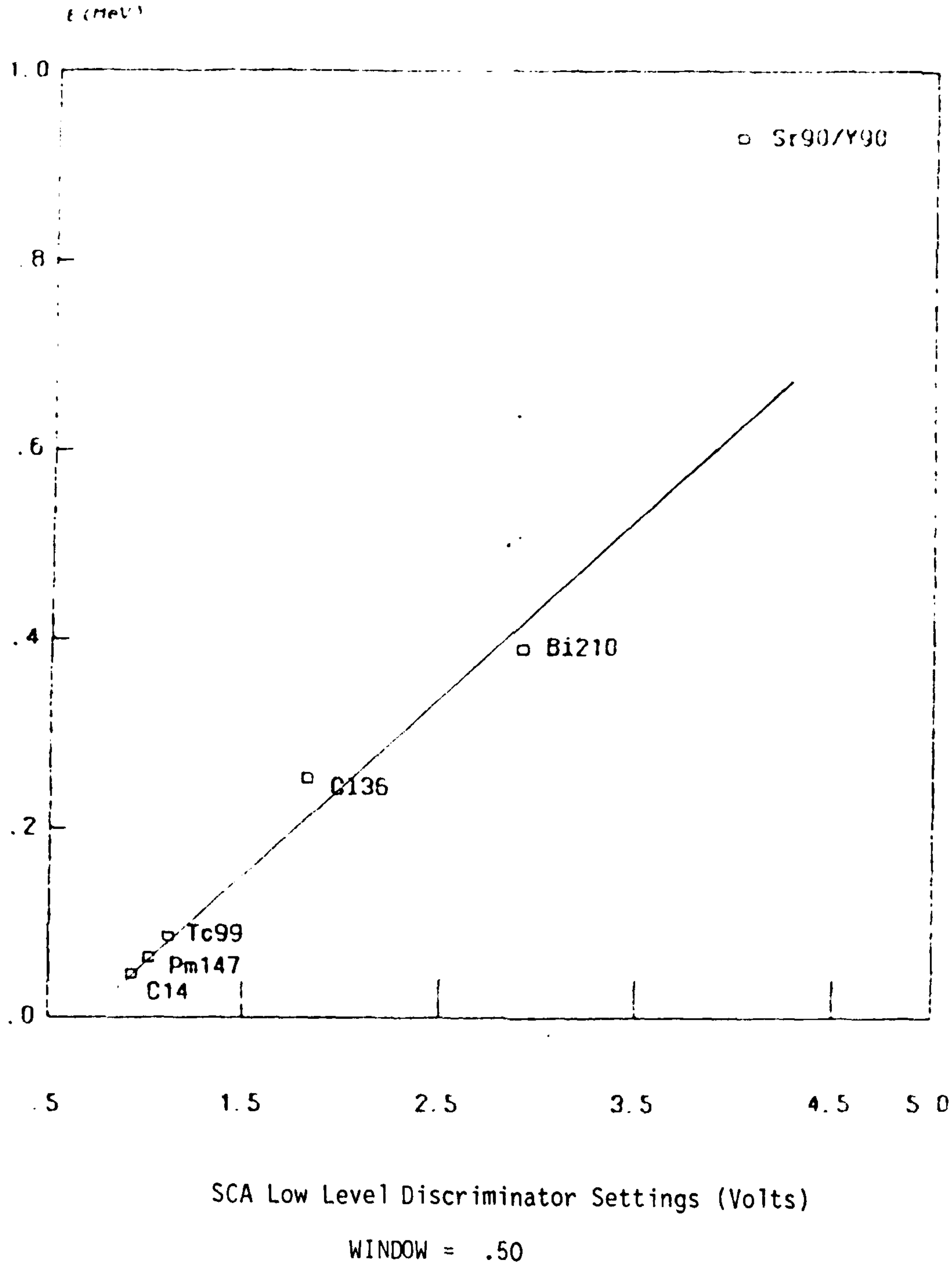



Figure 2. DIAD II Energy Response (AVG. E vs. DISC. V) with BIAS at -20V.

in Figure 2 demonstrate that, even with the encapsulation, the DIAD II is sensitive to betas with an average energy as low as 0.049 MeV.

The results of the preliminary tests of the detector in the presence of a 100 mR/hr gamma field created with a Cs-137 source are given in Table 4. The measurements were conducted with and without the presence of water in a one-liter container and the sensitive surface of the SSB detector was positioned slightly above the surface of the water. An 1100 pCi Sr-90/Y-90 source was used as the beta source during these tests.

The maximum amplitude of the output pulses from the DIAD II SSB detector was 1.60 volts when the gain of the amplifier was set at 100. The maximum amplitude of the output pulses due to the Sr-90/Y-90 betas interacting with the SSB detector was greater than 5 V. The Sr-90/Y-90 source was not submerged under water during these tests; instead, it was attached to the sensitive face of the detector. The preliminary tests demonstrated that the presence of betas can be detected from Sr-90/Y-90 in a 100 mR/hr Cs-137 gamma field by appropriately setting the discriminator level on the input to a single-channel analyzer.

Throughout these tests, the depletion depth of the SSB was 120 microns. At this depletion depth, most of the energy of the incident betas is not absorbed in the sensitive zone of the detector. The range of a 0.2 MeV beta in silicon is 229 microns.[8] This range is much greater than the thickness of the depletion layer in the DIAD II SSB used in these

Table 4

PRELIMINARY TESTS OF THE SSB USING A 1100 pCi Sr-90/Y-90 SOURCE AND A 100 mR/hr Cs-137 GAMMA BACKGROUND

| ~100 mR/hr BACKGROUND: | 4.8" UNDER DET. | 4.75" SIDE DET. | 4.75" ABOVE DET. |
|---|---|---|---|
| NO WATER | 3.3 cpm | 2.5 cpm | 3.6 cpm |
| WATER | 0.5 cpm | 1.2 cpm | 2.8 cpm |
| Sr-90/Y-90 SOURCE AND WATER | 20.4 cpm | 21.9 cpm | 24.9 cpm |
| NO BACKGROUND (< 0.01mR/hr) Sr-90/Y-90 SOURCE AND WATER | 19.9 cpm | | |

ELECTRONIC SETUP:

DEPLETION DEPTH 120 MICRONS
DETECTOR BIAS -20 V
LINEAR OUTPUT
AMPLIFIER GAIN 100X
SHAPING TIME 6u SEC
SCA WINDOW 10 V
LOWER LEVEL 1.60 V

measurements. To increase the detection efficiency of the FWRM system, a second detector with a greater depletion depth (300 microns) was selected for use in the engineering prototype unit. With a 300-micron depletion depth, the engineering prototype SSB would stop all betas with energies <0.2 MeV.

## Section 5.

## DESIGN OF ENGINEERING PROTOTYPE FWRM

The source container geometry and dimensions for this system were selected based on the source characteristics determined in Section 4 (e.g., beta energy spectrum).

In order to assure consistent, accurate results from the system, it was necessary to have an accurate repeatable source detector geometry. In addition, to meet the battlefield conditions, the source (water) container must be small and rugged. To meet these requirements, a collapsible container (e.g., rubberized cloth cylinder) was designed with a minimum amount of folding rigid structure to assure that the detector can be positioned consistently. More water is useful for shielding the background gamma field from the detector.

Figure 3 shows an assembly drawing of the FWRM. The water bag has a capacity of 3.3 liters. When the detector is inserted into the water, a thick layer of water is between the detector and the outer water bag surface. This thickness of water acts as an effective shield against gamma rays reaching the detector from outside the water bag. The detector holder in Figure 3 is designed to be inserted in the water to a

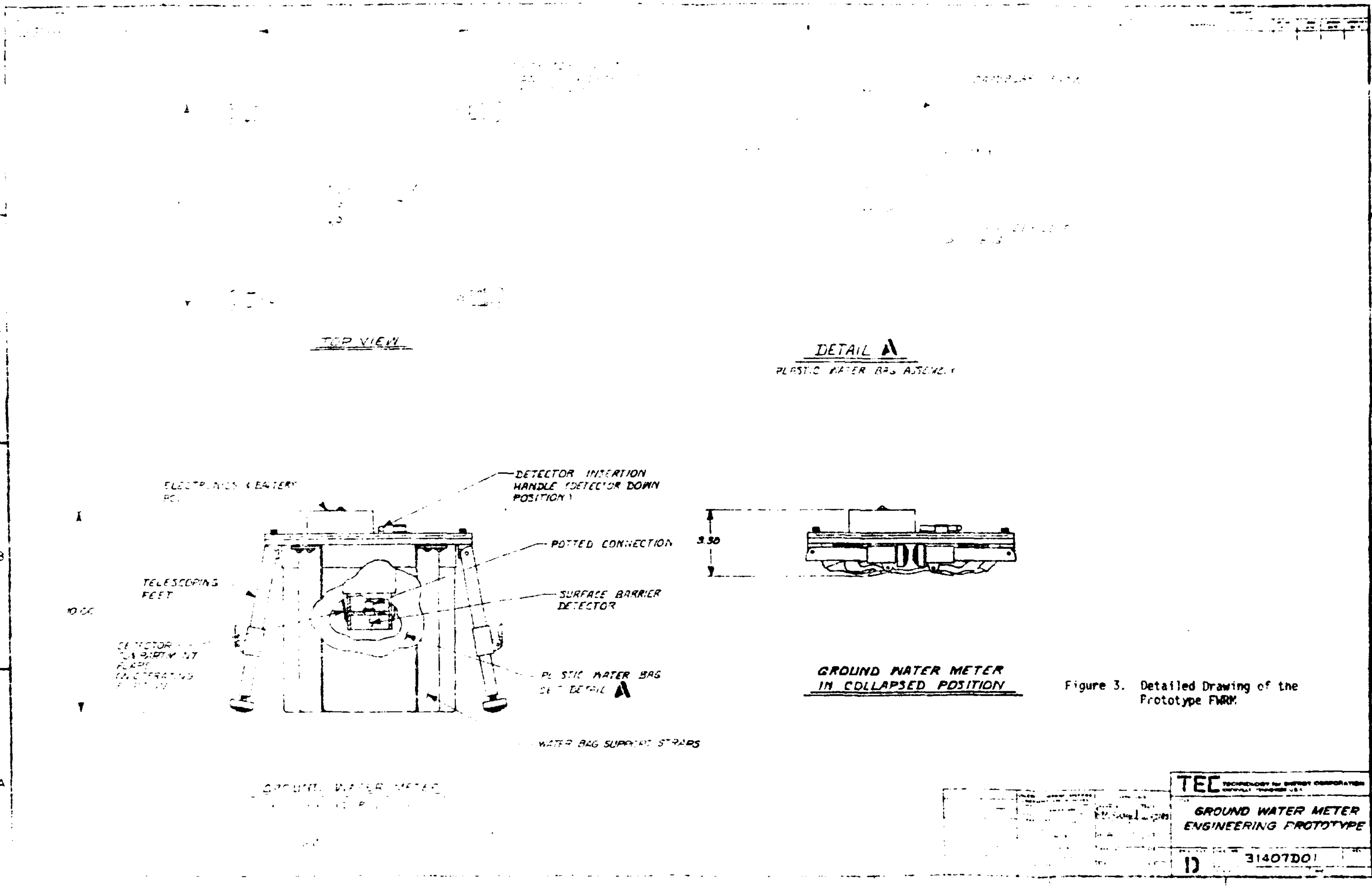



Figure 3. Detailed Drawing of the Prototype FWRM

depth of 6.35 cm when a sample of water is being analyzed for contamination.

The detector tube assembly slides inside a 3.81 cm I.D. laminated plastic tube. A 0.63 cm diameter metal shaft is attached to the rear of the detector assembly which acts as a plunger and is used to position the detector tube in the "down" (measurement) or "up" (storage) position. In the "up" position, the plunger shaft is designed to be clamped to the cover plate to hold the detector in this position. A rubber seal at the end of the outer tube prevents any moisture build-up between the two tubes.

The detector in the engineering prototype was potted in epoxy to prevent the leakage of water into the detector from the back. The front face was coated with an acrylic spray to protect its thin entrance window. The detector response to an 1100 pCi Sr-90 source was obtained before and after the acrylic coating was sprayed on, and it was determined that the sensitivity of the detector had not changed as a result of the process.

Photographs of the prototype FWRM are shown in Figures 4 and 5. In Figure 4, the FWRM is shown as it would be used in the field. Figure 5 shows the device in its collapsed state.

