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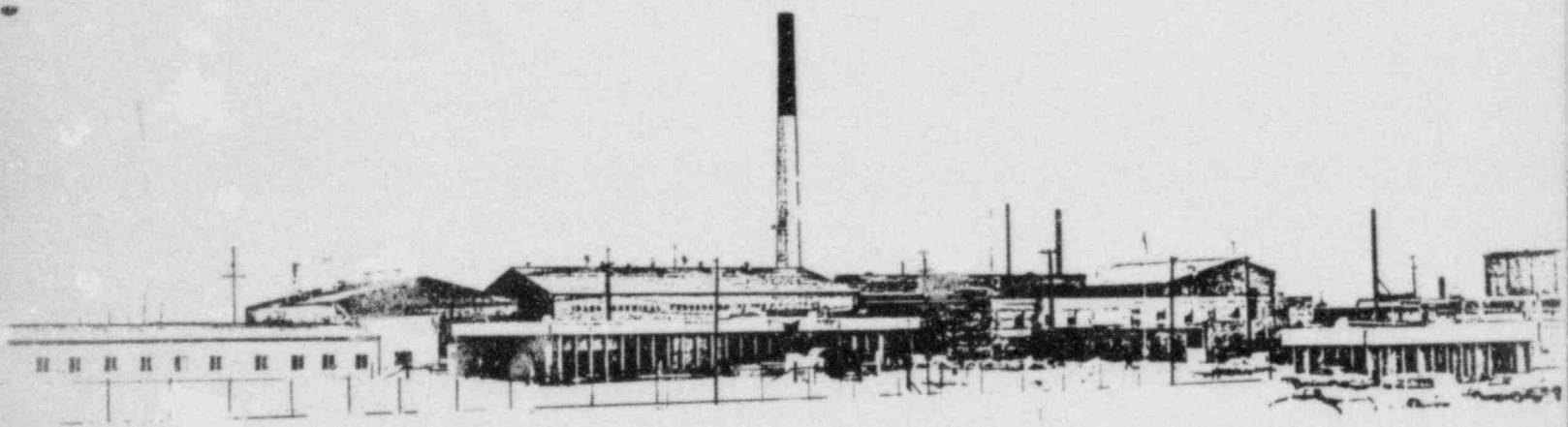
EVALUATION OF PORTABLE RADIOLOGICAL INSTRUMENTS FOR EMERGENCY RESPONSE MEASUREMENT OF RADIOIODINE



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EVALUATION OF PORTABLE RADIOLOGICAL INSTRUMENTS FOR EMERGENCY RESPONSE MEASUREMENT OF RADIOIODINE

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ABSTRACT

In the event radionuclides are released to the environment following an accident at a commercial nuclear power facility, measurement methods are required to assess the potential radiological hazards to the surrounding populace. This document reports the results of a study to evaluate the relative ability of selected portable radiological instruments to measure ^{131}I in milk, on barren and grass covered ground, and in human and bovine thyroid phantoms. The instruments, sensitivities, accuracies, energy responses, and performance characteristics were evaluated in regard to operation at different temperatures and relative humidities and their resistance to mechanical shock and vibration.

ACKNOWLEDGEMENTS

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SUMMARY

The Federal Interagency Task Force for Offsite Emergency Instrumentation for Nuclear Incidents, including the NRC, has the lead responsibility for the development of emergency radiation detection and measurement systems. In support of this effort, and under contract of NRC's Office of Nuclear Regulatory Research, Exxon Nuclear Idaho Co., Inc. (ENICO)[a] evaluated the usefulness of selected radiological instruments for measuring radioiodine subsequent to an accidental release of radionuclides from a nuclear power station.

The radiological instruments evaluated by ENICO were: 1) a CDV-700 Model 6B Civil Defense survey meter with a standard OCD-D-103 GM detector, 2) a modified CDV-700 survey meter with a specially-shielded, Victoreen 6306[b] bismuth-screened GM tube, 3) a Victoreen 490 Thyac III ratemeter with a 489-4 GM detector, 4) a Victoreen 490 Thyac III ratemeter with a 489-55 scintillation detector, 5) a Ludlum 2200 (scaler, ratemeter, single channel analyzer) with an Eberline SPA-3 scintillation detector, 6) an Eberline SAM II (stabilized assay meter) with a RD-22 scintillation detector, and 7) two CDV-715, 0-500 R/hr survey meters.

In general, each instrument was evaluated for its sensitivity, its ability to discriminate between ^{131}I and other selected gamma emitting radionuclides, its measurement accuracy and precision, and its performance under anticipated field conditions. More specifically, the gamma

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[a] This contract was originally administered by and the work completed under Exxon Nuclear Idaho Company, Inc.; the current operating contractor for this program is Westinghouse Idaho Nuclear Company, Inc.

[b] Use of specific vendor instrumentation or equipment does not constitute endorsement of these products by ENICO, WINCO, or the US Government.

ray energy responses were determined for each detector using point sources. The effects of temperature and relative humidity (RH) on instrument response were determined in an environmental test chamber at temperatures of -20 to 110°F and at relative humidities of 30 and 90%. Instrument responses per unit ^{131}I content were determined for bovine and human thyroid models; these were used to establish instrument response versus dose commitment for adults and juveniles.

Additionally, the ability of the instruments to measure ^{131}I on the ground and in liquids was determined. To evalute the instrument's ability to measure ^{131}I on the ground, pasture and fields tests were performed using ten-meter-radius sod and blotter paper sources contaminated with ^{133}Ba (an ^{131}I simulant) and ^{137}Cs (to simulate interfering high energy nuclides); subsequently, the measured field values were extrapolated to an "infinite" source using computer generated buildup calculations. Instrument responses of ^{131}I in liquids were determined by direct measurement of large volumes of liquids and by measurement of ^{131}I concentrated on an anion exchange resin.

The effects of vibration and shock on instrument operation were also determined. Vibration was tested by conveying the instruments in foam padded cases over rough roads; shock was evaluated by dropping them from two feet and four feet onto grass and barren ground.

The conclusions of the study were the following:

1. Scintillation detectors, followed by the 6306 GM tubes, have the highest sensitivity for ^{131}I measurement:

    a) The SPA-3 and RD-22 instruments had the highest sensitivity for measuring ^{131}I in bovine and human thyroids;

    b) The SPA-3 and RD-22 instruments had the lowest increase in ^{131}I response as a result of ^{134}Cs and ^{137}Cs interference; and

    c) With 67% recovery of ^{131}I activity from milk onto resin, only the scintillation detectors and the 6306 GM tubes measured ^{131}I at the FDA preventive PAG level.

2. Only the scintillation detectors detected ^{131}I at the Federal Drug Administration (FDA) preventive protection action guide (PAG) level on fields and pastures.

3. Only the scintillation detectors and 6306 GM tubes detected ^{131}I in milk or water at the FDA preventive PAG level.

4. With the exception of the SAM II/RD-22, all instruments showed changes of <16% in absolute and relative response when operated between 0 and 110°F at 90% RH.

5. Operation at -20°F caused changes in response ranging from a 26% increase for the CDV-700/6306 detector to a 40% decrease in the SAM II/RD-22 detector.

6. With the exception of the THYAC III/489-4, all instruments returned to their initial responses when retested at ambient conditions (70°F).

7. The CDV-715, 0-500 R/hr survey meters showed response changes (10-30%) when tested at -20 to 110°F at 90% RH. With the exception of requiring an adjustment of the instrument zero, they were unaffected by vibration and shock tests.

8. No instruments showed damage as a result of vibration testing.

9. No instruments, with the exception of one CDV-700-6306 detector, showed damage as a result of shock testing.

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FIGURES

1. INTRODUCTION

The Federal Interagency Task Force on Offsite Emergency Instrumentation for Nuclear Incidents, including the NRC, has the lead responsibility for development and verification of radionuclide collection and measurement systems for use in the event of accident-related radionuclide releases from nuclear power plants. The Safety and Environmental Protection Division of Brookhaven National Laboratory (BNL) was contracted previously by the NRC to study a limited number of radiological instruments for field monitoring of radioiodine[1]. Radioiodine was selected due to its: 1) tendency to accumulate in the thyroid, 2) availability in the food chain through the grass-cow-milk pathway, 3) high fission yield, and 4) high release fraction in most proposed accident scenarios.[2]

Exxon Nuclear Idaho Co., Inc. (ENICO) was contracted to extend this BNL investigation to include additional portable radiological instruments and a wider range of environmental test conditions. Accordingly, each instrument selected was evaluated in regard to its sensitivity, ability to discriminate between ^{131}I and other selected radionuclides, measurement precision, and performance under anticipated field conditions; these factors indicate the relative appropriateness of each instrument for field measurement of ^{131}I.

The following instruments were selected for testing: 1) a CDV-700 Model 6B Civil Defense survey meter equipped with a standard OCD-D-103 GM probe, 2) a CDV-700 survey meter equipped with a Victoreen 6306 bismuth-screened cathode GM tube and a 0.127-cm lead and 0.08-cm copper shield, 3) a Victoreen 490 Thyac III ratemeter equipped with a 489-4 GM probe, 4) a Victoreen 490 Thyac III ratemeter equipped with a 489-55 NaI(Tl) detector, 5) a Ludlum Model 2200 scaler, ratemeter, and single channel analyzer equipped with an Eberline SPA-3 NaI(Tl) detector, and 6) an Eberline SAM II dual-channel analzyer equipped with a RD-22 NaI(Tl) detector. In addition, a pair of CDV-715 0-500 R/hr survey meters were tested under limited conditions; their detectable dose rate (>100mR/hr) precluded their use in other evaluations.

Instrument performance was evaluated under field and laboratory conditions to determine the following:

1. Instrument gamma energy response curves in cps/mR/hr and counts/gamma.

2. Instrument sensitivities, response accuracies and precisions as a function of temperature and humidity.

3. Instrument responses per dose commitment for human adult and juvenile (2 and 5-year old) thyroids.

4. Instrument responses per microcurie ^{131}I activity in bovine thyroids.

5. Instrument responses per microcurie per square meter of an ^{131}I simulant, ^{133}Ba, and an interfering radionuclide, ^{137}Cs, deposited on ten-meter-radius sources of blotter paper and sod (representing barren ground and pasture, respectively).

6. Instrument responses per microcurie ^{131}I per liter of liquids in a five gallon rectangular container and in a larger volume cylindrical container.

7. Instrument responses per microcurie ^{131}I adsorbed from milk on an anion exchange resin using methods outlined by Distenfeld,[3] including OCD-D-103 and 6306 GM measurements:

   a) inside a proposed air sampling canister,[3]
   b) outside the proposed canister,
   c) outside a one liter plastic bottle.

8. Instrument responses per microcurie ^{131}I adsorbed from milk on an anion ion exchange resin, including the remaining instruments and the latter two geometries.