### 5.1 Engineering Prototype Signal-Conditioning Electronics

The early feasibility measurements were performed with a DIAD II SSB with on-board hybrid signal-conditioning electronics which included a

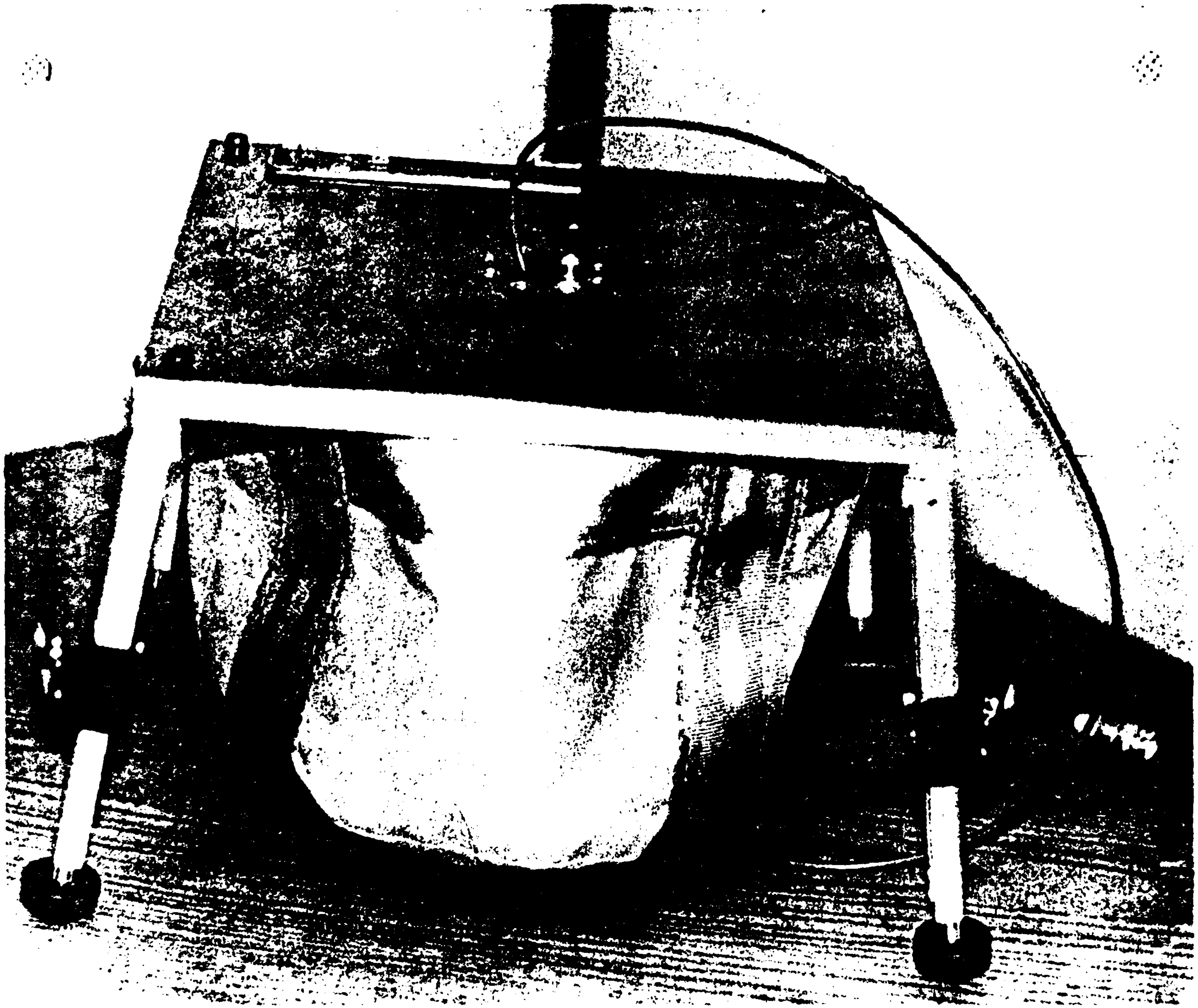


Figure 4. FWRM Shown as it Would be Deployed During Use.

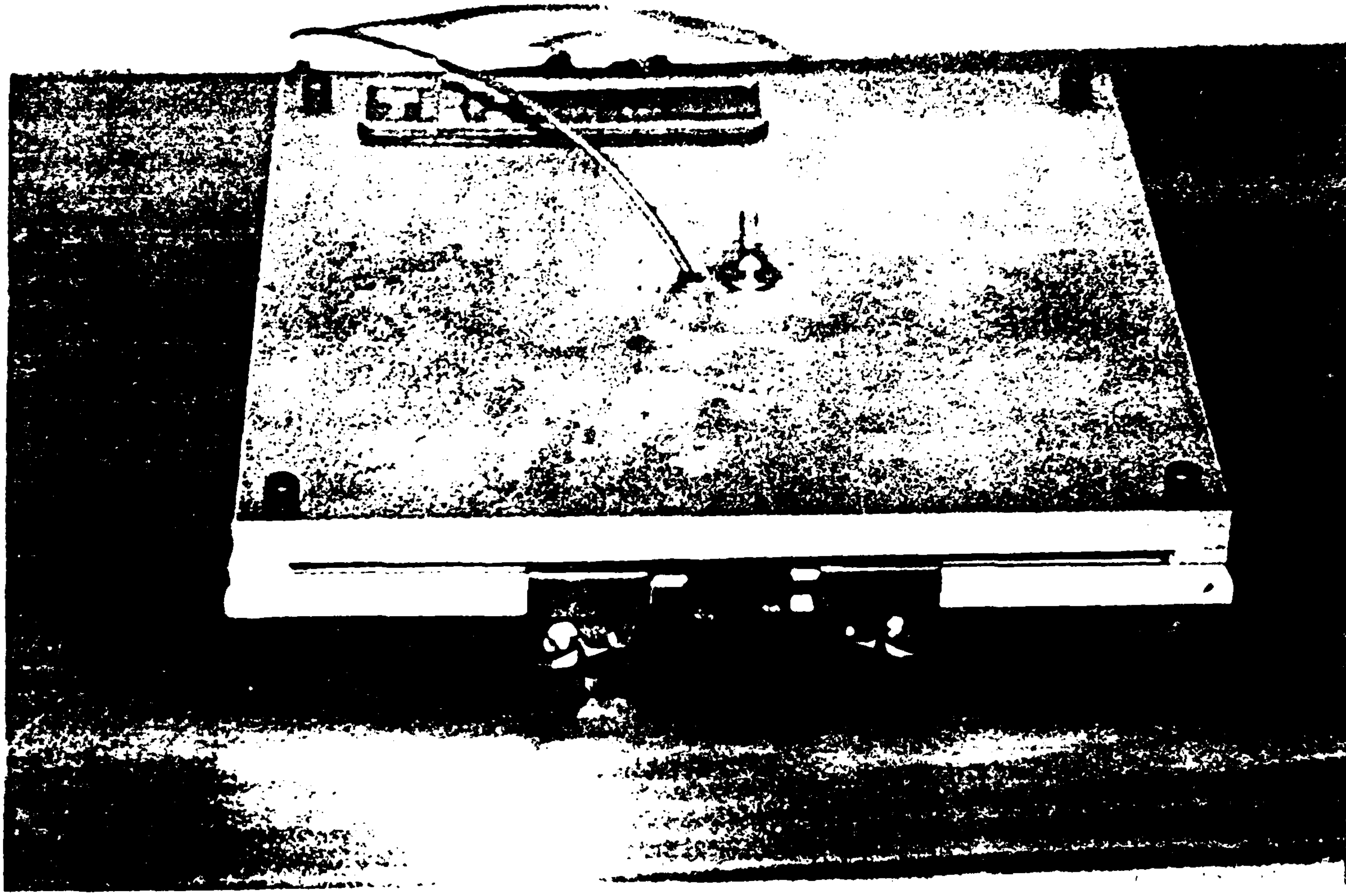


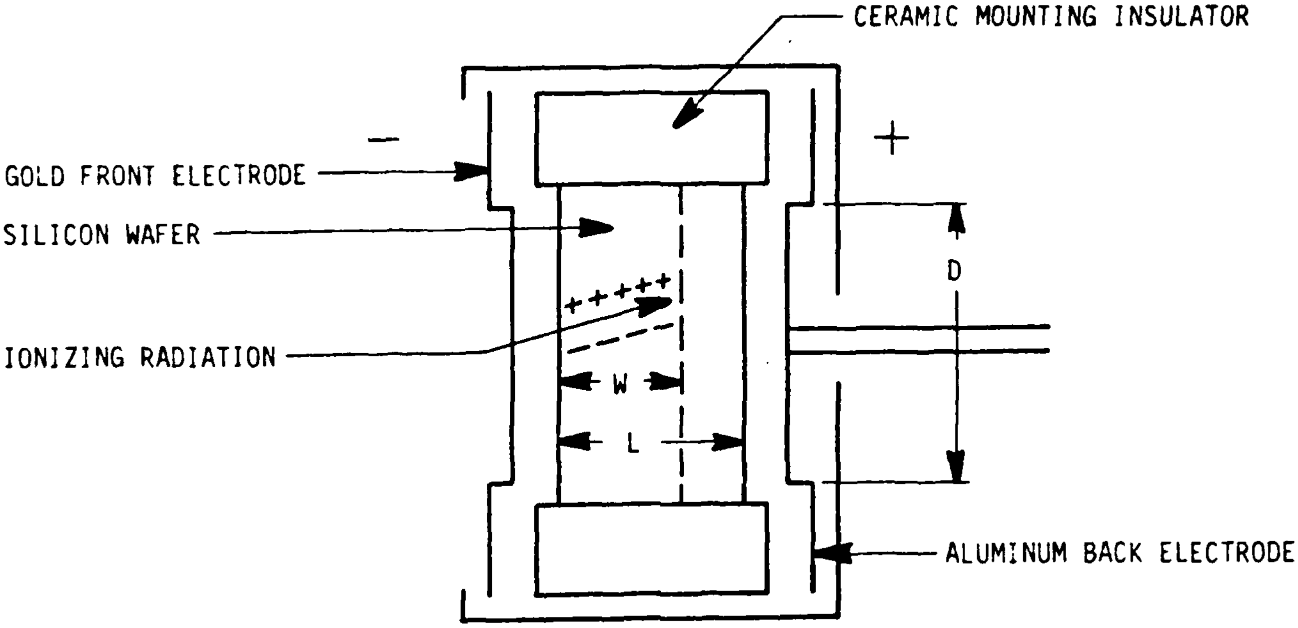
Figure 5. Prototype FWRM in Collapsed State.

preamplifier, amplifier and single-channel analyzer. These units were not available without long delivery schedules. Therefore, TEC purchased a ruggedized SSB (See Figure 6) with a depletion depth of 300 microns for use in the engineering prototype. This detector does not have on-board signal-conditioning electronics. The signal-conditioning electronics used in the prototype is shown in Figure 7.

The detector was connected to an external charge-sensitive preamplifier (preamp) via an RG 174 coaxial signal cable. The H.V. bias was connected to the preamp and applied to the detector through the signal cable. The linear output of the preamp was then amplified and analyzed with a single-channel analyzer (SCA). Pulses from the detector could be electronically rejected or counted by setting the lower level threshold of the SCA from 0-10 volts. The output pulses from the SCA were counted with a counter/timer. The amplifier, SCA, counter/timer, and high voltage supply are all NIM type modules and were contained and powered by a NIM instrumentation rack. The preamp is a stand-alone box with power supplied by a cable from the amplifier. Table 5 lists all of the instruments used during these measurements along with their settings.

**5.2 Conceptual Design of the Circuitry to be Used in a Field Unit**

The detector preamplifier, a shaping amplifier, and a single-channel analyzer are all contained in a miniature hybrid electronics package located at the detector (see Figure 8). Output pulses from the SCA are converted to 5-volt rectangular positive pulses with a constant width using a monostable multivibrator. The output pulse width is independent




W = 300 μm
L=
D= 450 mm²

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Figure 6. Schematic Drawing of the Ruggedized Beta SSB Detector with a 300 Micron Depletion Depth.

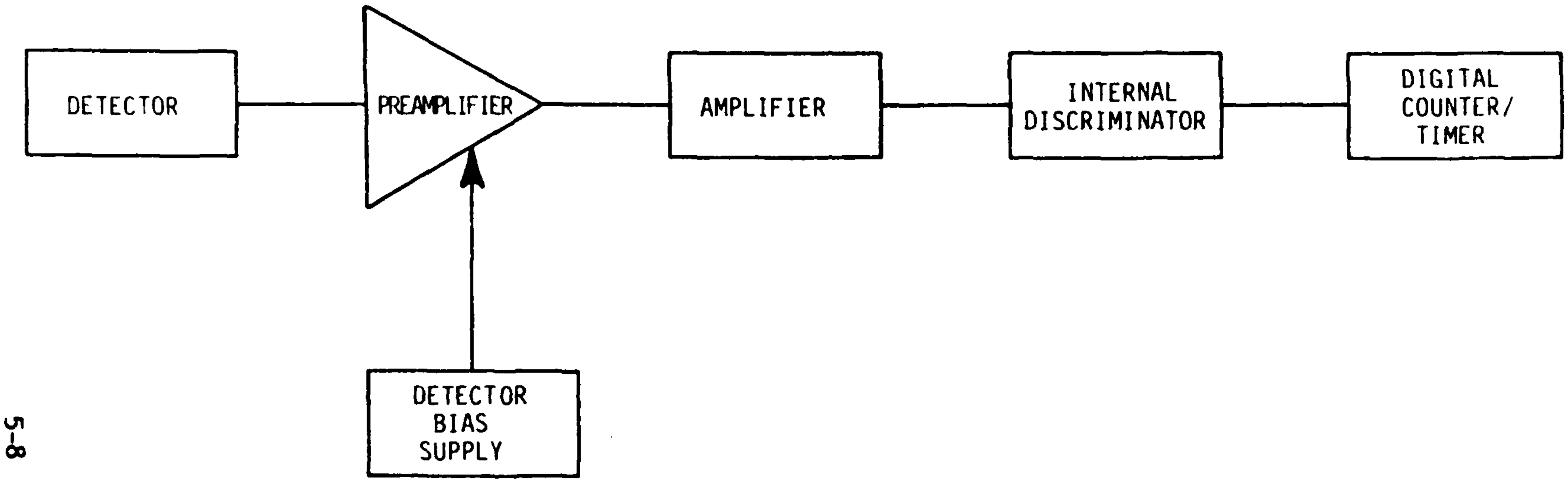


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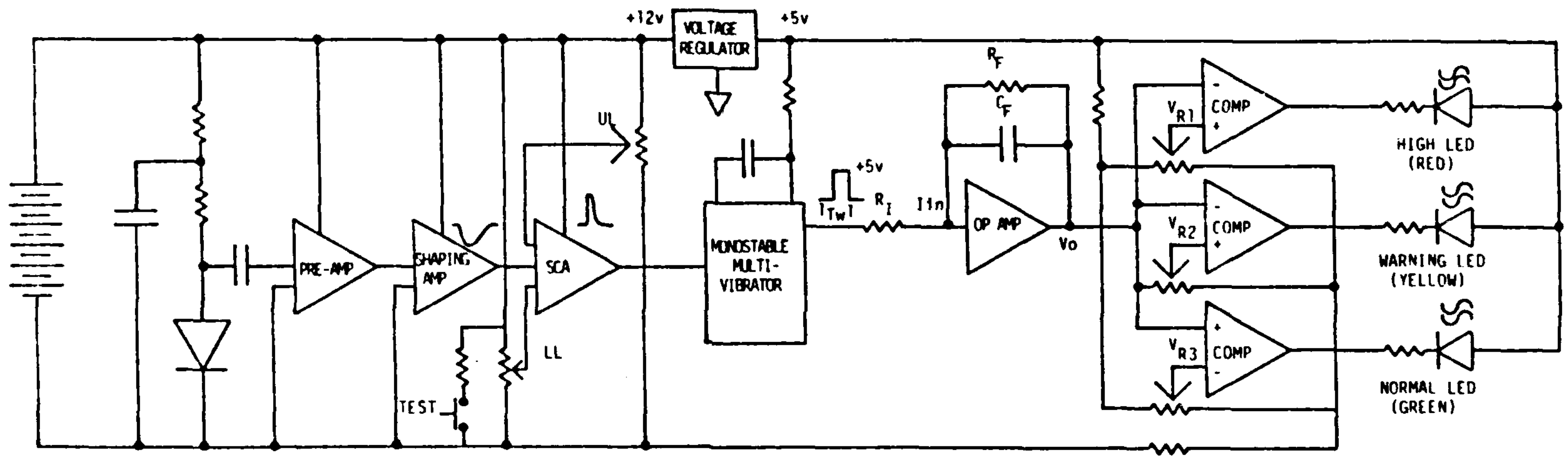
Figure 7. The Instrumentation Set-up Used in the FWRM Measurements.