9. The effect of vibration and shock on instrument sensitivity and response accuracy.

2. EXPERIMENTAL PROCEDURES, DISCUSSION AND RESULTS

The following sections describe the instruments tested, the experimental procedures used, and the test results. Section 2.1 and Section 2.2, respectively, describe the instruments, their setup, and preparation for measurements; Section 2.3 describes the determination of detector energy responses; and Section 2.4 details the determination of the effect of temperature and humidity on instrument sensitivities, response accuracies and precision. In Sections 2.5, 2.6, and 2.7, respectively, the experimental procedures used to determine the instrument responses to ^{131}I in human and bovine thyroids, radioiodine simulants on fields and pastures, and radioiodine and interfering radionuclides in liquids and on an anion exchange resin are discussed. Lastly, Section 2.8 describes the effect of mechanical vibration and shock on instrument performance.

2.1 Description of Radiological Instruments

The instruments evaluated for their applicability to in-field measurement of ^{131}I are described in detail below.

2.1.1 Civil Defense Survey Meter CDV-700 with OCD-D-103 GM Detector. The CDV-700 ratemeter has three ranges: 0-300, 0-3000, and 0-30,000 cpm. The OCD-D-103 GM detector has a stainless steel shield with a moveable window for beta radiation measurements. The detector is hardwired to the CDV-700 ratemeter. It is designed for use in long term clean-up and decontamination operations, for personnel monitoring, and for indicating the degree of radioactive contamination in food and water. It is designed to operate in the normal range of expected operating environments, is powered by four D-cell batteries, has a six-second time constant, and weighs ~2.2 kg. The ratemeter is 10.8 x 9.5 x 21-cm; the probe 13 x 2.2-cm. The meter has a phone jack output and a check source. It is shown on the right in Figure 1.

2.1.2 CDV-700 with 6306 Bismuth-Screened Cathode GM Detector, Shielded with 0.127-cm Lead and 0.08-cm Copper. The ratemeter is the

Figure 1. CDV-700/OCD-D-103 and Victoreen Model 490 Thyac III/489-4

same as that described in 2.1.1. The 6306 GM tube has an internal bismuth-screen around the cathode to provide increased response to gamma radiation. The tube is coupled to the CDV-700 with a BNC connector. The lead and copper probe shield is that proposed by Distenfeld;[3] it is designed to reduce the interference of low energy photons from noble gases during measurement of radioiodine collected on silver silica gel contained in the BNL air sampling cannisters. Detailed and exploded drawings of the probe shield, as manufactured by ENICO, are shown in Appendix A. Overall, the shielded probe is 14.0 x 3.2-cm. The ~2.5 kg CDV-700/6306 is shown in Figure 3 with a disassembled probe.

2.1.3 Victoreen Model 490 Thyac III Pulse Count Ratemeter with a 489-4 GM Tube Detector. The Thyac III is a commercial, general use survey instrument with a Model 490 ratemeter and a 489-4 GM probe with a stainless steel shield with a moveable window. The instrument has three ranges: 0-800, 0-8000, and 0-80,000 cpm. It is powered by two D-cell batteries and is nominally designed to operate in the range from -20 to 125°F. The instrument has 1.5, 5 and 15 second time constants; the 5 second time constant was used in all ENICO experiments. The ratemeter is 10.8 x 9.5 x 21.6-cm and the probe is 13.3 x 3.2-cm. The instrument has a phone jack output and a check source. The meter and probe weigh ~1.2 kg and are shown on the left in Figure 1.

2.1.4 Victoreen Model 490 Thyac III Pulse Count Ratemeter with a 489-55 NaI(Tl) Scintillation Detector. The instrument's ratemeter is identical to that described in 2.1.3; however, the ratemeter has an additional range, 0-800,000 cpm for use with a scintillation detector. Its time constants are similar to those described in 2.1.3; during testing the 5 second time constant was used. The 489-55 probe consists of a photomultiplier and a 3.2-cm diameter x 3.8-cm thick NaI(Tl) crystal with a resolution of 12% (FWHM) at 364 KeV. The probe is 23.2 x 5-cm. The meter and probe weigh 2.3 kg; they are shown on the right in Figure 2.

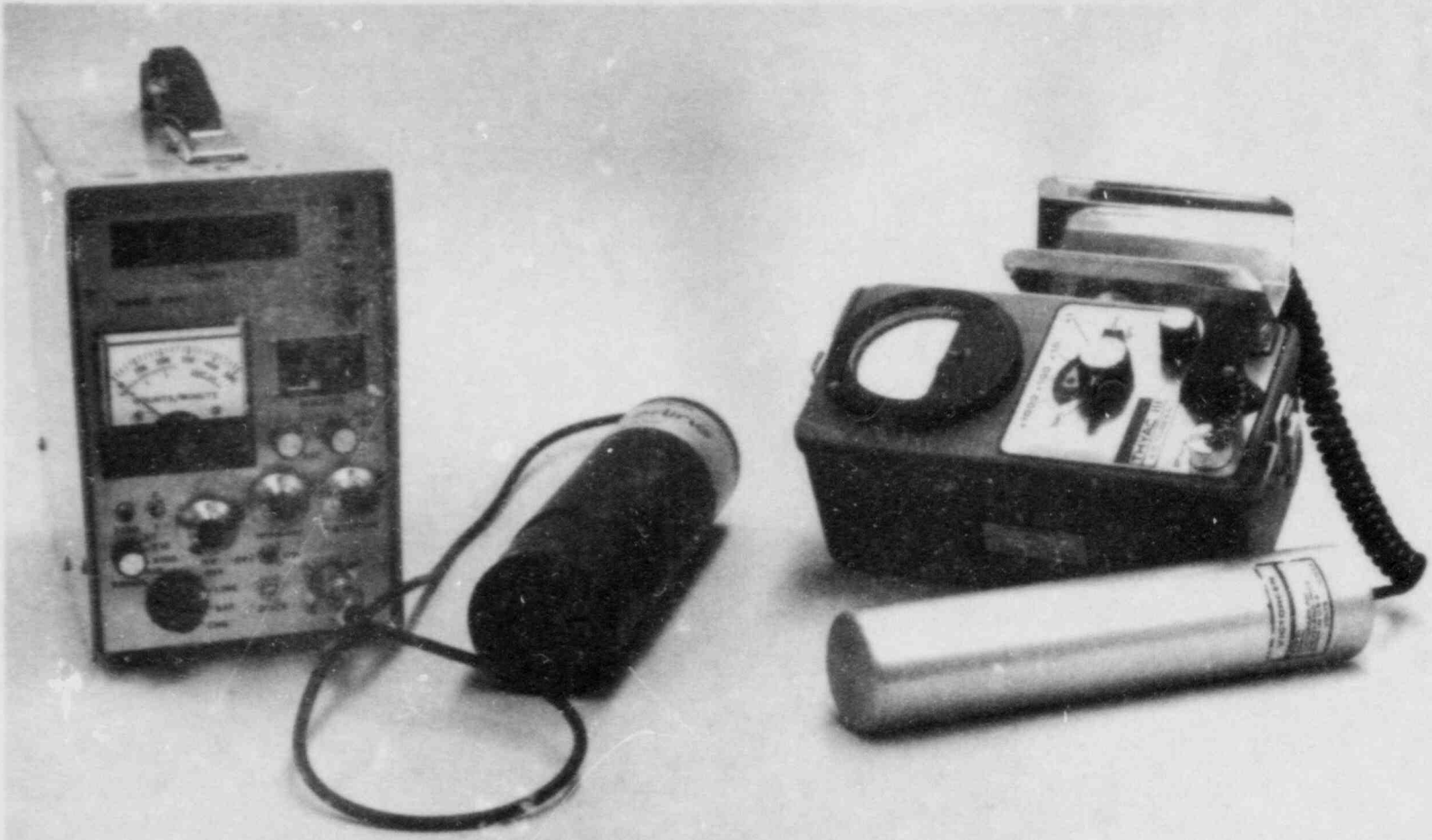

Figure 2. LUDLUM 2200/SPA-3 and Victoreen Model 490 Thyac III/489-55

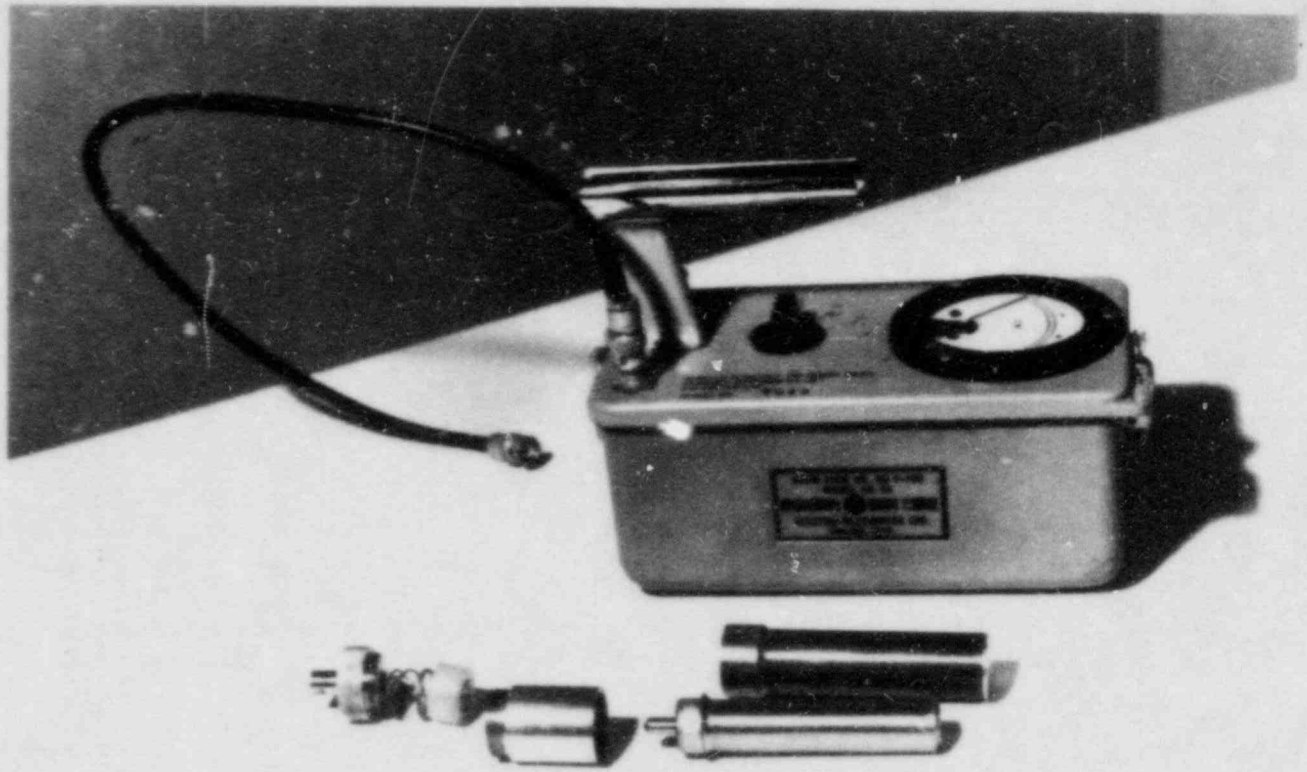

Figure 3 CDV-700/6306

2.1.5 Ludlum 2200 Single Channel Analyzer with Eberline SPA-3 NaI (Tl) Scintillation Detector. The Ludlum Model 2200 Single Channel Analyzer consists of the single channel analyzer, a scaler, a ratemeter and a timer. It is powered by four flashlight batteries or AC line voltage. A built-in charger is supplied for rechargeable cells. The unit can be used with or without the single channel analyzer feature. The threshold, window, and high voltage are each controlled with ten turn potentiometers. The amplifier gain discriminator is controlled with a one turn potentiometer. The SPA-3 probe contains a 5.0-cm diameter x 5.0-cm thick NaI(Tl)crystal and photomultiplier. Its resolution is approximately 13% (FWHM) at 364 KeV. The ratemeter is 23.8 x 21.6 x 13.3-cm and the probe is 7 x 25.4-cm. The unit weighs ∿5.8 kg; it is shown on the left in Figure 2.

2.1.6 Eberline Stabilized Assay Meter (SAM) II with RD-22 Scintillation Detector. The SAM II is a two channel analyzer stabilized to adjust automatically for gain changes caused by environmental conditions, component aging, etc. The instrument is powered by AC line voltage or by an optional external battery pack. Stabilization is achieved by doping the NaI(Tl) scintillation crystal with ∿0.027 μCi of ^{241}Am, which yields ∿3.5 MeV gamma equivalent pulses from the RD-22. These pulses are counted and used to control the high voltage applied to the detector, thereby maintaining constant gain. High voltage, thresholds, and windows are controlled with ten turn potentiometers. Each channel can be set in additive, subtractive, or null mode. The subtractive channel is typically used for background subtraction. Nominal operating temperature range is 32 to 140°F. The RD-22 detector is an integral 5.0-cm diameter x 5.0-cm thick NaI(Tl) crystal and photomultiplier. Resolution is typically 13% (FWHM) at 364 Kev. The probe and meter weigh ∿4.7 kg (excluding the separate battery pack). The battery pack is a gel-cell unit weighing 3.3 kg. Its dimensions are 11.1 x 16.2 x 15.9-cm. The ratemeter is 27.3 x 10.8 x 23.5-cm and the probe is 7 x 25.4-cm. The instrument is shown in Figure 4.

Figure 4. SAM II/RD-22

2.1.7 CDV-715. The CDV-715, designed for use in detecting high level radiation sources, is an ionization chamber gamma-ray flux monitor with four ranges: 0-0.5, 0-5, 0-50, and 0-500 R/hr. The unit weighs 1.4 kg and is 11.4 x 21.6 x 16.5-cm. Because of its low sensitivity, this instrument was only evaluated for reliability after being subjected to extremes of temperature, humidity, shock, and vibration.

2.2 Set-up and Preparation For Testing

The CDV-715 monitor, the CDV-700 survey meters with OCD-D-103 probes, and the CDV-700 survey meters for the 6306 probes were obtained from the Federal Emergency Management Agency (FEMA). The remaining equipment, with the exception of the shields for the 6306 tubes, were obtained from commercial vendors.

Except where instruments were used as received, the following preparation and set-up steps were followed:

1. The Pb-Cu shields and electrical signal-high voltage connectors for the 6306 GM tubes were fabricated (Figure A-1 and A-2, Appendix A).

2. Optimum operating high voltages and appropriate threshold and window settings were determined for the Ludlum 2200/SPA-3 and SAM II/RD-22. To achieve this for the Ludlum 2200, a high voltage plateau was first determined by varying the high/voltage and recording the background and signal from a ^{133}Ba source. Next, the discriminator (gain) of the Ludlum 2200 was adjusted at a given high voltage on the plateau to calibrate the instrument for a measurement range of 0-1000 KeV, which corresponds to 0-10 volts. A ^{133}Ba source (356 KeV) and an ^{131}I source (364 KeV) was then used to establish threshold and window settings.

The gain of the SAM II is internally preset at the factory. To calibrate the instrument to a desired measurement range, the threshold and width of the window were set to correspond to a known radionuclide photon energy and the high voltage varied to position the photopeak with the desired energy in the window. The measurement range of the SAM II was also set to 0-1000 KeV.

Optimum detector windows for the SAM II and Ludlum 2200 were selected to provide a high signal to background ratio and detect the bulk of the peak counts. Spectra of ^{133}Ba and ^{131}I were taken with different width windows by varying the threshold with a previously determined constant high voltage. A 50 KeV window width was the optimum for measurement of either ^{133}Ba or ^{131}I and was used throughout the measurements.

3. The utility of the dual-channel feature of the SAM II/RD-22 was determined. The second channel (window) of the SAM II is often used in measurements to subtract background; it is typically set with a threshold above the gamma-ray energy of interest. The window width is then adjusted so that the background count rate in the second channel is the same as the background count rate in the channel of interest. Measurements are then made with the first channel in the additive mode and the second channel in the subtractive mode, providing background subtraction.

In the event of a release of radioactivity from a nuclear facility, many isotopes (^{130}I, ^{132}I, ^{133}I, ^{135}I, ^{134}Cs, ^{137}Cs) with gamma-rays energies in the region of 500-1000 KeV will likely be present. Since the sensitivity of a sodium iodide decreases with higher gamma energy and there is less natural radiation at higher energies, a wide window would therefore be required to provide background subtraction for ^{131}I measurements. Therefore, because the wide window would decrease the apparent ^{131}I signal, giving a low value for the ^{131}I present, use of this

second channel was not appropriate. Accordingly, the only use of this dual-channel feature was for measuring ^{137}Cs in the field (Section 2.6).

4. A pretest quality assurance program using a fixed-geometry ^{133}Ba check source was used to verify proper detector operation. The detector's response to the check source was compared to a known value; if the values varied by an amount beyond experimental uncertainty, the instrument was examined to identify and correct potential problems and/or not used in experiments.

2.3 Energy Responses

Detector energy response curves (cps/mR/hr vs KeV) were determined in two stages. In the first stage, responses of each detector to different energy photons of various nuclides were determined by counting ~10 µCi point source standards positioned at a distance of 10-cm from the center of the detector to the source. Nuclides used included: ^{137}Cs (100%, 662 KeV), ^{57}Co (85.6%, 122 KeV), ^{54}Mn (100%, 835 KeV), ^{60}Co (100% 1.1732/1.332 KeV), ^{203}Hg (100%, 279 KeV), ^{131}I (81%, 364 KeV), and ^{133}Ba (62% 356 KeV).[a] The activity levels of the radionuclide standards were verified with a computer-based Ge(Li) detector gamma-ray analysis system calibrated with standards traceable to the National Bureau of Standards (NBS). The ^{131}I sources were produced in-house by stapling 20 microliters of a NaI/^{131}I solution onto a 1-cm diameter glass fibre filter, previously soaked in a dilute (0.01 M) silver nitrate solution and dried. The filter paper was mounted in a standard geometry and analyzed with the gamma-ray analysis system.

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[a] All sources, except ^{131}I, were purchased in calibration grade (±5% of stated activity value) from Isotope Products Laboratories, Burbank, California.

In the measurement of the instrument responses at 10-cm, ten readings were taken with each instrument. For those instruments with analog meters, the average high and low points of the instrument response band were recorded. The center of the band was taken to be the detector response. The average and standardized deviation of the ten readings were determined and used in subsequent calculations. From these values the radiation fields, mR/hr, from the different radionuclides were calculated for the 10-cm distance from the equation: $mR/hr = n\Gamma/s^2$, where n = number of microcuries, Γ = mR/hr at 1 meter per μCi, and s = source distance in meters.[5]

After each detector's response was determined at the 10-cm distance, responses were measured at distances of greater than one meter in NBS traceable ^{137}Cs fields of 1.5, 2, and 4 mR/hr. These measurements minimized uncertainties in the uniformity of radiation fields that can occur at shorter distances. For example, at an appreciable source to detector distance, both the source and detector appear as points and the detector is in a uniform radiation field. In comparison, at 10 centimeters, the source to detector distance is less easily defined and, as a result, different parts of the detector may lie in different level radiation fields.

Next, a ratio of responses at the longer distance to those at 10-cm was calculated. Subsequently, the geometry correction factors obtained were used to adjust the calculated radiation fields at 10-cm for each instrument and for the other radionuclides. The correction factors were on the order of 10-30%. Detector energy response was also calculated[6] in terms of counts/photon passing through the cross-sectional area of the detector.

Detector energy responses curves, expressed as cps/mR/hr vs KeV and c/gamma vs KeV, were then developed (Appendix B). As expected, the sodium iodide detectors showed the highest response, followed by the 6306 bismuth-screened cathode GM tubes. Both the standard CDV-700/OCDD-103 and Thyac III/489-4 showed low, $<10^{-3}$/gamma at 364 keV, efficiencies for counting I-131.

2.4 Temperature and Relative Humidity Effects

Each of the instruments was tested for its sensitivity, response accuracy, and precision under various temperature and relative humidities in an environmental test chamber. The tests were performed at -20, 0, 90 and 100°F. At the two lower temperatures, evaluations were made at an estimated RH of 100%; tests at both 30 and 90% RH were conducted using the two higher temperatures.

To measure the effects of these conditions, two sources were used: a ^{133}Ba source and a mixed source of ^{133}Ba, ^{137}Cs and ^{134}Cs. The ^{133}Ba was used to simulate ^{131}I because of its longer half life (10.7 yrs vs 8.05 days for ^{131}I), its similar gamma ray spectrum (Table 1), and its lack of volatility. The ^{133}Ba ^{137}Cs and ^{134}Cs activity ratios used in the mixed source were predicted ground deposition values for postulated accidents, as calculated in another ENICO program, "Offsite Emergency Instrumentation for Accidents Involving Light Water Nuclear Power Plants." Ratios used were 0.37 and 0.21 for $^{137}Cs/^{133}Ba$ and $^{134}Cs/^{133}Ba$, respectively; these approximate the ratio at which the radionuclides are predicted to be deposited at 8000 meters following a PWR 9A accident.