Table 5

INSTRUMENTATION USED DURING THESE MEASUREMENTS

| | |
|---|---|
| DETECTOR: | ORTEC BR-024-450-300<br>BIAS -98 v |
| PREAMPLIFIER: | TENNELEC TC 174<br>E OUT |
| AMPLIFIER: | ORTEC 572<br>GAIN X1000<br>SHAPING TIME 6 uSEC<br>BLR AUTO<br>NEG. INPUT<br>BI OUT |
| SCA: | ORTEC 550<br>INTEGRAL MODE<br>POS OUT |
| H.V. SUPPLY: | ORTEC 478<br>NEGATIVE OUT<br>98.0 v |
| COUNTER: | ORTEC 478<br>INPUT 2 |




$$I_{in} = \left(\frac{5v}{R_I}\right)\left(\frac{CONTS}{SEC}\right)\left(T_W\ (SEC)\right)$$

$$V_o = I_{in} \times R_F$$

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Figure 8. Conceptual Design of Circuitry for Field FWRM.

of the input pulse width and can be varied from 35 nanoseconds to over one minute. Pulse width stability is achieved through compensation internal to the monostable multivibrator chip and is virtually independent of supply voltage and temperature. $R_I$ provides a current ($I_{in}$) proportional to the count rate from the detector. An operational amplifier is used with a resistor and capacitor in parallel as an integrator to produce a voltage proportional to the current, $I_{in}$. The large pulse width adjustment of the monostable multivibrator will allow small count rates to produce enough current so that they can be practically integrated to a voltage level that can trigger the comparators. The comparators will drive LEDs to indicate different levels of count rates. There are three comparators, one for a "normal" count rate that will illuminate a green LED when the count rate is below the preset level, the second will illuminate a yellow LED when the count rate exceeds the "warning" preset level, and the third will illuminate a red LED when the "high" preset count rate level is exceeded. A detector "test" button will reduce the lower level discriminator voltage such that the SCA output will include the detector noise and indicate a "high" count rate reading.

## Section 6.

### BETA/ELECTRON SOURCE TERM

The beta and electron source terms in the volume of water proximate the face of the detector will result from the beta decay of radionuclides in the water and electrons produced by gammas interactions in the water.

### 6.1 Beta Source Term

A set of calculations were performed to estimate the range of beta particles with an average energy of 0.6 MeV in water. The range of these particles effectively defines the sampling volume of the detector. Sr-90 emits betas with a maximum energy of 0.574 MeV. The range of a 0.574 MeV beta in water is approximately 0.2 cm. The range of the Sr-90 0.574 MeV beta was experimentally verified by inserting known thicknesses of Lexan (used to simulate water) between the front face of the surface barrier detector and a 0.92 nCi Sr-90 source. The data is shown in Table 6. From the data in Table 6, the range in Lexan of betas from Sr-90 was estimated to be $\sim$0.25 cm which is close to the calculated value. The active area of the surface barrier detector is $\sim$6.0 $cm^2$. Therefore, the maximum volume from which betas from Sr-90 can be expected to interact with the detector is 1.2 $cm^3$. Thus, if the total activity in the water is 1 nCi/liter, the activity of the volume of water to which the detector is sensitive is 1.2 pCi.

Table 6

RANGE OF Sr-90 BETAS IN LEXAN

| Lexan thickness, cm (dia., cm) | Counts/Minute |
|---|---|
| 0 | 26.4 |
| 0.081 (1.27 cm) | 6.8 |
| 0.162 (1.27 cm) | 2.87 |
| 0.243 (1.27 cm) | 1.23 |
| 0.325 (1.27 cm) | 0.43 |

To determine a source strength equivalent to 1.2 pCi, the familiar Beer-Lambert law was applied to estimate the thickness of Lexan needed to reduce the activity of the source from $4.5 \times 10^{-9}$ Ci to $1.2 \times 10^{-12}$ Ci. Based on the data in Table 6, the thickness of Lexan required was $\sim$0.8 mm. A 0.8 mm Lexan absorber was inserted between the detector and the source with a resultant count rate of <8 CPM. Therefore, the beta source term is highly localized, and the activity of the volume of water to which the detector responds is extremely low. Thus, to reliably detect the presence of radionulides (Sr-90) at the levels required for the FWRM, the gamma-created electron flux near the detector must be small and contain predominantly low-energy electrons. The creation of electrons by gamma with a high probability of reaching the detector must take place in the 1.2 $cm^3$ volume proximate the detector's sensitive face. The electron source term was examined experimentally by filling the water bag with water and creating a 100 mR/hr field at its surface. Several measurements were made with the low-level discriminator set at 1.60 V, from which it was concluded that the bulk of Compton-created electrons have energies less than 0.1 MeV. For a 100 mR/hr gamma field, the gamma flux is $1 \times 10^5$ $\gamma/cm^2$ sec (see Figure 9). With a water shield around the detector of 12.7 cm, the $\gamma$ flux at the detector is $\sim 3.8 \times 10^4$ $\gamma/cm^2$ sec. The electron source term can be calculated using the relationship

$$I_e = N \, Z \, \sigma \, \gamma_0 \, f$$

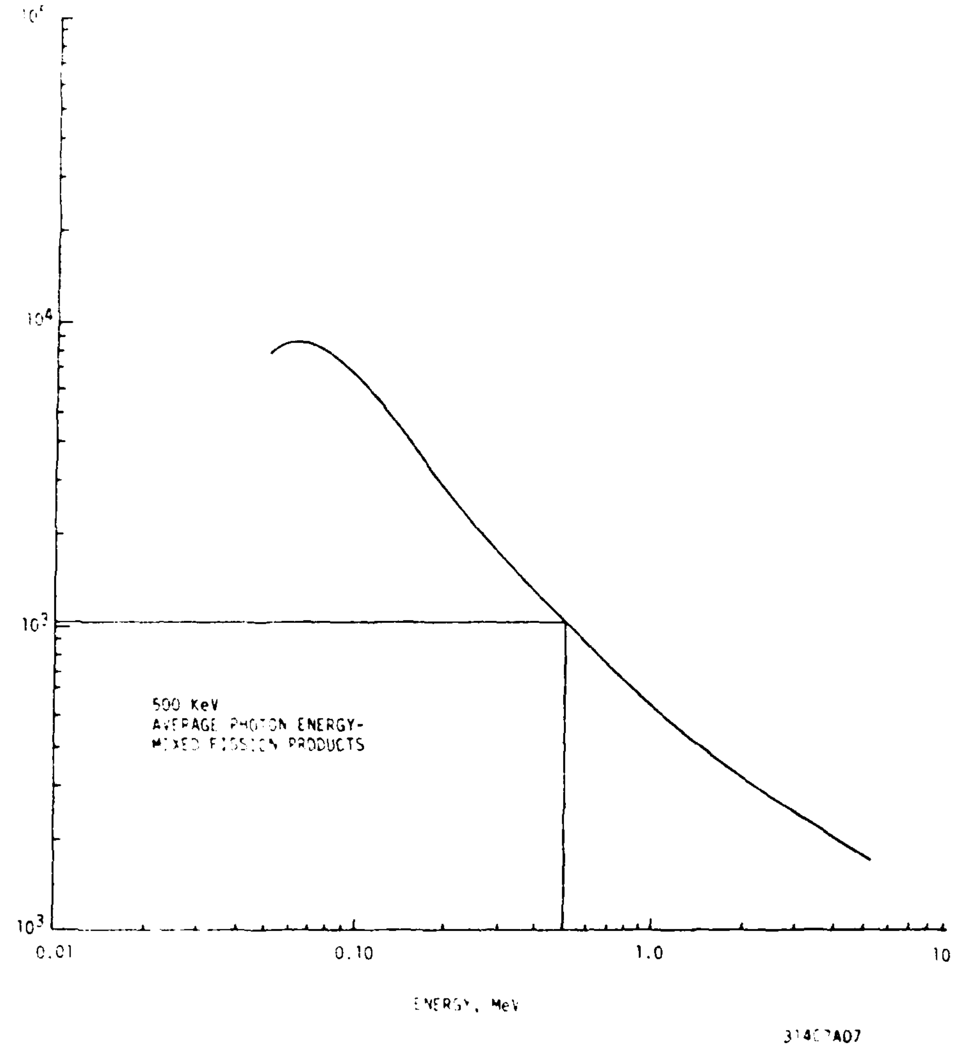


**Figure 9. Variation of Gamma Ray Flux as a Function of the Incident Gamma Ray Energy for 1.0 mR/hour Exposure.**

where

$I_e$ = electron source term, electrons/cm$^3$ sec.

N = atom number density, atoms/cm$^3$

Z = effective Z of water

$\sigma$ = Klein-Nishina cross section

$\gamma_0$ = Photon flux, $\gamma$/cm$^2$ sec

f = 1, electron/photon

The electron density is calculated from Equation 1 to be 204 electrons/cm$^3$ sec. For a volume 1.2 cm$^3$, the source term is 244 electrons/cm$^3$ sec.

When the discriminator was set just above the noise level (30 keV), the pulse rate from the detector was 500 events/sec which agrees with the expected gamma-ray-created *electron source term*. *This* value could vary by as much as ±100% depending on the ambient conditions and other factors. Therefore, the disagreement between the measured and calculated electron volume generation rate is not disturbing.

This result, however, demonstrates that there is a significant source of gamma-ray-created low energy electrons. Therefore, the FWRM must have the capability of electronically discriminating against low-energy electrons born in the water in front of the detector.

## Section 7.

## PROTOTYPE TEST PROCEDURE

The test procedure and test results are described below. The prototype was tested separately with a 100 mR/hr Cs-137 and 100 mR/hr Co-60 background.

### 7.1 Test Procedure

The FWRM and associated electronics previously described were set up in the TEC radiation laboratory. The detector and electronics were powered and allowed to warm up for 10 minutes before any measurements were made. An experiment was performed to measure the attenuation of a 0.00127 cm thick plastic wrap used to protect the detector and also to seal the beta source from moisture. The meter cover plate with the detector in the "down" (operate) position was placed in a lead-shielded box with the detector face 0.125 inches from the bottom of the lead box. The 0.45 nCi Sr-90 source used to simulate contaminated water was placed between the bottom of the lead box and the detector face, and a count rate was taken at five discriminator levels. Extreme care was taken not to disturb the detector-source geometry. Two layers of plastic wrap were placed between the source and the detector, and a count rate was taken again at the five discriminator levels. A 0.157 cm thick 2.54 cm diameter lexan disk was placed on top of the source and plastic wrap. Count rates were taken again at the five discriminator levels. The measurements performed with the plastic wrap surrounding the source and detector demonstrated that the attenuation of betas by the protective wrap was negligible. The lexan measurements were designed to determine the thickness of lexan needed to reduce the 0.45 nCi Sr-90 detectable activity to a level comparable to that expected from water with Sr-90 at concentrations of 1000 pCi/liter.

A 100 mR/hr gamma background at the water bag surface was created using a 5 mCi Cs-137 source. The gamma dose rate calibrated at the bottom of the FWRM sample bag was verified with a Model 96070 Keithley 60 cc ion chamber and a Model 35614 Keithley ammeter. A count rate (with no water in the FWRM bag) was taken at five discriminator levels. The FWRM was filled with 3.3 liters of water (this placed the detector about 2.54 cms under water), and a count rate was taken at the five discriminator levels. Finally, a 0.45 nCi Sr-90 (12/5/83) source was wrapped in plastic and taped to the lexan disk in front of the detector face. The detector source lexan assembly was submerged in the water and a measurement performed in a 100 mR/hr gamma field. Count rates at the aforementioned discriminator levels were conducted. This procedure was then used to determine the performance of the FWRM in 100 mR/hr gamma background generated with a 1 mCi Co-60 source. The results of these measurements are reported in Section 8.

## Section 8.

## DISCUSSION OF EXPERIMENTAL RESULTS

### 8.1 Detector Sensitivity with a CS-137 Radiation Background

The experimental setup described in Section 6.1 was used to obtain the background results in Table 7. These results were obtained with the upper level window set at 10 V. The lower level (LL) discriminator setting was varied between 0 and 6.1 volts. Table 7 shows that, above a LL discriminator setting of 6.1 volts, there are no counts due to Cs-137. Cs-137 was selected as the background source because, in the case of the typical bomb design with no deadly special effects, Cs-137[2] is one of the principal long-lived dangerous fission products. (The Cs-137 formed by a 10-MT-yield bomb, according to DRDME-GS Memorandum 21,(3) is 1580 kilocuries.)

With the Cs-137 source maintained in the same position as in Table 7, a 0.45 nCi Strontium-90 source was used to verify the detectability of 1000 pCi/liter of Sr-90 in this 100 mR/hr field. To simulate the presence of Sr-90 uniformly distributed in water at concentration levels of 1000 pCi/liter, the volume of radioactive water to which the detector would be sensitive was calculated. The maximum range in water of a 0.6

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2. Cesium-137 results from the beta decay of Xenon-137.

Table 7

Background Counts Using a Cs-137 Source to Create a 100 mR/hr Gamma Field at the Surface of the Water Bag with the Detector in Place

BACKGROUND WITH NO WATER IN FWRM
(100 mR/hr Cs-137 Gamma Field)

| Lower Level Discriminator Setting, V | Counts/Minute* |
|---|---|
| 3.1 | 74.0 |
| 3.5 | 38.5 |
| 3.7 | 14.0 |
| 4.1 | 8.0 |
| 4.5 | 1.5 |
| 4.7 | 2.5 |
| 6.1 | 0.0 |

BACKGROUND WITH FWRM FILLED WITH WATER
(100 mR/hr Cs-137 Gamma Field)

| Lower Level Discriminator Setting, V | Counts/Minute |
|---|---|
| 3.1 | 18.5 |
| 3.5 | 10.5 |
| 3.7 | 5.5 |
| 4.1 | 1.5 |
| 4.5 | 1.5 |
| 4.7 | 0.0 |
| 6.1 | 0.0 |

*Average values based on 5-minute counting intervals.