2.4.1 Test Sequence. The test sequence for environmental radioiodine measurements was as follows:

1. Two instruments and a ^{133}Ba source were placed in the test chamber in a test fixture which provided a fixed detector geometry with respect to the source. Instruments were placed so that meter responses could be read through the chamber door. Ten measurements were then taken at ambient temperature with each instrument to provide a baseline for ensuing tests; all instruments were turned on at least one hour before being tested and were operated on battery power.

2. The mixed source was then inserted in place of the ^{133}Ba source; the measurement sequence was then repeated.

TABLE 1

COMPARISON OF ^{133}BA and ^{131}I GAMMA RAY SPECTRA

^{133}Ba		^{133}I	
Gamma Ray Energy (KeV)	Absolute Intensity (%)	Gamma Ray Energy (KeV)	Absolute Intensity (%)
30.6	34.0	29.0	3.90
31.0	62.9	80.2	2.62
35.0	18.6	284.3	6.06
35.8	4.0	364.5	81.24
53.2	2.2	637.0	7.27
79.6	2.4	722.9	1.80
81.0	32.8		
276.3	7.3		
302.7	18.6		
355.9	62.3		
383.7	8.8		

3. The environmental test chamber controls were then set to achieve 100°F and 30% RH. The system was allowed to equilibrate after reaching these conditions for about fifteen minutes. Ten readings were then taken with each instrument over approximately a 30 minute period.[a]

4. The ^{133}Ba source was replaced in the fixture and the measurement sequence was repeated.

[a] The SAM II and Ludlum 2200 required opening the chamber door to activate the digital scaler. Therefore, the test chamber environment was allowed to return to the test conditions before the chamber door was reopened for a subsequent measurement.

5. The environmental chamber controls were set to achieve 110°F and 90% RH and the system was allowed to come to equilibrium for fifteen minutes. The ^{133}Ba and the mixed sources were then counted ten times each, as above.

6. The environmental chamber controls were adjusted to achieve 90°F and 90% RH and the system was allowed to equilibrate for fifteen minutes. Measurements were then repeated with the two sources.

7. The environmental chamber controls were adjusted to 90°F and 30% RH, the system was allowed to equilibrate, and measurements repeated for each source.

8. The humidity control was turned off and the temperature brought to 0°F by decreasing the temperature by 30° increments in fifteen minute intervals. The system was allowed to equilibrate for fifteen minutes and measurements were taken again for each source.

9. The temperature was then reduced to -20°F, the system allowed to equilibrate for fifteen minutes, and measurements repeated for each source.

10. The temperature was then increased to 70°F, in 30° increments over 15 minute intervals. Measurements of the instrument response with the sources present were compared to step 1 values to determine whether the cumulative effect of the environmental chamber tests caused any change or deterioration in instrument performance.

11. Two different instruments were then placed in the chamber and the entire sequence repeated.

As noted, in addition to the initial six instruments identified for evaluation, two CDV-715, 0-500 R/hr survey meters were also tested in the environmental test chamber. For these tests, the instrument was first checked on a multicurie ^{137}Cs source, placed in the environmental test chamber, and then tested under the following sequence of conditions: 1) 100°F with 90% RH; 2) 110°F with 30% RH; 3) 90°F with 90% RH; 4) 90°F with 30% RH; 5) 0°F; and 6) -20°F.

After the chamber reached each of the desired conditions, the instruments were allowed to equilibrate for 30 minutes. They were then removed from the test chamber, immediately retested with the multicurie source for response, and then placed back in the chamber for testing at the next set of conditions.

2.4.2 Test Results. Two types of measurements were calculated subsequent to the environmental testing:

1. The ratio, designated as Ba-133 RESP, was determined by comparing the response to the ^{133}Ba source at each test condition with the initial responses to this source as recorded at 70°F. This ratio reflects the change in sensitivity for $^{133}Ba(^{131}I)$.

2. A ratio was determined at each test condition comparing the instrument's response to the ^{133}Ba source with its response to the mixed source; this value was then divided by the ^{133}Ba/mixed source response ratio determined at 70°F. The numerator and denominator of the first ratio, designated REL RESP, reflect, respectively, the change in instrument sensitivity and response accuracy at the test and ambient conditions owing to the presence of radiocesiums. The latter ratio reflects a change in the instrument response curves as a result of varied environmental conditions.

   All but two instruments responded within 15% of the initial 70°F values between 0 and 100°F at all humidities. The two exceptions occured using the CDV-700/OCD-D-103 instrument at

110°F/90% RH (shown as a bar chart on Figure 5) and using the SAM II/ RD-22 at all conditions tested (Figures 6 & 7); however, the SAM II/RD-22 responses were expected since the detector has a specified operating temperature range of 32-140°F.

At -20°F both ratios for each instrument changed more drastically. However, with the exception of the Ludlum 2200/SPA-3 and the SAM II/RD-22, the changes were within 25%. For the Ludlum and the SAM II, as expected from earlier tests, the changes in the ^{133}Ba ratios at -20°F were 40 and 99% respectively. The changes in the ^{133}Ba plus radiocesiums to ^{133}Ba ratios for these instruments were significantly less.

Because these observations are indicative of shifts in instrument amplifier gain or high voltages, an adjustment of the high voltage on the SAM II/RD-22 was attempted to correct the low temperature values to the initial values. The former ratio was corrected to within 60% of the initial value, the latter to within 10% of the initial value. Adjustment on the Ludlum 2200/SPA-3 was not attempted since more extensive testing is required to verify proper operation of instruments with single channel analyzers at low temperatures.

When retested at ambient conditions, all instruments except the THYAC III/489-4 returned to the same initial response. The THYAC II/489-4 showed a larger change in response after testing than evidenced during the testing sequence. The cause of this loss in response is not known.

No large change in response occured for either CDV-715 0-500 R/h survey meters for any of the test conditions. Response to a 10 R/hr gamma radiation field for the two instruments is shown in Table 2.

2.5 Evaluation of Radioiodine in Thyroids

The purpose of the radiological instrument evaluation of radioiodine in thyroids was to determine detector responses for cow and human (adult, 5 year old child, and 2 year old child) thyroid models.

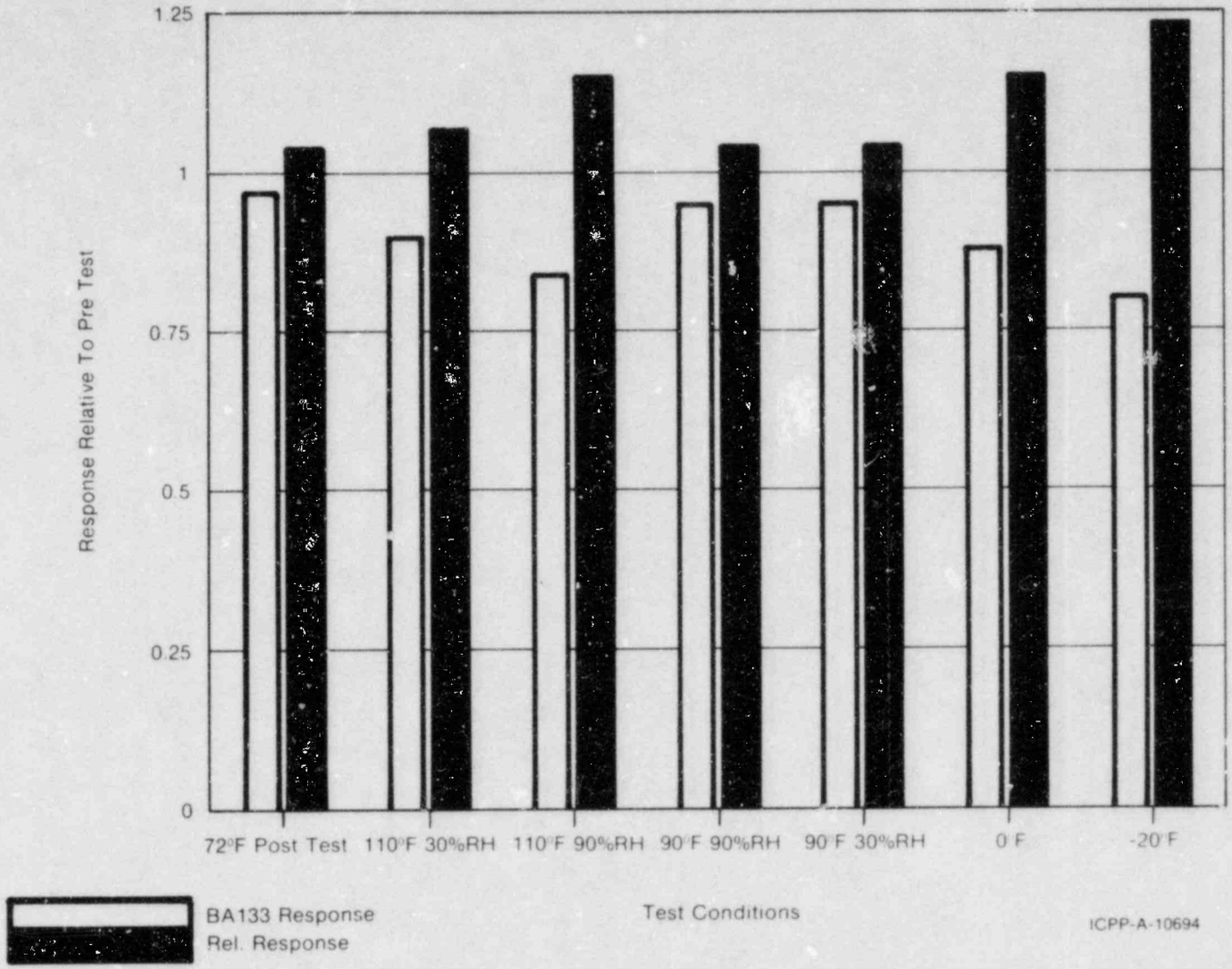


Figure 5. Environmental Test Of CDV 700/OCD-D-103#1

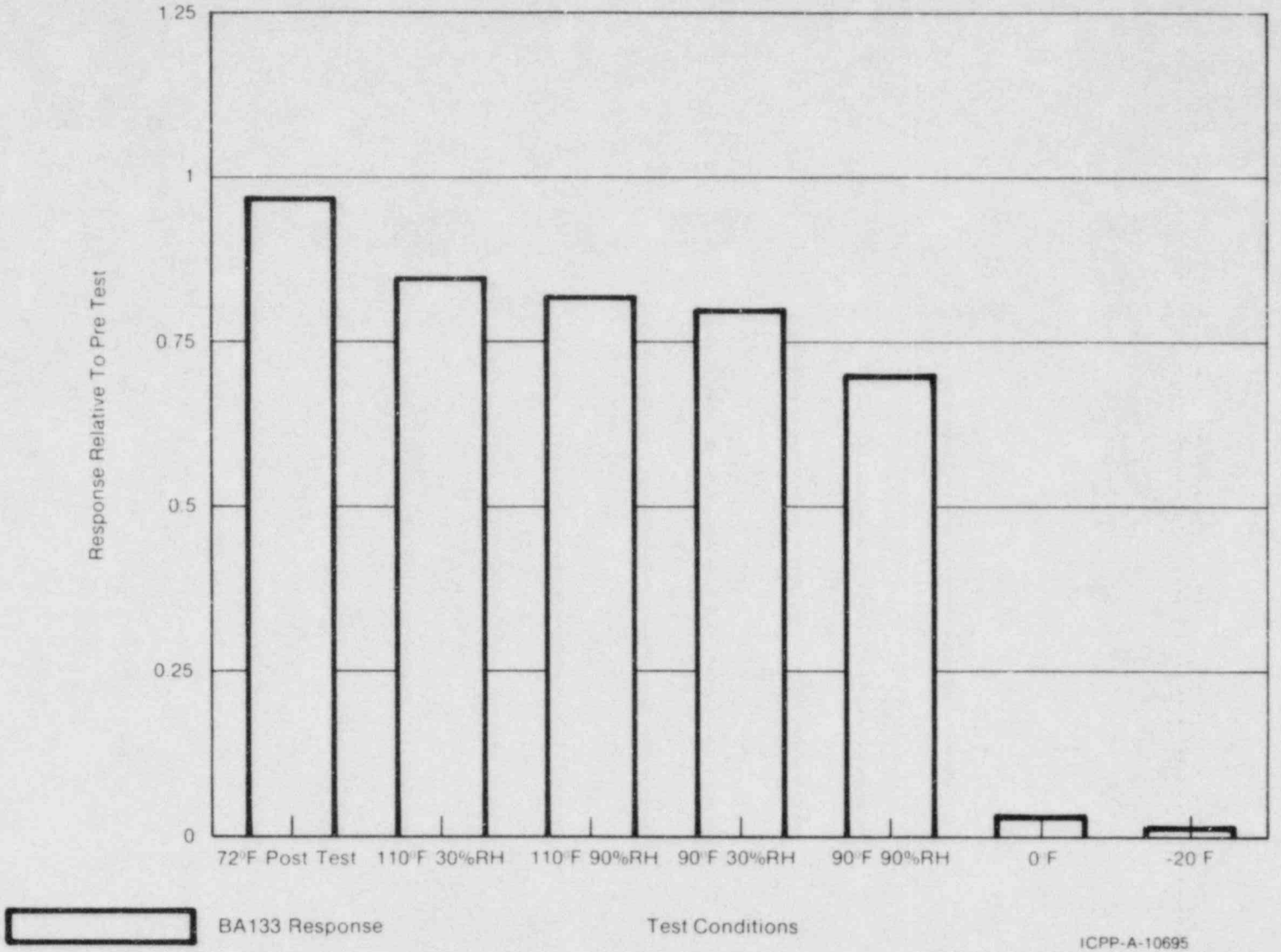


Figure 6. Environmental Test Of SAMII/RD-22

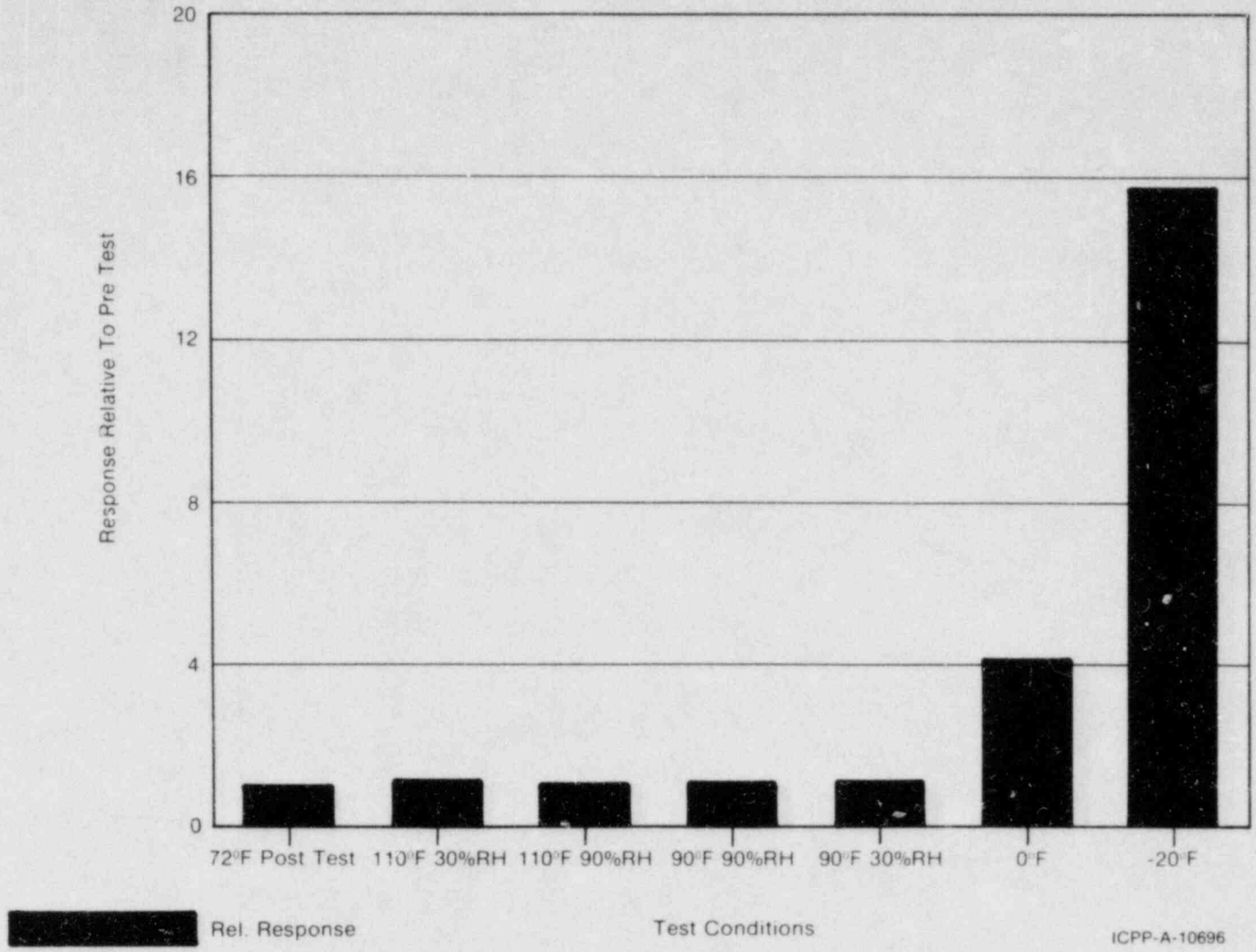


Figure 7. Environmental Test Of SAMII/RD-22

TABLE 2

RESPONSE OF CDV-715 TO 10 R/hr GAMMA RADIATION FIELD ENVIRONMENTAL CHAMBER TESTS

Test Condition	Response	
	Instrument 1 (R/hr)	Instrument 2 (R/hr)
Pretest	8.5	10.0
90°F, 30% RH	8.7	10.5
110°F, 30% RH	11.0	11.5
110°F, 90% RH	10.0	11.0
90°F, 90% RH	10.0	11.0
0°F	9.0	11.0
-20°F	10.5	10.0

Human thyroid phantoms were constructed from data in ICRP-23, "Task Force on Reference Man."[4] The three constructed human thyroid phantoms are shown in Figure 8; shown counter clockwise from top left are the adult, two year old child, and five year old child thyroid models. Drawings of the thyroids are provided in Appendix A. For comparison purposes, an ANSI standard adult human thyroid phantom was purchased from Nuclear Associates, Inc., Carle Place, New York. The cow thyroid phantom, supplied by Brookhaven National Laboratory, is the same as used by Distenfeld[1] (Figure 9).

In preparation for measurement, the human and cow thyroids and plastic bottle of the ANSI standard were tared in plastic bags to prevent contamination, filled with solution, and reweighed. The solution used contained ^{131}I (0.9 μCi/mL) in 0.05 M NaOH; 0.05 M $NaHSO_3$; and 0.005 M NaI. The ^{131}I solution was standardized by weight and gamma-ray analysis as follows. Five mL of solution were aliquoted into each of two tared 5 mL glass ampoules. The ampoules were sealed, weighed, and analyzed for ^{131}I on a gamma ray spectroscopy system calibrated with NBS traceable