MeV beta particle is 0.25 cm. Thus, for a detector with a 5.56 cm diameter, the volume of radioactive water that the detector would be sensitive to is $\sim$5.92 $cm^3$, and the source strength of uniformly mixed Sr-90 at concentration levels of 1000 pCi/liter in water would be (5.92/1000) x 3.7 x 10 d/s or 0.200 d/s. The Beer-Lambert law(2) was used to determine the thickness of Lexan needed to reduce the activity of the 0.45 nCi Sr-90 source to 0.200 d/s. The Lexan (0.154 cm thick) was inserted between the Sr-90 source and the front face of the surface barrier detector (see Section 4). These calculations are based on a pure Sr-90 source; however, Strontium-90 (29.9 years half-life) decays to Yttium-90 (64 hours half-life) which adds a complicating factor. The TEC source was purchased in 1981 and is in a state of secular equilibrium; that is, the actual number of disintegrations is twice the value calculated for pure Sr-90 (16.6 d/s). Therefore, one would expect the actual count to be higher than that predicted for Sr-90. This phenomenon is illustrated in Figure 10.

The results of a measurement with the Cs-137 background and the Sr-90 source with Lexan inserted in the water filled bag are shown in Table 8, which also shows the signal-to-background ratio for several lower level discriminator settings.

The results shown in Table 8 demonstrate that a planar source approximation of a radioactive water volume ($\sim$1000 pCi/liter) can be detected by the surface barrier detector in the presence of a 100 mR/hr gamma field with an average gamma energy of 0.632 MeV. The signal-to-noise ratio can be changed significantly by using different LL

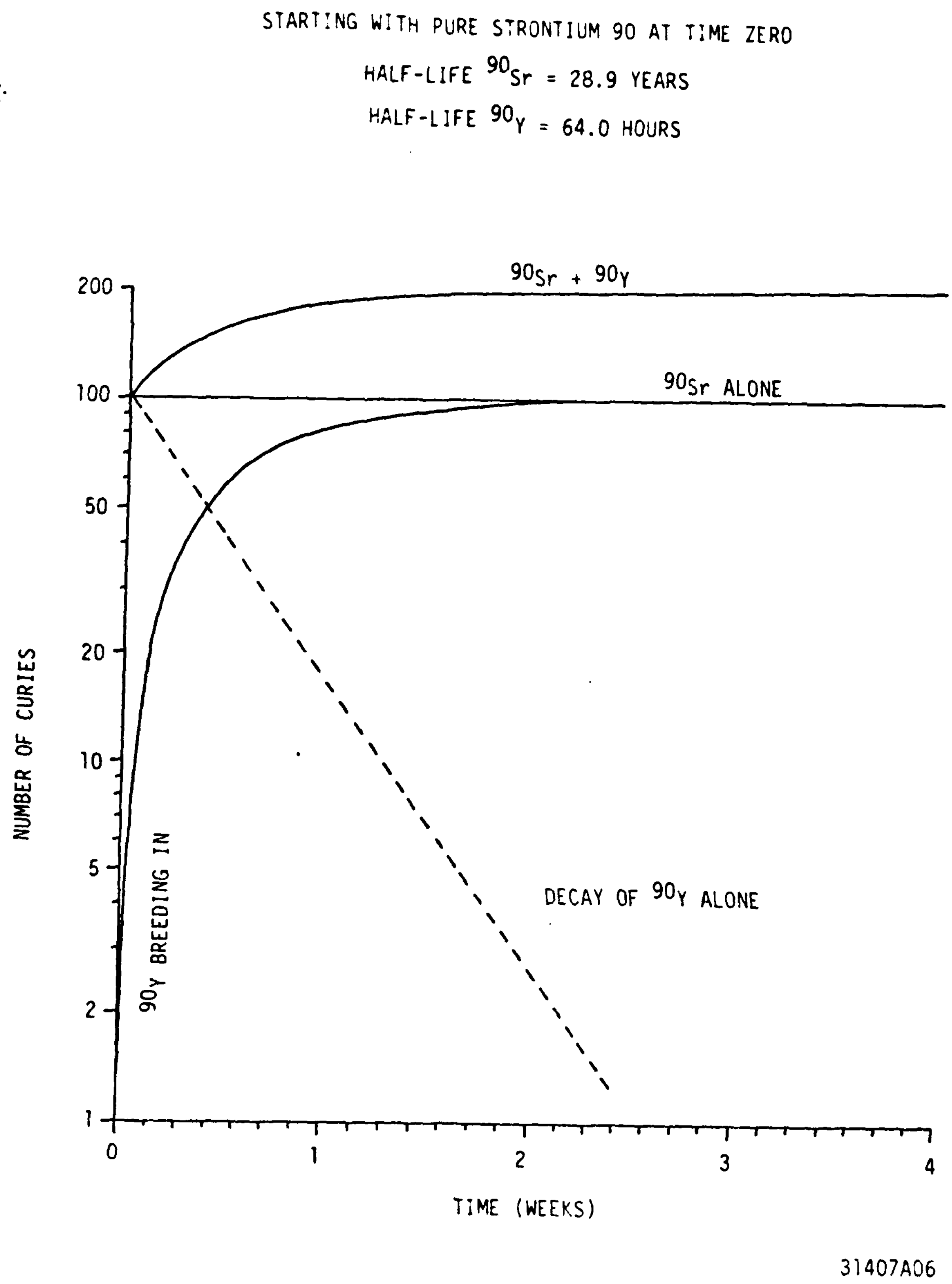


**Figure 10. Secular Equilibrium Strontium-90/Yttrium-90 (Ref. 3)**

Table 8

DETECTOR RESPONSE WITH 100 mR/hr CS-137
BACKGROUND AND SIMULATED RADIOACTIVE WATER

| Lower Level Discriminator Setting, V | Counts/Minute[a] | Signal to Bck. Ratio[b] |
|---|---|---|
| 3.1 | 140.5 | 7.6:1 |
| 3.5 | 99.0 | 9.4:1 |
| 3.7 | 76.0 | 13.8:1 |
| 4.1 | 59.5 | 40.0:1 |
| 4.5 | 35.0 | 23.3:1 |
| 4.7 | 40.0 | - |

[a]Based on the results of Table 7.

[b]See footnote on Table 7.

discriminator settings. Thus, we are recommending that, in the final system, a LL discriminator setting of 4.7 V be used to achieve the best signal-to-noise ratio.

Since the source was essentially a point source, the 100 mR/hr gamma field was impressed on only a portion of the surface area of the water bag. The affected surface area was computed and the ratio of the total bag surface area to the surface area of the impinging photon beam was used to estimate the counts that would accumulate if the gamma field was isotropic. This assumes that the detector does not exhibit different sensitivities to photons incident from different directions (i.e., side, front or back faces). This assumption is supported by measurements performed with the source positioned at 90° intervals in a vertical plane around the detector-water bag system. The 0° source position was directly below the detector water bag system. These measurements are shown in Table 9.

**8.2 Detection Sensitivity with a Cobalt-60 Radiation Background**

Since there is a class of "seeded" bombs, we also examined the response of the FWRM to an isotope common in one of those seeded bombs (i.e., cobalt). In Section 7.1, we established that the field water radioactivity monitor will detect the presence of beta emitters in a contaminated water supply at levels of 1000 pCi/liter in an isotopic 100 mR/hr Cs-137 gamma field.

Table 9

Cs-137 BACKGROUND MEASUREMENTS WITH SOURCE AT TWO POSITIONS (90°, 0°) RELATIVE TO THE WATER BAG SURFACE

Placed Cs-137 source at side (90°) of FWRM bag to create a 100 mR/hr bkg. at the water bag surface - (No Sr-90 source). The bag was filled with water.

| Lower Level Discriminator Setting, V | Counts/Minute[c] |
|---|---|
| 3.1 | 12.3 |
| 3.5 | 4.3 |
| 3.7 | 2.3 |
| 4.1 | 1.3 |
| 4.3 | 0.7 |

Placed Cs-137 source below (0°) bottom of FWRM bag to create a 100 mR/hr bkg. at the water bag surface - (No Sr-90 source). The bag was filled with water.

| Lower Level Discriminator Setting, V | Counts/Minute |
|---|---|
| 3.1 | 19.0 |
| 3.5 | 2.0 |
| 3.7 | 3.3 |
| 4.1 | 2.0 |
| 4.3 | 0.0 |

[c]See footnote on Table 7.

The detector water bag system was also exposed to a 100 mR/hr Co-60 field. The results of these measurements are shown in Tables 10 and 11. The source positions are also indicated in Tables 10 and 11. The high energy photons from the Co-60 ($E_{AV}$ = 1.25 MeV versus 0.632 MeV for Cs-137) penetrate the water shield and reach the detector in much larger quantities. For the Co-60 source, the calculated gamma flux at the detector, surrounded by 13.97 cm of water, was found to be approximately 1.5 times that of Cs-137. From Tables 10 and 11, it is clear that Co-60 poses a much different problem from that experienced with Cs-137. In the case of Cs-137, the LL discriminator could be raised so that Cs-137 gamma-induced pulses are electronically rejected while maintaining the sensitivity of the system to betas emitted by Sr-90.

A possible solution to the Co-60 background problem is to use the concept of a compensated detector. This concept was partially evaluated. The measurements consisted of performing a set of experiments with and without the detector encapsulated in lead. A 0.3175 cm thick lead sheet with 0.005 cm thick tin sheets between the lead and detector were used to make the detector insensitive to electrons created in the water proximate to the detector. The tin sheets prevented electrons created in the lead from reaching the detector. These measurements showed that an encapsulated detector positioned above a bare detector (with LL discriminator settings of $\sim$4.7 volts) could be used to compensate for gamma-induced pulses from photon interactions in the detector on materials surrounding the detector (see Table 7). This approach will be examined further in Phase II.

Table 10

Co-60 SOURCE POSITIONED UNDER FIELD WATER RADIOACTIVITY
MONITOR (FWRM) TO CREATE A 100 mR/hr FIELD
(The Water Bag Was Filled With Water)

| Lower Level Discriminator Setting, V | Counts/Minute |
|---|---|
| 3.1 | 524 |
| 3.5 | 328 |
| 3.7 | 217 |
| 4.1 | 111 |
| 4.3 | 66 |
| 4.5 | 45 |
| 4.7 | 38 |
| 4.9 | 28 |
| 5.1 | 11 |
| 5.5 | 3 |

Table 11

Co-60 SOURCE POSITIONED AT THE SIDE OF FIELD WATER RADIOACTIVE
MONITOR (FWRM) TO CREATE A 100 mR/hr FIELD
(The Water Bag Was Filled With Water)

| Lower Level Discriminator Setting, V | Counts/Minute |
|---|---|
| 3.1 | 374 |
| 3.5 | 228 |
| 3.7 | 181 |
| 4.1 | 109 |
| 4.5 | 69 |
| 4.7 | 45 |
| 4.9 | 39 |
| 5.1 | 22 |
| 5.3 | 21 |
| 5.5 | 15 |

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## Appendix A.

### Financial Statement

Status of Contract
DAAK70-85-C-0101

Hours Expended to Date: (thru February 23, 1986)

| Labor Level | Hours |
|---|---|
| Level I | 168.5 |
| Level II | 185.1 |
| Level III | 3.0 |
| Level IV | 314.3 |
| Total | 670.9 |

Total Amount Invoiced:

| Month | Invoice # | Amount |
|---|---|---|
| September 1985 | | $ 0.00 |
| October 1985 | 6112-001 | 8,577.00 |
| November 1985 | 6193-002 | 3,676.00 |
| January 1986 | 6265-003 | 6,166.00 |
| February 1986 | 6338-004 | 7,724.00 |
| March 1986 | 6407-005 | 14,835.00 |
| Total Invoiced to Date | | $ 40,978.00 |

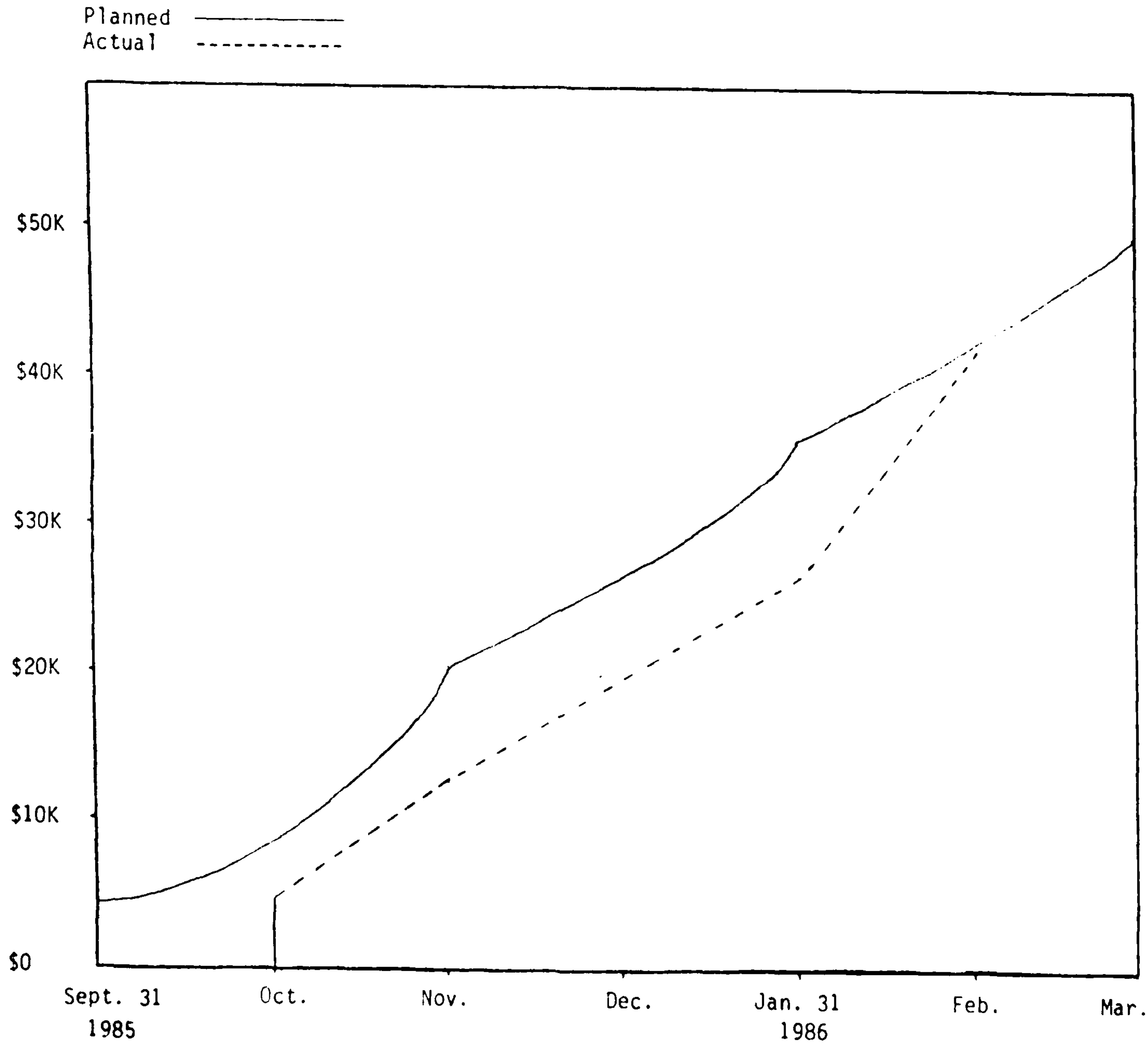
| | |
|---|---|
| Contract Amount | $48,374.92 |
| Amount Invoiced to Date | $40,978.00 |
| Amount Remaining to be Invoiced | $ 7,396.92 |