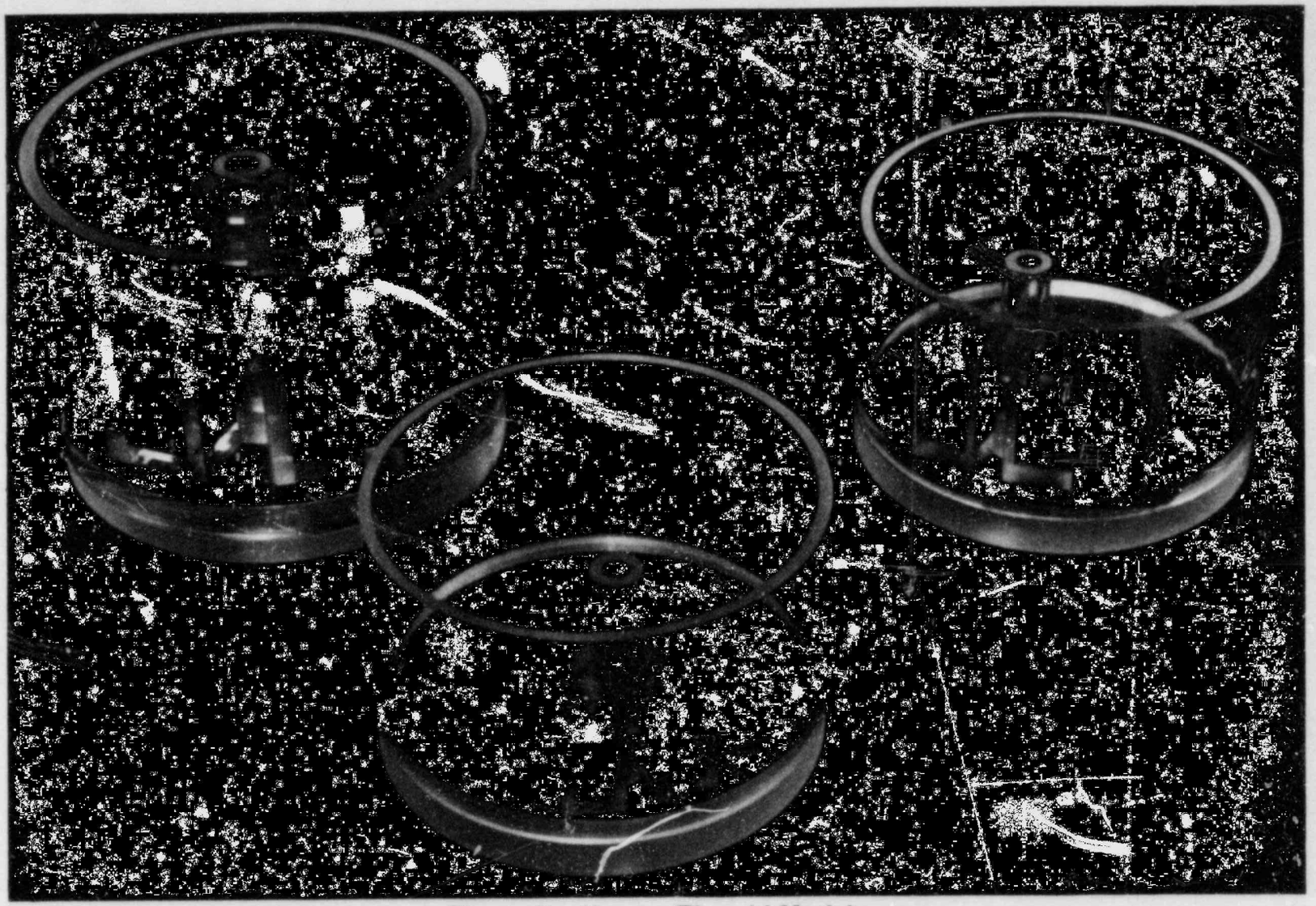


Figure 8. Human Thyroid Models

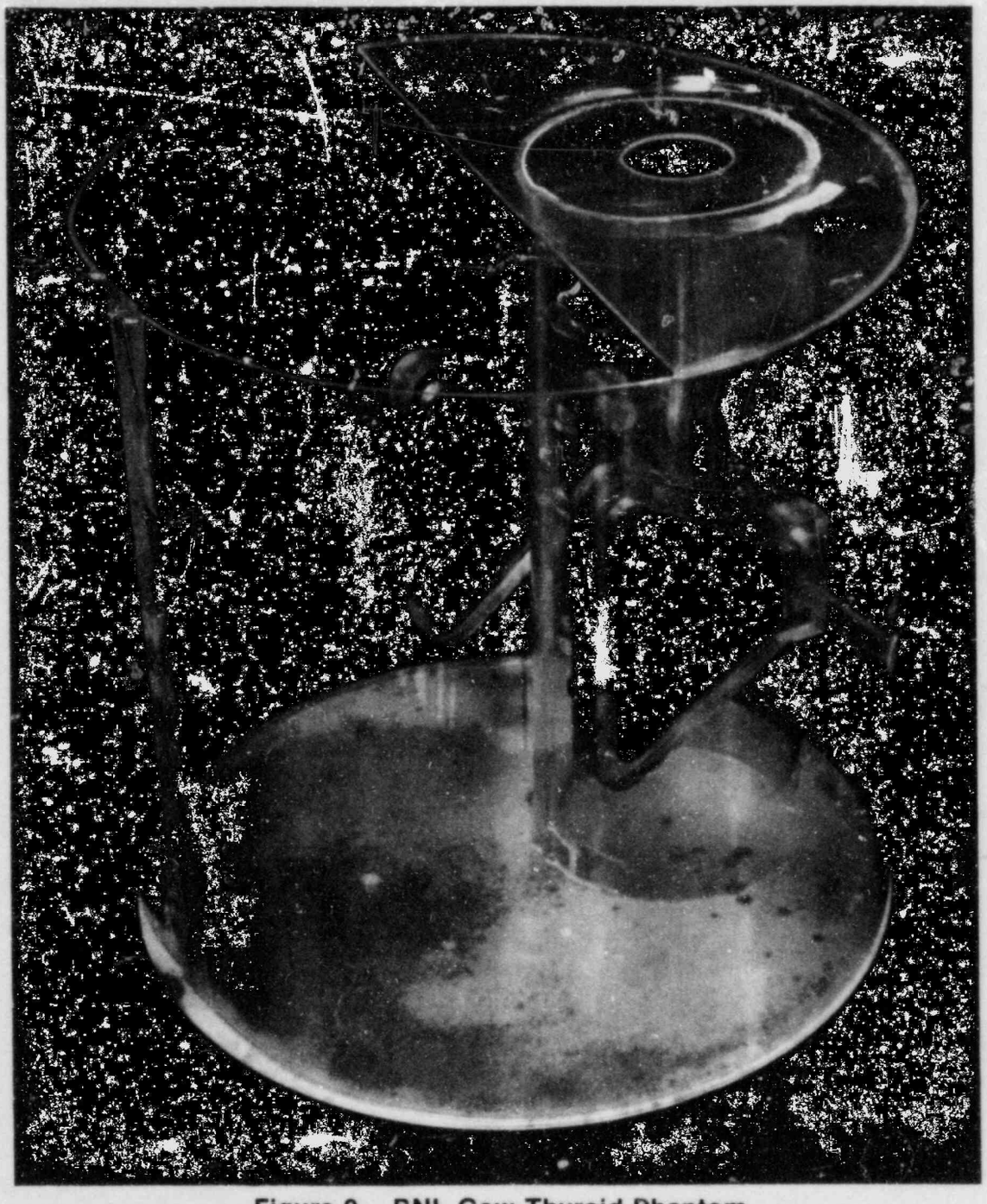


Figure 9. BNL Cow Thyroid Phantom

standards. The thyroids were taken to a low background area where they were measured in their respective fixtures with water added to the fixtures to represent the shielding provided by tissue.

Ten measurements were made of the thyroid models with each instrument's detector positioned to give maximum responses: perpendicular to the neck, with the detectors' active area[6] centered between the thyroid lobes. Detector responses to ^{131}I in the different thyroids are presented in Table 3.

Subsequently, minimum detectable levels (MDL) of ^{131}I were calculated for each instrument in μCi of ^{131}I for the bovine thyroid phantom (Table 4). As the MDLs are a function of the uncertainty of instrument backgrounds, laboratory backgrounds observed in this study were used. The resultant MDLs in cpm for each instrument are shown in Table 5.

For instruments with analog readouts, all but the Ludlum 2200 and SAM II, MDLs in cpm were calculated from the equation:

$$MDL = 2\sqrt{\frac{B}{2RC}}$$

In the equation B is the background count rate in counts/minute and RC is the meter time constant in minutes. For the Ludlum 2200/SPA-3 and SAM II/RD-22, the expression used was:

$$MDL = 2\sqrt{B_m}$$

where B_m is the background count rate in counts per minute.

For the human thyroids, the observed cpm per μCi of ^{131}I were converted into dose commitments in cpm per REM infinity (Table 6). Conversion factors used were 1.95, 5.72, and 13.9 $REM_\infty/\mu Ci^{131}I$ for adults, 5 year olds, and 2 year olds, respectively.[6] Table 7 provides the minimum

TABLE 3

DETECTOR RESPONSE FOR THYROID MODELS
(Net cpm per microcurie ^{131}I)

Thyroid Model	Detector							
	D-103 #1	D-103 #2	6306 #1	6306 #2	489-4	489-55	SPA-3	RD-22
Bovine	39[a]	31	139	171	33	18850	7680	7290
	8	9	21	24	6	4257	396	409
ANSI Standard Adult	152	151	1149	1232	258	75780	53570	54970
	33	26	77	159	117	6244	2950	1324
Adult	124	123	668	682	149	45840	32490	30270
	23	14	51	110	31	2056	173	996
Five Year Old Child	224	231	1390	1580	321	81840	58100	56830
	52	20	61	53	79	3060	4917	2521
Two Year Old Child	277	274	1640	1910	381	102120	72980	73020
	53	46	234	115	79	5428	3791	3830

[a] For each set of numbers, the upper number is the average, the lower is the standard deviation for the series of ten tests.

TABLE 4

BOVINE THYROID MINIMUM DETECTABLE LEVELS-MICROCURIES ^{131}I

D-103[a]	6306[a]	489-4
0.592	0.258	1.363
489-55	**SPA-3**	**RD-22**
0.022	0.007	0.007

[a] Average of two instruments

TABLE 5

MINIMUM DETECTABLE LEVELS-CPM

D-103 #1	D-103 #2	6306 #1	6306 #2
22	19	40	40
489-4	**489-55**	**SPA-3**	**RD-22**
45	411	54	49

TABLE 6

DETECTOR RESPONSE - NET CPM PER REM INFINITY

	Detector							
Thyroid Model	D-103 #1	D-103 #2	6306 #1	6306 #2	489-4	489-55	SPA-3	RD-22
ANSI Standard Adult	78[a] 17	77 13	589 39	632 81	132 60	38863 3202	27473 1513	28190 679
Adult	64 12	63 7	343 26	350 57	76 16	23507 1054	16663 89	15524 511
Five Year Old Child	43 9	40 4	243 11	276 9	56 14	14308 535	10160 860	9936 441
Two Year Old Child	20 4	20 3	118 17	138 8	27 6	7347 390	5251 273	5243 276

a For each set of numbers, the upper number is the average, the lower is the standard deviation for the series of ten tests.

TABLE 7

MINIMUM DETECTABLE REM INFINITY DOSE RATES FOR THYROIDS

	Thyroid			
Detector	ANSI Standard Adult	Adult	5 Year Old	2 Year Old
D-103	0.2640	0.3237	0.4925	1.0331
6306	0.0688	0.1213	0.1622	0.3291
489-4	0.3400	0.5896	0.8029	1.6432
489-55	0.0106	0.0175	0.0287	0.0559
SPA-3	0.0018	0.0029	0.0048	0.0093
RD-22	0.0017	0.0032	0.0049	0.0093

detectable dose commitment in REM_{∞} as calculated from the minimum detectable count rates for the different instruments and the different human thyroid models.

2.6 Evaluation of Radioiodine on Fields and Pastures

The evaluation to determine the instruments' response to ^{131}I and ^{137}Cs were made with the two radionuclides deposited on semi-infinite sources simulating pastures and fields. Barium-133 was again used as an iodine simulant. Cs-137 was used to evaluate the effect of interfering nuclides. Both the ^{133}Ba and ^{137}Cs were deposited by spraying the two radionuclides onto sod and blotter paper, representing pastures and barren ground respectively. The sizes of the sources used were ten-meter-radius circles. At one meter above the surface of the source, calculations predict a ten meter circle provides 42% of an infinite

field value for ^{133}Ba and 43% of an infinite field value for ^{137}Cs. At one foot above the surface, 54% and 56% of the infinite field values for ^{133}Ba and ^{137}Cs, respectively, are obtained with a ten-meter-radius source.

Pasture studies were accomplished using commercially purchased sod. The 20" x 40" flats were cut into 4870 ten-inch squares with a linoleum cutter. The ten-inch sod squares were set out and watered until the grass reached ~4" in height. The sod squares were then transported on wooden pallets to the laboratory for deposition of the ^{131}I simulant and ^{137}Cs.