**Appendix B.**

**PROJECT SCHEDULE**

**Budget Schedule**
**(Planned vs. Actual)**

CONTRACT DAAK70-85-C-0101



**Appendix C.**

**Phase II Proposal:**
**Development of a Field-Usable**
**Manufacturable Prototype**

**Phase II Proposal:**
**Development of a Field-Usable**
**Manufacturable Prototype.**

**Based On:**
**Phase I Contract DAAK70-85-C-0101**
**"Feasibility Study For Field Monitoring of**
**Water Supplies for Radioactivity"**

**Submitted to:**

**Department of the Army**
**US Army Belvoir Research & Development Center**
**Fort Belvoir, Virginia 22060-5606**

**Attention:**

**Mr. Don C. Lindsten**
**STRBE-FS Building**
**Belvoir R&D Center**
**Fort Belvoir, VA 22060-5606**

**Submitted by:**

**Technology for Energy Corporation**
**One Energy Center, Lexington Drive**
**Knoxville, Tennessee 37922**

**March 24, 1986**

## Abstract

The Phase I feasibility study designed to demonstrate that a Surface Barrier Detector based system could be used to detect the presence of radioactivity in drinking water at levels as low as 1000 pCi/liter has been successfully completed. An engineering prototype[1] was constructed and tested in Phase I. The effort in Phase I not only demonstrated the feasibility of the development of a field water radioactivity monitor (FWRM) with a detection sensitivity of 1000 pCi/liter for Sr-90, it also served to highlight the areas where work is needed to develop a reliable, rugged, accurate and field worthy monitor. The field worthy FWRM, unlike the engineering prototype of Phase I, will have the detector, the signal conditioning and display modules integrated into a single package. TEC is hereby proposing a program that will lead to the development of a FWRM based on the results of the successful feasibility study conducted in Phase I.

The development effort will include:

1. Miniaturization of the electronic circuitry used in the Phase I work.

2. Mechanical design of the various components of the FWRM for protection of the detector, including waterproofing of the detector.

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1. TEC defines an engineering prototype as a prototype wherein standard laboratory equipment without modification is used to demonstrate the feasibility of a concept.

3. Mechanical and electronic subsystems integration.

4. Human engineering.

The final prototype will be tested by TEC and modifications made. This prototype with design package and drawings will be delivered to the Army.

## Section 1.

## BACKGROUND

Phase I of TEC's SBIR contract with the U. S. Army Belvoir Research and Development Center (Contract DAAK70-85-C-0101) has been completed. This contract was awarded to TEC to demonstrate the feasibility of the development of a Field Water Radioactivity Monitor (FWRM). An engineering prototype of the FWRM, a silicon surface barrier (SSB) detector based system, was constructed and tested and found to be sensitive enough to detect Sr-90 contamination in water at a level of 1000 pCi/liter in a 100 mR/hr Cs-137 background.

The FWRM engineering prototype which was designed to detect betas is shown in Figure C-1. The liquid sample that is to be tested for contamination is placed in the water bag, which has a liquid capacity of 3.3 liters, and is attached to the top plate of the FWRM. The water in the canvas bag also acts as a shield against background gamma rays and charged particles emitted by earthbound or airborne radioactive nuclides. The water in the bag prevents all charged particles borne external to the bag from reaching the detector, but it is not as effective against gamma rays. For the layer of water, approximately 10 cm, between the detector and the surface of the bag in the engineering prototype FWRM, as many as 40% of the Cs-137 gammas reach the detector's location without undergoing a collision in the water. Thus gamma interaction in the water proximate the detector and in the detector's encapsulation material was found to be a significant source

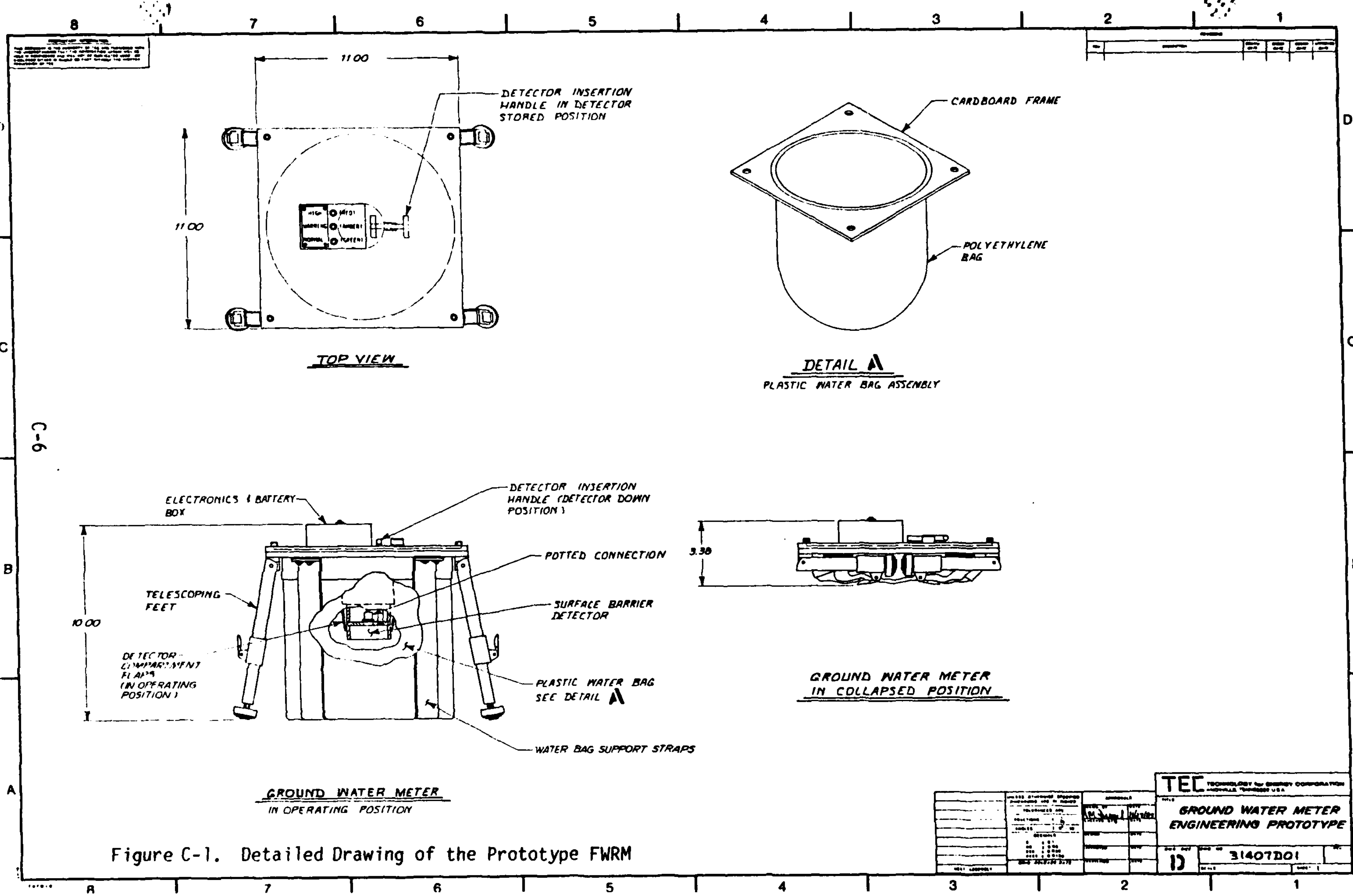



Figure C-1. Detailed Drawing of the Prototype FWRM of Compton electrons, some of which are absorbed in the SSB detector. effectively discriminated against electronically to prevent them from being counted. This was accomplished with the instrumentation shown in Figure C-2. If the 1000 pCi/liter sensitivity is to be achieved, the FWRM requires that the low-energy Compton electrons not be counted. The circuitry shown in Figure C-2 was used to condition and count the pulses generated by beta particles interacting with the silicon surface barrier (SSB) detector in the Phase I FWRM system. The SSB detector used in these tests was a standard SSB with a 300 micron depletion depth with encapsulation that is designed to be light-tight. It was not designed for use in situations where it is submerged in water. TEC performed the waterproofing of this detector by spraying its front face with an acrylic spray. While this provided a temporary seal against water damage to the detector for these measurements, it will not suffice as a fix for this problem in a field unit. This is one of the engineering design problems that will be solved in Phase II of this effort.

The signal-conditioning and counting circuitry shown in Figure C-2 was standard laboratory equipment. This system will have to be miniaturized and designed using electronics with relatively low power requirements for use in the field FWRM unit.

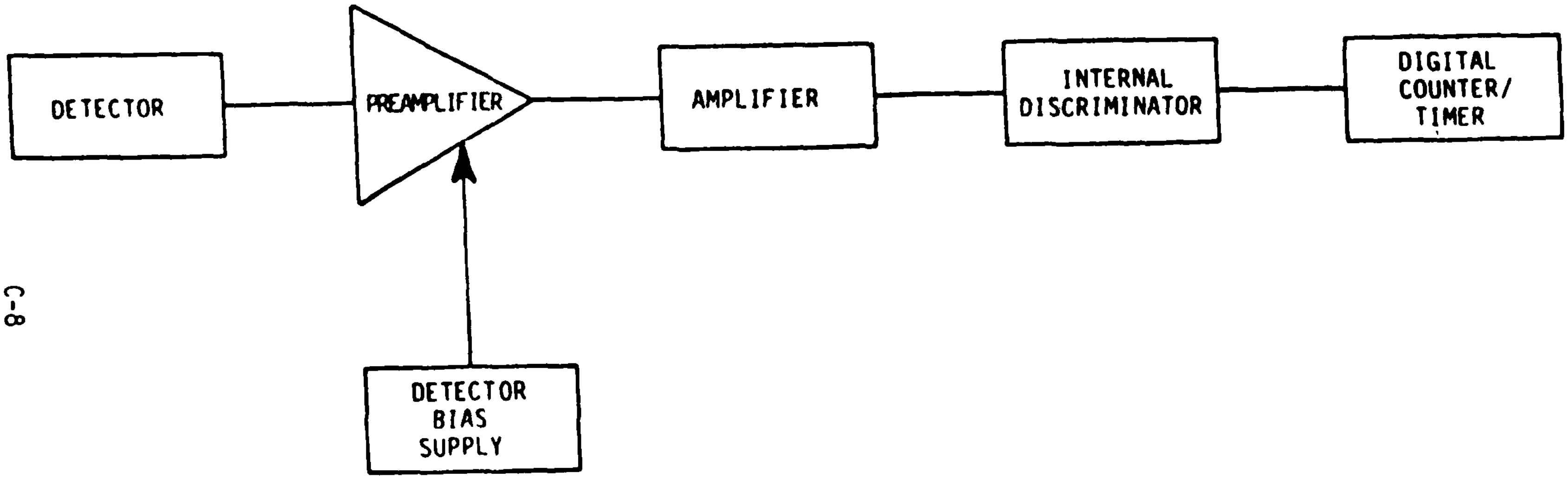



Figure C-2. The Instrumentation Set-up Used in the FWRM Measurements.

In addition to the problems with waterproofing and miniaturization of the signal-conditioning circuitry, several areas were identified during the course of the feasibility study of the Phase I effort in which improvements are needed. These are:

1. Definition of the specifications the FWRM must meet.
2. Mechanical design and packaging of the FWRM to ensure that it will survive the handling associated with field use.
3. Electronic circuitry design that will provide an unambiguous indication of radioactivity levels greater than 1000 pCi/liter.
4. Determination of a fixed counting time required to accurately determine the condition of water.
5. Modification of the SSB encapsulating procedure to ensure waterproofing during the manufacturing process.

These areas require some additional design (mechanical and electrical) and testing to ensure the development of a reliable, rugged FWRM for use in the field by Army personnel and also by others such as local municipalities for monitoring their water supplies.

## Section 2.

## TECHNICAL OBJECTIVES

The objective of this proposal work scope is to develop a prototype of a portable FWRM instrument which will meet the Army's requirements for monitoring the radionuclide content of drinking water. The instrument must be designed to be portable, rugged, lightweight, simple to operate and reliable. The work plan given in Section 3 describes our methodology for achieving this goal.

The principle objective of this Phase II development proposal may be achieved through the following five major efforts:

1. Develop specifications with input from the Army on the electronic design and packaging of the prototype.
2. Develop mechanical and electrical systems designs for the components of the FWRM prototype.
3. Fabricate and assemble the FWRM prototype.
4. Test instrument to verify that it meets specifications set forth in Item 1.
5. Deliver an operational instrument for field applications.