Eighteen liters of solution containing a 4:1 activity ratio of ^{133}Ba to ^{137}Cs were prepared to contaminate the sod squares. The final ^{133}Ba activity was 0.05 μCi/mL. The activity values were determined by aliquoting 5 mL of solution into a 5 mL glass ampoule, sealing the ampoule, and analyzing the contents for ^{133}Ba and ^{137}Cs with a calibrated Ge(Li) gamma ray analysis system. A dye was added to the radioactive solution to allow visual inspection of the uniformity of application of the tracer to the sod. To apply the solution, three mL of tracer were added to the cup of an air brush with an 8 mL capacity; the solution was then evenly sprayed over the surface of the grass, the grass flats bagged in polyethylene bags and sealed. Outsides of the bags were swiped to ensure the bags had not become contaminated. All preparations were done in a hood, except the bagging operation. Final activities deposited on the sod, as confirmed by analysis of several samples, were 2.29 $\mu Ci/m^2$ ^{133}Ba and 0.660 $\mu Ci/m^2$ ^{137}Cs. Lastly, the processed grass flats were loaded into larger plastic bags, the bags sealed with tape, and shipped to the test site in 2' x 4' x 8' plywood boxes.

Preparation of the simulated barren field followed the same procedure, except laboratory blotter paper was used instead of sod. A 2:1 ^{133}Ba to ^{137}Cs ratio was used. ^{133}Ba activity was 0.04 μCi/mL of tracer; final activities on the blotter paper were 1.36 $\mu Ci/m^2$ ^{133}Ba and 0.660 $\mu Ci/m^2$ ^{137}Cs.

Measurement of instrument responses was carried out at the Experimental Field Station (EFS) at the Idaho National Engineering Laboratoy (INEL). In preparation, a ten meter grid was staked out on a relatively flat area. Background measurements were taken using the Ludlum 2200/SPA-3 (no window) and 5 x 10-cm cores of soil were collected for analysis at fifteen random locations in the grid. Stakes were pounded flush with the ground to note these locations (Figure 10). Additional core samples and background measurements were taken at these locations at the conclusion of the tests.

For laying out the grass or blotter paper, the following sequence was followed: First a layer of plastic was placed over the grid and secured. Then the grass grid was layed out solid, except for a one foot wide strip to allow for access to the center of the grid. A test fixture was placed in center of the grid to position the detectors for measurement at one foot and one meter above the grid. The blotter paper grid was layed out in a similar fashion, with the exception that the squares required securing with tape to the base plastic. Ten measurements each at one foot and one meter distance above the sources were taken with each instrument. Measurements were also taken at one foot along two intersecting traverses across the grids. These measurements confirmed that the activity was uniformly dispersed. After the data were analyzed, the grid was dismantled and placed in large plywood boxes for disposal. Figure 11 shows measurements being made at the sod grid.

The results of the field measurements at the two distances are summarized in Table 8. The ^{133}Ba measurements were corrected for the ^{137}Cs interference; this was done using energy response curve data and subtracting, the amount of ^{137}Cs present, as measured using the SAM II instrument.

The ^{133}Ba responses were also converted to an equivalent ^{131}I infinite field response using the energy response factors and the calculated percentage of infinite field represented by a ten meter circle, as noted above. Table 9 shows the estimated ^{131}I and ^{137}Cs responses for an

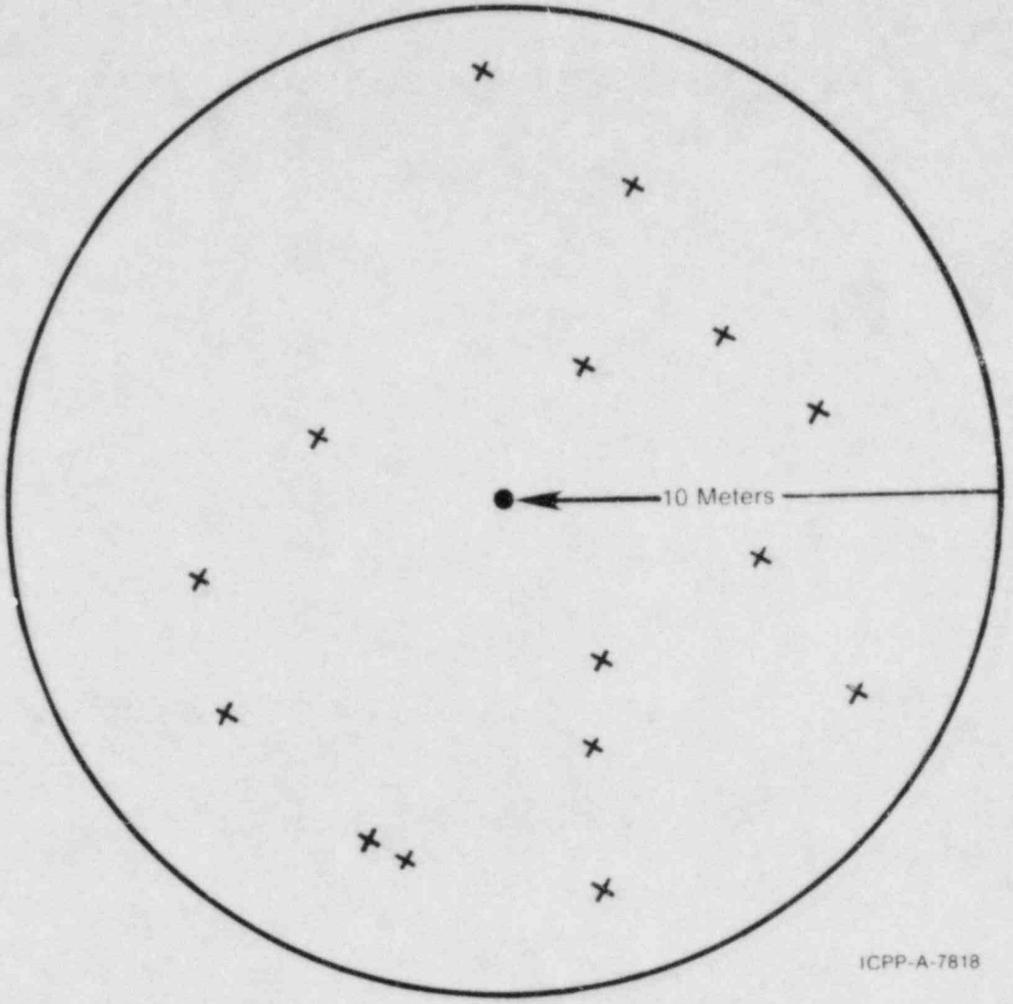


Figure 10. Ten Meter Radius Source Background Sampling Locations

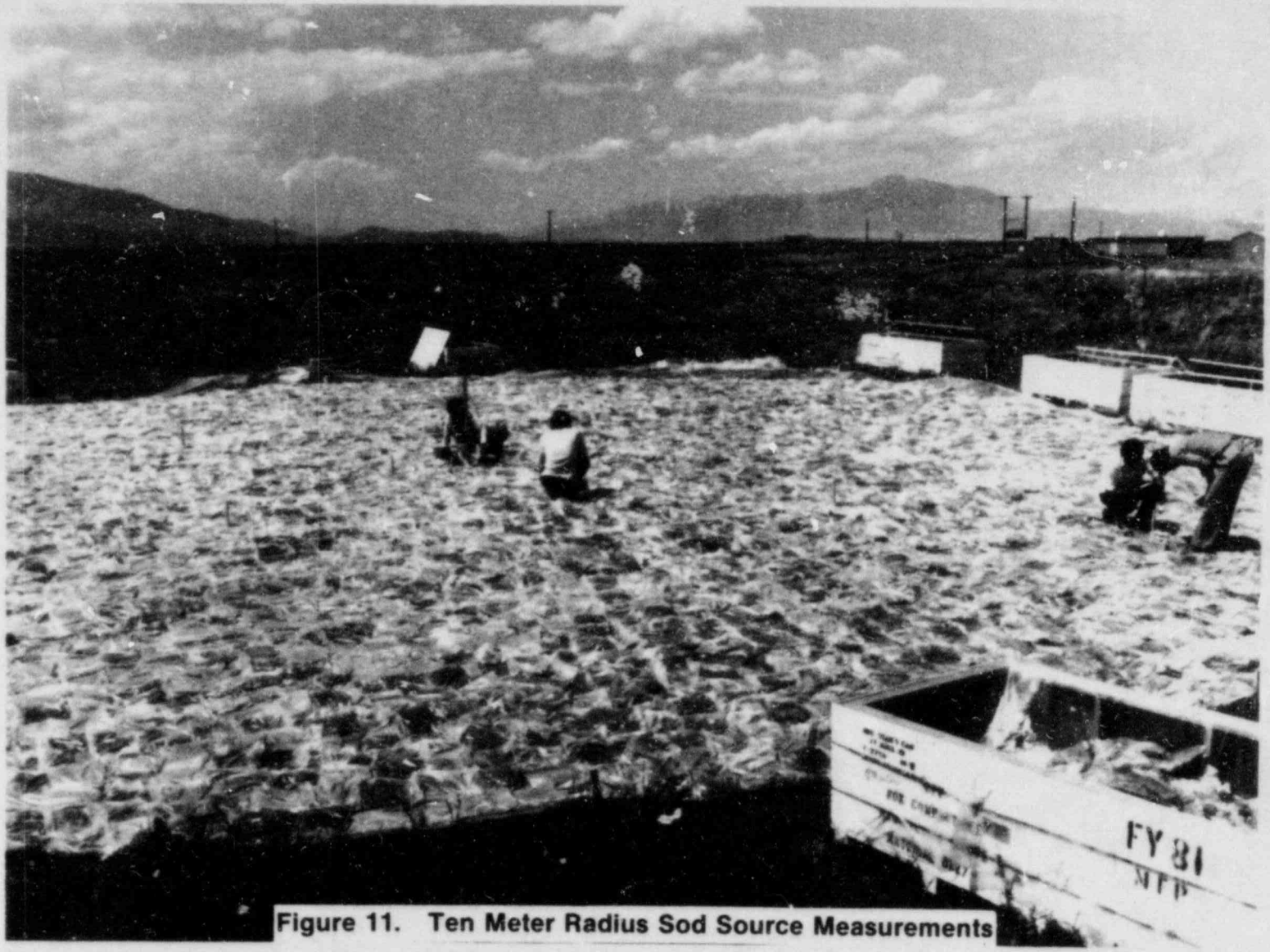


Figure 11. Ten Meter Radius Sod Source Measurements

TABLE 8

FIELD MEASUREMENTS - CENTER GRID DETECTOR RESPONSE
(Net cpm per μCi^{133} Ba/m^2)

Material Tested	Distance from Source	Detector							
		D-103 #1	D-103 #2	6306 #1	6306 #2	489-4	489-55	SPA-3	RD-22
Blotter	1 ft	4[a]	3	62	42	4	4553	1461	1432
Paper		6	7	11	24	15	427	89	67
	1 m	5	6	32	40	10	3443	1345	1162
		3	8	17	23	24	222	38	30
Sod	1 ft	ND	ND	45	41	12	3879	1661	1517
				10	15	3	127	39	19
	1 m	ND	ND	34	40	12	2731	1222	981
				9	13	2	69	66	43

[a] For each set of numbers, the upper number is the average, the lower is the standard deviation.