## Section 3.

## WORK PLAN

### TASK 1 - DEVELOP DESIGN SPECIFICATIONS FOR THE FIELD WATER RADIOACTIVITY MONITOR

During this task, the design and performance specifications for the FWRM will be developed. It is anticipated that these specifications will be jointly developed by Army engineers and TEC engineers. Currently, only the design specification for sensitivity of 1000 pCi/l is known. The general understanding that the FWRM must be lightweight, rugged, storable, and portable must be developed into specific design requirements. Some examples of specific items that need clarifying are:

1. What is the temperature range over which units must operate?
2. Does the unit have to be battery operated or is power available at the water plant?

   (a) If power available, what voltages/current?

   (b) If the FWRM needs to be battery operated, how long does it need to operate before the battery is recharged?

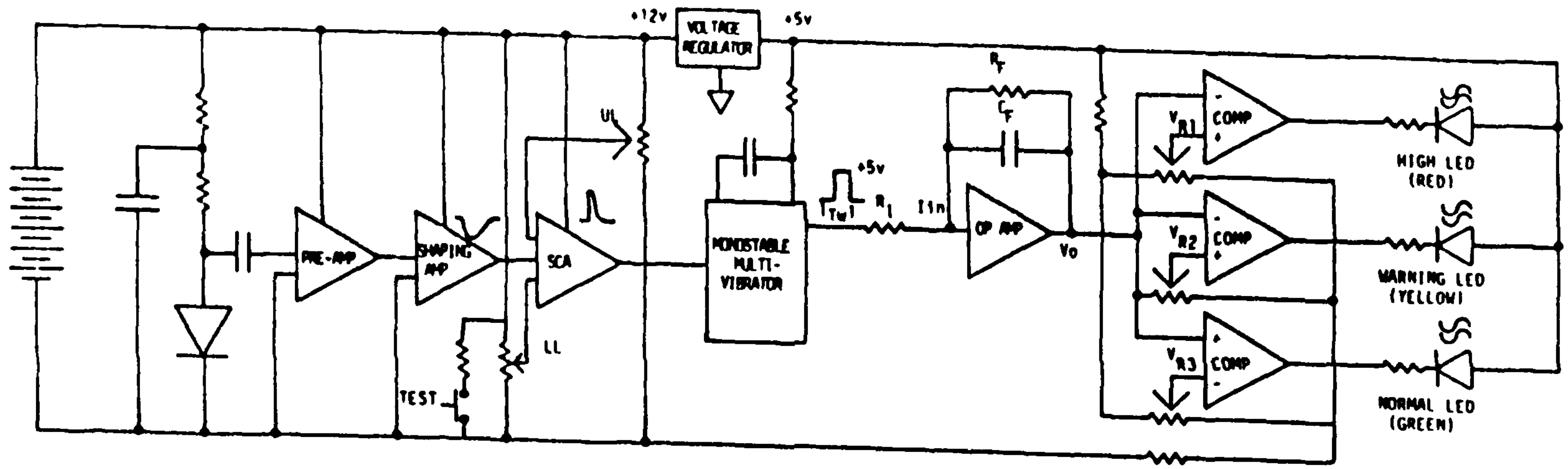
3. What size constraints apply to the device?
4. What readout information is necessary and desirable?
5. What are the applicable military standards that the unit must be designed to meet?

To establish system design specifications, it is anticipated that TEC engineers will need to visit Fort Belvoir for discussions with the appropriate Army staff engineers. When the overall system design specifications are established, then specifications for the individual subsections can be developed.

## TASK II - DESIGN AND CONSTRUCTION OF THE DETECTOR/ELECTRONICS SUBASSEMBLY

The design of the detector/electronics subassembly can be developed after determining the specifications in Task I. Although precise details cannot be stated until the specifications are developed, general needs were defined in Phase I and can be outlined here.

The Phase I engineering prototype used standard laboratory instruments. These electronic components will be redesigned into miniature low-power circuits. A conceptual design of the electronic circuit needed to provide an unambiguous indication of the presence of radioactivity at levels greater than 1000 pCi/liter is shown in Figure C-3, which also provides a representation of the circuitry that will be fabricated in a hybrid state for use in the field unit. Most of the components in Figure C-3 have been tested in Phase I. The major electronic design effort will be concentrated on that part of the circuit starting at the output of the SCA and including the output circuit and annunciators for the operation. A test circuit will need to be designed into the system so that operability can be verified prior to each use. By utilizing hybrid technology for these circuits, we can reduce the size and power requirements.




$$I_{in} = \left(\frac{5v}{R_I}\right)\left(\frac{COUNTS}{SEC}\right)\left(T_w\ (SEC)\right)$$

$$V_o = I_{in} \times R_F$$

Figure C-3. **Conceptual Design of Circuitry for Field FWRM.**

The input power, battery or other, will need to be conditioned and converted to the appropriate levels for detector bias and electronics circuits. These circuits will be designed consistent with power requirements.

Once the general size and layout of the detector/electronics package is determined, the design for waterproofing the unit can commence. The electronics and all surfaces of the detector except the front face of the system can be encapsulated in a material such as epoxy. It will be necessary to determine the correct material that will meet the temperature, water permeability, light-tightness, and thermal expansion requirements. On the detector face, a tradeoff will have to be determined between ruggedness and beta particle transmission. Generally, the more rugged a material is, the thicker it is and the more energy loss the beta particles will suffer. TEC will work with EG&G ORTEC, the potential supplier of the SSB, to determine appropriate choices of materials to ensure compatibility with the detector.

Upon completion of the design phase, a prototype waterproof detector/ electronic package will be built. This unit will be subjected to a series of tests to determine if it meets the design specifications for both electronics and waterproofing. Any deviations determined in this testing will be corrected and retested. At the conclusion of this phase, the detector/electronics subassembly will be ready to integrate into the system.

## TASK III - MECHANICAL DESIGN AND SYSTEM INTEGRATION

### A. Protection of the Detector

The SSB must be protected against sharp blows to the front face and mechanical shock. The Phase I design utilized a lid that was driven into an open position when the detector was moved to its operating position (i.e. submerged in the water sample). While this approach provided protection for the detector in these tests, the design must be improved such that the lid will be strong enough to prevent a direct puncture of the detector (when it is not in use).

The Phase I detector-protected tube must also be improved such that it can prevent the transfer of the impact loads to the detector when it is subjected to normal field handling. For example, the detector housing tube used in Phase I will not be rigidly mounted to the top plate of the Phase II FWRM but will be attached to the top plate (See Figure C-4) by an energy-absorbing material. The energy-absorbing material will be designed to prevent the direct transmittance of impact loads to the detector.

### B. Human Interface

This part of the task will be influenced almost entirely by the specification and performance requirements set forth by the U. S. Army in the initial project meetings of Task 1.

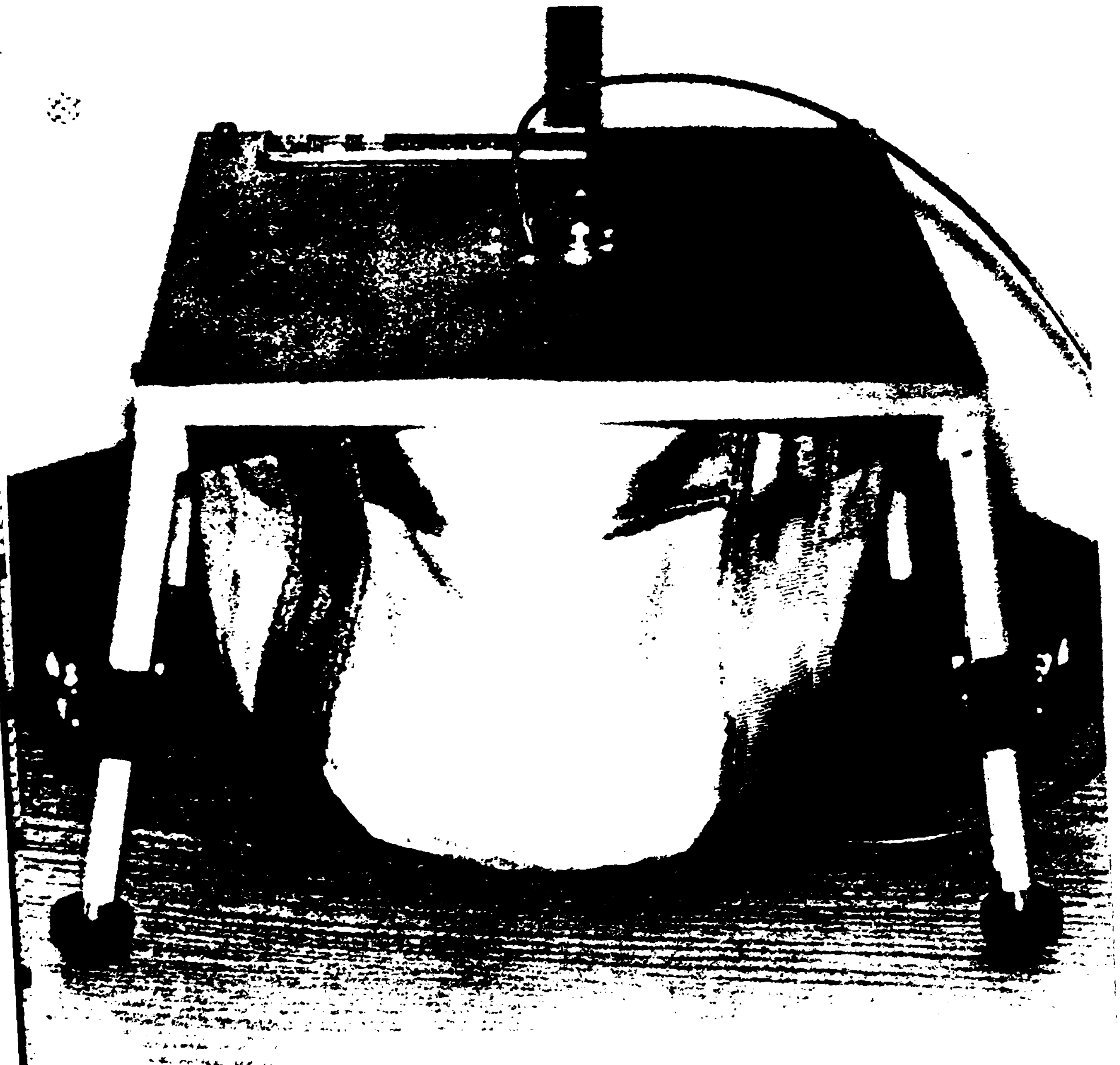


Figure C-4. FWRM Shown as it Would be Deployed During Use.

The work of Phase I demonstrated that a 3.3-liter water container would be adequate for measurements of the levels of radioactivity in water when the measurements are conducted in the presence of a gamma background in which the average energy of background gammas is near .632 MeV.

One of the primary goals of this task will be to mechanically design the FWRM such that it will be easily deployed and quickly collapsed for storage and to prevent contamination of the detector when it is used to interrogate radioactive liquid samples. Plastic inserts that can quickly be inserted into the bag and over the forward end of the detector will be designed in this task. The purpose of these plastic units will be to prevent the detector and water bag from becoming contaminated. However, these plastic units will have to be designed for easy use in the field under less than ideal conditions. A second goal will be to human engineer the output indicators that provide the user with the information on the condition of the drinking water. The FWRM will have a self test to assure the operator of the operability and capability of the device.

C. Detector Electronic System Integration

The detector, the detector's protective tube, the collapsible mounting stand and electronics will be integrated in a rugged package during this task. Size, ease of use, ruggedness, and quick deployment will be emphasized.

## TASK IV - TESTING FWRM UNDER SIMULATED FIELD CONDITIONS

TEC has acquired 10 gallons of water contaminated with Sr-90 and other mixed fission products from the Oak Ridge National Laboratory. The activity of the water samples is 27000 pCi/liter. These will be used along with a 3300 curie Cs-137 and a 50 mCi Co-60 source owned by TEC to test the Phase II prototype FWRM.

In this task TEC will demonstrate that the FWRM can distinguish between water with Sr-90 at activity levels greater than 1000 pCi/l and water in which the concentration of Sr-90 is less than or equal to 1000 pCi/l under conditions that could exist at a battlefield water plant. The design specification determined during Task I will be the guideline of how the instrument must perform under these conditions.

A series of tests is planned to demonstrate that the system meets the design specifications. First tests will be conducted utilizing water with known concentrations of Sr-90. These tests will establish the performance under the best possible conditions. A second group of tests using known concentration of Sr-90 in water will be conducted over the specified temperature range to determine that the instrument performs under the specified environment. The third set of tests would repeat the first set with the addition of a 100 mR/hr background from a Cs-137 source. This establishes any performance change due to background radiation. The fourth set of tests would be a repeat of the second series but with the addition of a 100 mR/hr background from a Cs-137 source. This set will demonstrate any additional effects from temperature cycling and background radiation.

Deviations from the design specifications determined in these tests will be documented. At the end of these tests, the design will be reviewed to determine where refinements can be made to bring the performance into specification. These design changes will then be incorporated with the appropriate test sets being repeated.

The last series of tests will be conducted with contaminated water, at different temperatures and a 100 mR/hr background from a Cs-137 source. This series is expected to be a final demonstration that the system performance specifications are met.

### TASK V - BUILD AND TEST COMPENSATED PROTOTYPE

The measurements conducted in Phase I showed that approximately 10 to 12 cm of water between the detector and the surface of the water bag when combined with electronic discrimination against detector pulses of certain amplitudes was enough to almost completely eliminate the effects of a 100 mR/hr Cs-137 background gamma field. However, those measurements also demonstrated that the same combination (i.e., water and electronic discrimination) could not be used to remove the effect of detector pulses generated when a 100 mR/hr Co-60 background was used without, at the same time, eliminating the sensitivity of the detector to betas emitted by the radionuclides in the water sample. To overcome this problem, it was demonstrated in Phase I that a two-detector compensation technique could be used to enable the FWRM to retain its sensitivity to the nuclides in the water sample in a 100 mR/hr Co-60 gamma field. In this task, TEC will develop a compensated engineering prototype. The compensated prototype will be tested to demonstrate that it will meet the Army's specifications. The testing will include tests with a liquid sample with and without Cs-137 and Co-60 backgrounds.

### TASK VI - BUILD A DELIVERABLE FWRM

At the completion of Tasks I through V, TEC will build a deliverable FWRM that will meet the Army's specifications set forth in Task 1. The FWRM will incorporate the results of the testing done in Task IV and Task V, if it is required that the FWRM operate in a Co-60 environment; otherwise, the FWRM design will be based on its use in a mixed fission product gamma field with an average gamma energy of .662 MeV. The prototype will be delivered with design packages and drawings.

### TASK VII - FINAL REPORT

The purpose of this task is to document the design and testing of the FWRM. A report will be generated that gives the design specifications. It will then detail the testing and test results obtained that demonstrate that the FWRM performance meets these specification. A package of engineering drawings and bill of materials will be included as part of this final report.

The final delivery will be the report plus the protocype FWRM.

## Section 4.

## PERFORMANCE SCHEDULE

The work to be performed will consist of seven tasks. They are:

1. Design Specifications
   - 1.1 Environmental Specifications
   - 1.2 Performance Specifications
   - 1.3 Human Factors
   - 1.4 Weight, Power, Storage Specifications
   - 1.5 Function Design Document

2. Design/Construct Detector Electronics Subassembly
   - 2.1 Electronic Dsign
   - 2.2 Hybridize to Above Design
   - 2.3 Mechanical Packaging Detector/Electronics
   - 2.4 Building Detector/Electronics Subassembly
   - 2.5 Testing

3. Mechanical Design/System Integration/Construction
   - 3.1 Protection of Detector/Electronics Subassembly
   - 3.2 Human Factors
   - 3.3 Detector/Electronics System Integration
   - 3.4 Build Test Prototype
   - 3.5 Test Prototype

## Section 4

## PERFORMANCE SCHEDULE
(Continued)

4. Testing FWRM Under Simulated Field Conditions

   4.1 Test with Water of Known Sr-90

   4.2 Test as in 4.1 with Variable Temperature

   4.3 Test as in 4.1 with 100 mR/hr Cs-137 Background

   4.4 Document Test Results

   4.5 Perform Design Modifications

   4.6 Observe Tests by Army

   4.7 Analysis

5.0 Proof of Principle for Compensated Unit

   5.1 Design and Construct Engineering Prototype

   5.2 Repeat Section 4.0 Testing

6.0 Build Deliverable Prototype

   6.1 Build Unit

   6.2 Test Electrically

7.0 Final Report

   7.1 Engineering Drawings

   7.2 Owners Manual

   7.3 Final Report

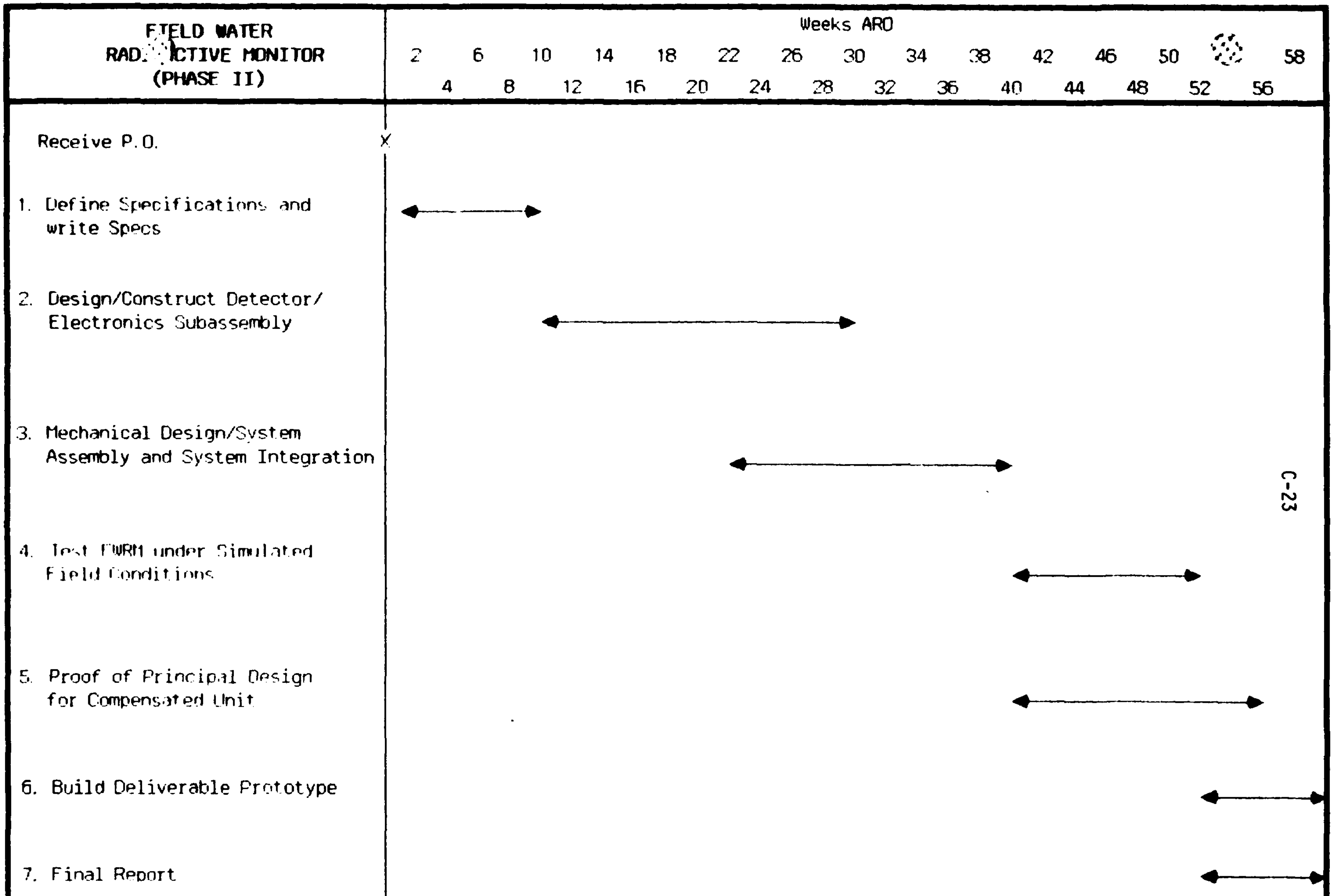



Figure C-5. Performance Schedule

## Section 5.

### Phase II Work Plan

The development described in Section 1 and the objectives of Section 5 will be accomplished in six tasks. This section describes the detailed work plan for each task and subtasks.

### 6.1 Task I - Understand the need and requirements of the FWRM

The general requirements for a field water radioactivity monitor are understood in broad terms. The device must be lightweight and collaspible for easy transport and storage; it must be rugged since it will be used under battlefield conditions; and it must be operable by unskilled technicians. In this task we will develop communication with the staff engineer at the U.S. Army Belvoir R&D Center to establish the exact requirements for the FWRM. The result of these discussions will be a set of design specifications for the FWRM.

### 6.2 Task II - Waterproofing the Detector

The detector used in the feasibility demonstration of Phase I was made waterproof by spraying a clear acrylic lacquer on its front face. A much more reliable and repeatable method for sealing the detector must be developed for the field demonstration unit. TEC will work with the detector vendor to insure that the detector is waterproof. Once a method for sealing the detector is developed, TEC will subject the new design to a series of tests in which it will be calibrated, submerged in water for several days, and recalibrated to check whether or not any water damage occurred.

## 6.3 Task III - Design and Construction of the Detector/Electronics Subassembly

Based upon the specifications developed in Task I, the low power electronics/detector subsystem will be designed and packaged to meet the specifications. The major design effort will be in designing a low power counter/timer, voltage multiplier, and a comparator. The comparator will be such that it will drive a green LED when the water is safe, switching to red when the radioactivity in the water exceeds 1000 pCi/l. It is anticipated that the package will be approximately the same size as the Phase I prototype which didn't contain all of the electronics.

Two field demonstration FWRMs detector assemblies will be developed in this task. A single detector system for use under conditions where the Co-60 is not present in any significant amount will be constructed. A dual detector system where one detector is used for gamma compensation will also be constructed. The primary emphasis, however, will be placed on the construction and testing of the single detector unit.

## 6.4 Task IV - Integration of Electronics/Detector Subassembly into Water Bag Assembly

At the completion of Task III, the electronics/detector subassembly will be integrated into the water bag system. The placement of the LEDs will be designed as well as the start/stop controls. Using radioactive sources, the unit would be tested to characterize its performance.

## 6.5 Task V - FWRM Testing under Simulated Battlefield Conditions

During this task, water solutions containing various concentrations of Sr-90 will be mixed to simulate water from the field water plant. These solutions will be used to test the response of the system to the expected field conditions. Any design deviations that this testing illustrates will be corrected at this stage.

## 6.6 Task VI - Final Report

During this task, the final engineering documents will be baselined. A report documenting all of the test results will be written. The Phase III proposal for introducing the instrument into commercial production will be a part of this final report.

## Section 6.

## KEY PERSONNEL

The project team will consist of Dr. Francis E. LeVert (principal investigator), Dr. James C. Robinson, Dr. F. Wayne Garber, Mr. Daniel M. Kopp, and Mr. Paul W. Standifer.

Dr. LeVert is one of TEC's principal scientists. He has over 13 years of experience in instrumentation design and development and is the author of over 25 instrumentation and measurement papers.

Dr. Robinson is Senior Vice President of the Engineering Applications Group. He is the company advisor in instrument development, and supervises the group responsible for new technology.

Dr. Garber is Director of TEC's Engineering Design and Manufacturing Division and has over 15 years of experience in development and application of radiation detection instrumentation.

Mr. Kopp is an Electronics Engineer in TEC's Design Engineering Division. He has a number of years experience in developing and testing radiation instruments. The testing of the Phase I unit was conducted by Mr. Kopp.

At TEC, Mr. Standifer has over the last few years been project manager on several different projects, ranging from $.5M mechanical/hardware systems to a $10M computer-based Emergency Response Data Acquisition and Display System. Mr. Standifer has had the responsibility for cost and schedule performance on a wide variety and complexity of projects.

Resumes of these individuals are provided in Section 10.

## Section 7.

## FACILITIES AND EQUIPMENT

Technology for Energy Corporation occupies approximately 46,100 square feet of floor space. R&D facilities include a computer software and system test laboratory, an electronics laboratory, a nuclear qualification laboratory, a radionuclide laboratory, and a computer-aided design (CAD) system. Included within the nuclear qualification laboratory is a high-intensity gamma irradiation facility which may be used to test equipment in the presence of high radiation fields. First-of-a-kind instruments are fabricated and tested in the prototype shop before fabrication by our manufacturing department.

The manufacturing facilities occupy 12,150 square feet and consist of a detector fabrication laboratory, an electronic assembly area, and an electronic system test laboratory. The manufacturing inventory and scheduling are monitored and controlled with the aid of a computer software system. Manufacturing is accomplished under quality assurance and quality control procedures which meet nuclear standards as outlined in ANSI N45.2.

All test equipment necessary for this project is presently available at TEC. It will be necessary to purchase detector, source material and electronic subassemblies specifically for this project. Upper limit costs for these items are included in the project cost estimate.

## Section 8.

## RELATED WORK

TEC develops and manufactures a wide variety of high-technology products and associated analog and digital modules for the commercial market. These include radiation detectors and monitors, x-ray and neutron detectors, diagnostic and surveillance systems and meters, post-accident sampling systems, and level/power monitors. TEC sells instrumentation world-wide and has placed several products in DOE-funded national laboratories, including Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Sandia National Laboratory, and the Stanford Synchrotron Radiation Laboratory.

TEC has developed and produced a number of radiation detectors and monitoring systems primarily for use in routine and post-accident monitoring within nuclear power plants. These have included such standard monitoring equipment as liquid and atmospheric effluent monitoring systems and area monitoring systems which include area radiation level detectors and continuous air monitors. TEC has also developed and produced more specializied monitoring systems such as the on-line post-accident sampling system for analysis of reactor coolant following a reactor accident and on- and off-line steamline radiation monitors for evaluating the presence of radionuclides within reactor steamlines. In addition, TEC has also gained significant experience in the area of highly specialized detector design and production such as position-sensitive detector assemblies.

TEC's continuing efforts in the design and production of radiation monitoring systems attests to the confidence that national laboratories and the nuclear industry have in our continuing ability to develop specialized monitoring systems for specific needs and to produce such systems to the highest quality standards.

## Section 9.

### CURRENT AND PENDING SUPPORT

The work described in this proposal is not now supported by any federal agency, nor does TEC plan to submit it to any other agency for support.

**Section 10.**

**F. Wayne Garber**

Director, Design Engineering and Manufacturing

EDUCATION

Southwestern College: B.A., Mathematics and Physics (1963)
The University of Tennessee: M.S., Health Physics (1965)
The University of Tennessee: Ph.D., Health Physics (1968)
The University of Tennessee: Executive Development Program (1980)

SUMMARY OF EXPERIENCE

At TEC, Dr. Garber is Director of the Design Engineering and Manufacturing Division. In this position, he is responsible for all manufacturing and hardware design for the corporation. Additionally, he serves as the corporate radiation safety officer.

Previous experience at TEC included Manager of Products Customer Services Department and Project Manager for Design and Fabrication of inadequate core cooling systems.

Prior to joining TEC, Dr. Garber was Director of Operations for the WEMCO I&C Group, being responsible for the field service, production control, manufacturing, purchasing, shipping, and receiving of an instrument division supplying analytical instruments to the mineral industry. The group was a manufacturer of electronic instrumentation and a system integrator. Major emphasis in the position was the installation and startup of a number of source-excited x-ray fluorescence systems for elemental assay of minerals in base metals processing plants.

Previous experience was gained in all phases of the instrumentation business at EG&G ORTEC. Assignments included development physicist in the semiconductor detector operations, manufacturing manager, program director, and project manager.

PROFESSIONAL ACHIEVEMENTS AND ACTIVITIES

Authored over 15 papers in the radiation instrument field.

AEC Health Physics Fellowship 1963-1966
ORINS Research Fellowship 1966-68
Valedictorian of Southwestern College, Class of 1963
Member: Health Physics Society, American Physical Society, IEEE Nuclear and Plasma Sciences Group, American Institute of Mining Engineers
Member: Oak Ridge Regional Planning Commission 1976-1982

**Daniel M. Kopp**

**Senior Associate Engineer**
**Product Design Department**

## EDUCATION

University of Tennessee, Knoxville, TN: Electrical Engineering; 1978 to present; 72 hours

Roane State Community College, Harriman/Oak Ridge, TN: A.S. Pre-Engineering Option; 1981 to 1985; 45 hours

## SUMMARY OF EXPERIENCE

Mr. Kopp is responsible for providing day-to-day product design support in the electrical and electronic system and component areas. Systems include loose parts detection, acoustic valve flow monitoring, and radiation monitoring. In addition, Mr. Kopp provides detector development and research assistance for development of high-range GM tube area radiation detectors, beta scintillation duct monitor detectors and surface barrier ion-implanted detectors for ground water contamination measurements.

Mr. Kopp has been responsible for radiation monitoring system proof-of-design and calibration activities. Systems include area radiation monitors, duct monitors, liquid monitors, and particulate monitors.

Prior to this, Mr. Kopp provided assistance on nuclear enviromental qualification programs for various radiation monitoring, isokinetic sampling, and acoustic monitoring systems. Work included component and system baseline testing, accelerated aging, irradiation, and seismic testing.

## Francis E. LeVert

Manager, Engineering Analysis Department

### EDUCATION

Tuskegee Institute: B.S., Mechanical Engineering (1964)

The University of Michigan: M.S., Nuclear Engineering (1966)

The Pennsylvania State University: Ph.D., Nuclear Engineering (1971)

### SUMMARY OF EXPERIENCE

As manager of the Engineering Analysis Department, Dr. LeVert has contributed to a wide variety of projects. He served as coordinator of instrumentation development in TEC's Measurement Technology Department. He was responsible for the initial conceptual design of the safety console and for the development and fabrication of TEC's gamma thermometer. He led the investigation of the relationship between acoustic noise and mass flow rate through orifices in the LOFT small break blowdown test. Recently, he was responsible for the development of the TEC prototype nuclear coal analyzer.

Prior to joing TEC, Dr. LeVert was employed at Argonne National Laboratory (ANL) where he was involved in the analysis of the effect of low enrichment on the performance of research thermal reactors. Also while at ANL, he participated in the development of in-core directional gamma and neutron detectors for fuel motion monitors. Prior to his work on fuel motion monitors, he was responsible for the initial conceptual design description of the reactor control system and the transient controller for the Safety Analysis Research Experimental Facility, Fast Burst Reactor.

Dr. LeVert also worked for the Commonwealth Edison Company of Chicago where he was involved in the application of modern control theory techniques in the study of the dynamic characteristics of large boiling water reactor systems.

Prior to joining Commonwealth Edison, Dr. LeVert was the Head of the Mechanical Engineering Department at Tuskegee Institute.

**Dr. Francis LeVert**
(Continued)

PROFESSIONAL ACHIEVEMENTS AND ACTIVITIES

Professional Engineer - Illinois, Alabama, and Tennessee

Author of over 25 technical papers, primarily concerned with nuclear instrumentation and measurements.

Holder of several patents and patents pending for radiation level detectors.

Ford Foundation Fellow, 1973-1974

Member, Beta Kappa Chi, Phi Kappa Phi, and Pi Tau Sigma Honor Societies

**James C. Robinson**

**Senior Vice President, Engineering Applications Group**

EDUCATION

The University of Tennessee: Executive Development program (1983)
The University of Tennessee: Ph.D., Engineering Science (1966)
The University of Tennessee: M.S., Nuclear Engineering (1961)
The University of Tennessee: B.S., Nuclear Engineering (1960)

SUMMARY OF EXPERIENCE

Dr. Robinson is a founder of TEC and serves as a senior company advisor in instrumentation development, field services, and surveillance and diagnostic activities.

Dr. Robinson was an Instructor and an Assistant, Associate, and Full Professor of Nuclear engineering at The University of Tennessee, Knoxville. He developed and presented several undergraduate and graduate engineering courses covering advanced calculational methodologies in instrumentation interpretations and classical deep penetration problems. Additionally, he directed numerous graduate research projects.

Dr. Robinson served as a consultant to the Development Section of the Oak Ridge National Laboratory. Dr. Robinson was significant in establishing the international reputation of that group as the center of excellence for noise analysis as applied to surveillance and diagnostic activities in the nuclear power industry.

PROFESSIONAL ACTIVITIES

Dr. Robinson is the author of several publications concerned with surveillance diagnostics and calculational methods in nuclear engineering. He was a member of the TMI Industry Review and Advisor Groups, is a Fellow of the American Nuclear society, a senior member of the Institute of Electrical and Electronic Engineers, Inc., a member of the Instrument Society of America, a member of the American Society for Engineering Educators, and recipient of the M. E. Brooks Distinguished Professor and the University of Tennessee Outstanding Engineering Alumnus Awards. Dr. Robinson is a registered Professional Engineer in the State of Tennessee, a reviewed for Nuclear Science and Engineering, and holds an active DOE "Q" security clearance.

**Paul W. Standifer**

**Senior Project Manager**

EDUCATION

Georgia Institute of Technology: B.S., Industrial Engineering (1969)
The University of Tennessee: MBA, Business Administration (1983)

SUMMARY OF EXPERIENCE

At TEC, Mr. Standifer is currently the Project Manager for a $10M computer-based Emergency Response Data Acquisition and Display System where he is responsible for cost and schedule performance. He is also TEC's Project Manager for Phase II of the NAVAIR SBIR program on stress analysis. Mr. Standifer has also served as Project Manager on several other projects ranging from $.5M mechanical/hardware systems to $4.5M computer-based information systems. For two years prior to these assignments, Mr. Standifer was Project Manager of the IDCOR project, responsible for the cost and schedule performance of TEC and fourteen participating contractors.

Prior to joining TEC, Mr. Standifer was a project engineer with the project Management Corporation on the Clinch River Breeder Reactor Project. As such, he was responsible for the control of the design and procurement of certain reactor system components for the project. In addition, he was a member of the Breeder Reactor Corporation's Speakers Bureau providing frequent presentations to civic and professional organizations on energy.

Prior to that, Mr. Standifer was employed with the Naval Nuclear Fuel Division (NNFD) of the Babcock and Wilcox Company as a contract specialist. In that capacity, he was responsible for the solicitation, proposal preparation and negotiation of government prime contracts and provided primary liaison with Contracting Officers on legal, technical and financial matters. In previous positions at NNFD, he was a production engineer responsible for production process control and refinement and prior to that, a project administrator, performing technical administrative functions on assigned projects.

Mr. Standifer served on active duty with the United States Marine Corps as an Aircraft Commander and Flight Instructor in KC130 aircraft. He was also the Air Transport Control Officer for the Second Marine Air Wing, responsible for schedule and control of all Marine air transport in the eastern United States and Europe. He now holds the rank of Major and has served as the commanding officer of the Marine Corps Reserve in Knoxville, Tennessee.

As a co-op student at Georgia Tech, Mr. Standifer was employed with the Chattanooga Electric Power Board and Management Science America, Inc.

| CONTRACT PRICING PROPOSAL (RESEARCH AND DEVELOPMENT) | Office of Management and Budget Approval No. 29-RO184 | |
|---|---|---|
| This form is for use when (i) submission of cost or pricing data (see FPR 1-3.807-3) is required and (ii) substitution for the Optional Form 59 is authorized by the contracting officer | PAGE NO 1 | NO. OF PAGES 2 |

| | |
|---|---|
| NAME OF OFFEROR: Technology for Energy Corporation | SUPPLIES AND/OR SERVICES TO BE FURNISHED: PHASE II PROPOSAL -- DEVELOPMENT OF A FIELD-USABLE MANUFACTURING PROTOTYPE |
| HOME OFFICE ADDRESS: One Energy Center, Lexington Drive, Knoxville, Tennessee 37922 | |
| DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED: Same as above | TOTAL AMOUNT OF PROPOSAL: $ 370,556 — GOV'T SOLICITATION NO: SBIR PHASE II |

## DETAIL DESCRIPTION OF COST ELEMENTS

| 1. DIRECT MATERIAL (Itemize on Exhibit A) | | | EST COST ($) | TOTAL EST COST | REFERENCE |
|---|---|---|---|---|---|
| a. PURCHASED PARTS | | | 36,520 | | |
| b. SUBCONTRACTED ITEMS | | | | | |
| c. OTHER—(1) RAW MATERIAL | | | | | |
| (2) YOUR STANDARD COMMERCIAL ITEMS | | | | | |
| (3) INTERDIVISIONAL TRANSFERS (At other than cost) | | | | | |
| TOTAL DIRECT MATERIAL | | | | 36,520 | A |
| 2. MATERIAL OVERHEAD (Rate %X$ base =) | | | | | |
| 3. DIRECT LABOR (Specify) | ESTIMATED HOURS | RATE/HOUR | EST COST ($) | | |
| Level V -- J. C. Robinson | 385 | 30.00 | 11,550 | | |
| Level IV -- F. E. Levert | 1,024 | 24.15 | 24,729 | | |
| Level IV -- F. W. Garber | 454 | 24.15 | 10,964 | | |
| Level III -- P.W. Standifer/Mech. Design | 662 | 18.90 | 12,512 | | |
| Level II -- Technician/Project Support | 1,731 | 14.25 | 24,667 | | |
| Level I -- Technician/Word Processing | 1,270 | 7.90 | 10,033 | | |
| TOTAL DIRECT LABOR | | | | 94,455 | |
| 4. LABOR OVERHEAD (Specify Department or Cost Center) | O.H. RATE | X BASE = | EST COST ($) | | |
| Engineering Overhead | 134.2% | 94,455 | 126,759 | | |
| TOTAL LABOR OVERHEAD | | | | 126,759 | |
| 5. SPECIAL TESTING (Including field work at Government installations) | | | EST COST ($) | | |
| TOTAL SPECIAL TESTING | | | | | |
| 6. SPECIAL EQUIPMENT (If direct charge) (Itemize on Exhibit A) | | | | | |
| 7. TRAVEL (If direct charge) (Give details on attached Schedule) | | | EST COST ($) | | |
| a. TRANSPORTATION | | | 992 | | |
| b. PER DIEM OR SUBSISTENCE | | | 600 | | |
| TOTAL TRAVEL | | | | 1,592 | B |
| 8. CONSULTANTS (Identify—purpose—rate) | | | EST COST ($) | | |
| TOTAL CONSULTANTS | | | | | |
| 9. OTHER DIRECT COSTS (Itemize on Exhibit A) | | | | 5,300 | C |
| 10. TOTAL DIRECT COST AND OVERHEAD | | | | 264,626 | |
| 11. GENERAL AND ADMINISTRATIVE EXPENSE (Rate 27.3% of cost element Nos. 10) | | | | 72,243 | |
| 12. ROYALTIES | | | | | |
| 13. TOTAL ESTIMATED COST | | | | 336,869 | |
| 14. FEE OR PROFIT | | | | 33,687 | |
| 15. TOTAL ESTIMATED COST AND FEE OR PROFIT | | | | 370,556 | |



OPTIONAL FORM 60
October 1971
General Services Administration
FPR 1-16.806

This proposal is submitted for use in connection with and in response to *(Describe RFP, etc.)*

PHASE II CONTRACT DAAK70-85-C-0101 FEASIBILITY STUDY FOR FIELD MONITORING OF WATER SUPPLIES FOR RADIOACTIVITY

and reflects our best estimates as of this date, in accordance with the Instructions to Offerors and the Footnotes which follow.

TYPED NAME AND TITLE: Ralph D. Wright, Contracts Manager

SIGNATURE: R. D. Wright

NAME OF FIRM: Technology for Energy Corporation

DATE OF SUBMISSION: March 24, 1986

**EXHIBIT A—SUPPORTING SCHEDULE** *(Specify. If more space is needed, use reverse)*

| COST EL NO | ITEM DESCRIPTION *(See footnote 5)* | EST COST ($) |
|---|---|---|
| A | Component Hybridization @ $15,000 | $36,520 |
| | Modified DIAD II Detectors, 5 @ $2,560 = $12,800 | |
| | Electronic & Mechanical Packaging @ $7,920 | |
| | Radioactive Sources @ $800 | |
| B | Travel | $ 1,592 |
| | One (1) round trip to Fort Belvoir, VA, two people | |
| | @ $450 = $900 | |
| | Subsistence -- includes meals, ground transportation, | |
| | lodging, and miscellaneous expenses, 2 days @ $150/day = | |
| | $300 X 2 people = $600 | |
| | Mileage expense -- 15 round trips from TEC to Oak Ridge, | |
| | 30 miles (15 trips X 30 miles = 450 miles) 450 miles | |
| | @ $0.205 per mile = $92 | |
| C | Reproduction, computer usage and other allowable costs | $ 5,300 |

I. HAS ANY EXECUTIVE AGENCY OF THE UNITED STATES GOVERNMENT PERFORMED ANY REVIEW OF YOUR ACCOUNTS OR RECORDS IN CONNECTION WITH ANY OTHER GOVERNMENT PRIME CONTRACT OR SUBCONTRACT WITHIN THE PAST TWELVE MONTHS?

[X] YES [ ] NO *(If yes, identify below.)*

NAME AND ADDRESS OF REVIEWING OFFICE AND INDIVIDUAL: Mr. William C. Bowers, Dept. of Energy, P.O. Box U, Oak Ridge, TN 37830

TELEPHONE NUMBER/EXTENSION: (615) 576-6040

II. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS PROPOSED CONTRACT?

[ ] YES [X] NO *(If yes, identify on reverse or separate page)*

III. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?

[X] YES [ ] NO *(If yes, identify.)*: [ ] ADVANCE PAYMENTS [X] PROGRESS PAYMENTS OR [ ] GUARANTEED LOANS Firm Fixed Price

IV. DO YOU NOW HOLD ANY CONTRACT *(Or, do you have any independently financed (IR&D) projects)* FOR THE SAME OR SIMILAR WORK CALLED FOR BY THIS PROPOSED CONTRACT?

[ ] YES [X] NO *(If yes, identify.)*:

V. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN AGENCY REGULATIONS?

[X] YES [ ] NO *(If no, explain on reverse or separate page)*

*See Reverse for Instructions and Footnotes*

OPTIONAL FORM 60 (10-71)

END
FILMED

6-86

DTIC