TABLE 9

ESTIMATED DETECTOR RESPONSES TO AN INFINITE ^{131}I / ^{137}Cs SOURCE
(Net cpm per $\mu Ci/m^2$)

Dectector	Distance	Response for Fields	Response for Pastures
D-103	1 ft	4, 6[a]	ND, 3
D-103	1 m	10, 6	ND, 2
6306	1 ft	79, 44	73, 23
6306	1 m	70, 48	87, 18
489-4	1 ft	1, 19	20, 10
489-4	1 m	18, 21	27, 8
489-55	1 ft	7002, 1994	6296, 1034
489-55	1 m	70002, 2204	6026, 823
SPA-3	1 ft	2677, 480	3192, 249
SPA-3	1 m	3350, 530	3188, 198
RD-22	1 ft	2135, 374	2346, 194
RD-22	1 m	2335, 414	2051, 155

[a] For each set of numbers in the response columns, the number left of the comma is response to the ^{131}I source; the number to the right is the response to the ^{137}Cs source.

infinite field. Good agreement between sod and blotter paper source values is seen for the ^{131}I values with the more sensitive detectors (6306, 489-55, SPA-3 and RD-22).

Minimum detectable levels of ^{131}I, Table 10, were calculated from the data in Table 9 and the minimum detectable counts provided in Table 4. As is shown, only the sodium iodide scintillation detectors are capable of detecting the level of ^{131}I projected by FDA to produce the preventative PAG level of 12,000 pCi/L of ^{131}I in milk (0.14μCi/m^2). Although the ^{137}Cs interference is slight, a complex mixture of nuclides would make measurement with the 489-55 uncertain.

For the four detectors capable of measuring low levels of ^{131}I on barren ground and pastures (CDV 700/6306, THYAC III/489-55, Ludlum 2200/SPA-3 and SAM II/RD-22), ^{137}Cs present at one-half the activity level of ^{131}I would cause increases in count rates in excess of those for ^{131}I alone; these increases would be approximately 30, 14, 10 and 10% respectively.

A ^{137}Cs to ^{131}I ratio of 0.5 represents the predicted levels of deposition at 8000 meters from the source of a postulated PWR 9A accident. The presence of other radionuclides in the field would increase the level of interference, but would likely still allow order of magnitude estimation of ground contamination levels.

2.7 Evaluation of Radioiodine in Water and Milk

The intent of this evaluation was to establish the ability of the radiological measurement instruments to directly measure radioiodine in water and milk, with and without radiocesiums. In addition to measurements of bulk liquids, detector responses to ^{131}I collected on an anion exchange resin from bulk liquid were studied.

2.7.1 Direct Measurement of Bulk Liquid. Measurement of ^{131}I in bulk liquid simulating measurement of tank cars, holding tanks, and reservoirs were made using an ~20-liter, 20.3-cm thick rectangular

TABLE 10

ESTIMATED MINIMUM DETECTABLE QUANTITIES OF ^{131}I
($\mu Ci/m^2$)

Dectector	Distance	Response for Fields	Response for Pastures
D-103	1 ft	5.34	ND
D-103	1 m	2.20	ND
6306	1 ft	0.57	0.583
6306	1 m	0.60	0.48
489-4	1 ft	67.9	2.21
489-4	1 m	2.52	1.65
489-55	1 ft	0.058	0.065
489-55	1 m	0.05	0.068
SPA-3	1 ft	0.018	0.015
SPA-3	1 m	0.01	0.015
RD-22	1 ft	0.022	0.021
RD-22	1 m	0.02	0.023

(33-cm x 34.3-cm) container and a 35.6-cm diameter, thirty-gallon Delrin drum filled to a height of 35.6-cm. The former container provided a geometry similar to that used by Distenfeld;[1] the latter container provided an easy geometry for extrapolation to an infinite source.

For the 20-liter container, measurements were taken inside and outside the container using ^{131}I only. Inside the container, a 7.0-cm inside diameter clear-plastic insert was used to place the detectors at the centroid of the container volume. (A schematic of the insert is provided in Appendix A).

In preparation for the 20-liter container measurements, the following procedure was used. The container with insert was weighed, filled with distilled water, and reweighed. The net weight was used to determine the volume of liquid in the container. Subsequently, a calibrated solution of ^{131}I, containing 5 mL of 0.05 M NaI, 0.05 M NaOH, and 0.05 M $NaHSO_3$ was added to the container. The ^{131}I ampoule was broken, the contents were transferred, and then the ampoule was rinsed with 500 microliter aliquots of 0.05 M NaOH. A check was then made with a Ge(Li) system to ensure there was no residual activity.

Total volumes of washes and tracer were noted and added to the volume as determined by weighing. Lastly, the insert was mounted in the container, a magnetic stirring bar was added, and the container was sealed with tape. Subsequently, the contents were stirred for 2-1/2 hours. Mixing was monitored by taking measurements with a survey meter in the insert and also outside the container at the center of the widest side. Equilibrium was achieved in the 2 1/2 hour mixing time.

Ten measurements were made with each instrument, both inside the insert and on the outside location giving the highest activity for the 20 liter container: at the center of the 30.5-cm x 34.3-cm side of the container. No differences in instrument responses were noted with the detector positioned horizontally or vertically as long as the center of the detector volume was positioned at the center of the large side of

the container. Measurements were also taken with all the GM tube instruments only, with and without beta shields and with a plastic bag used in place of the insert.

Post test analysis of the ^{131}I in the 20-liter container was performed by removing three one-mL aliquots and tranferring them into tared vials. The vials were weighed and then analyzed by gamma spectroscopy. Activity levels were compared to the original gamma spectroscopy analysis. The original and final activities were within 2-3%, indicating no plateout of the radioiodine.

The results of the twenty-liter container measurements are presented in Tables 11-12. Table 11 provides a comparison of measurements inside and outside the container. Table 12 provides a comparison of the GM detector responses inside the insert with the shield in place, inside a plastic bag with the shields in place, and inside a plastic bag with the shields removed or opened.

Overall, the data indicate the scintillation detectors, followed by the 6306 GM detectors, are the most sensitive; the 489-4 and OCD-D-103 detectors are the least sensitive. Also shown, as anticipated, is that measurements inside the container are approximately a factor of two higher than measurements outside the container. More specifically, the data for the shielded versus nonshielded GM detector measurements indicate the 6306 detector responses increased, the 489-4 detector responses decreased. Although the OCD-D-103 responses also decreased, these results should be disregarded because the measurements were highly variable due to low sensitivity and ^{131}I concentrations.

The inverse trend of the 6306 and 489-4 detector is explained by comparing the detectors' construction. The 6306 detectors have a bismuth screened cathode, the 489-4 detectors do not. As a result, upon removal of the shield, the response of the 6306 detector increased from less photon attenuation in the shield and predominantly from more photon interaction with the bismuth cathode screen. Correspondingly, upon removal of its shield, the response of the 489-4 detector decreased from lack of a cathode screen.

TABLE 11

DETECTOR RESPONSE INSIDE AND OUTSIDE TWENTY-LITER JUG
(Net cpm per Microcurie μCi ^{131}I/L)

	Detector							
Detector Position	D-103 #1	D-103 #2	6306 #1	6306 #2	489-4	489-55	SPA-3	RD-22
Inside	336[a]	347	2234	2486	577	336700	141400	128300
	66	54	83	191	99	9000	2100	3300
Outside	159	158	1038	1106	312	138200	59000	52111
	97	73	62	57	59	1060	1700	1600

[a] For each set of numbers, the upper number represents the average; the lower number, the standard deviation.

TABLE 12

TWENTY-LITER JUG MEASUREMENTS - INSIDE PLASTIC BAG
(Net cpm per Microcurie μCi ^{131}I/L)

	Detector				
Beta Shield Status	D-103 #1	D-103 #2	6306 #1	6306 #2	489-4
Closed	246[a]	101	2497	2622	572
	134	84	171	201	144
Outside	163	237	--	--	264
	177	107	--	--	159
Removed	--	--	8271	8437	--
	--	--	496	971	--

[a] For each set of numbers, the upper number represents the average; the lower number, the standard deviation.

TABLE 13

ISOTOPE ACTIVITIES FOR 30 GALLON BARREL TESTS

Test #	^{131}I (μCi/L)	^{137}Cs (μCi/L)	^{134}Cs (μCi/L)	Ratios $^{137}Cs/^{131}I$ (μCi/L)	Ratios $^{134}Cs/^{131}I$ (μCi/L)
1	0.298	--	--	--	--
2	0.285	0.141	--	0.496	--
3	0.245	0.134	0.075	0.545	0.304

For the thirty-gallon barrel test, three test solutions were used: a solution of ^{131}I only, a solution of ^{131}I and ^{137}Cs, and a solution of ^{131}I, ^{137}Cs and ^{134}Cs. The three solutions, Table 13, are representative of projected radionuclide distributions in milk associated with a postulated class PWR 9A accident.

The procedures used in these measurements were similiar to those described for the 20-liter container test. However, due to much lower instrument responses outside the container in the twenty liter study, no such measurements were made on the thirty-gallon source. Also, a different CDV-700/OCD-D-103 instrument, designated D-103 #3, was substituted for the failed D-103 #2 instrument used in earlier liquid studies.

Instrument responses for the three solutions in cpm/μCi ^{131}I are given in Tables 14-15. As observed previously, the 6306 GM tube was the most sensitive of the GM tubes, being factors of ~10 and ~5 more sensitive than the OCD-D-103 and 489-4 detectors, respectively. Overall, however, the scintillation detectors again showed the highest response, the 489-55 being a factor of ~150 more sensitive than the 6306 and the SPA-3 and RD-22 being a factor of ~50 more sensitive than the 6306.

TABLE 14

30 GALLON TEST WITH SMALL INSERT
(Net cpm per μCi ^{131}I/L)

	Dectector					
Solution	D-103 #1	D-103 #3	6306 #1	6306 #2	489-4	6306 #2[a]
^{131}I	439[b]	250	3129	3479	688	--
	15	10	56	41	11	--
^{131}I, ^{137}Cs	526	406	5932	6399	1573	4209
	42	40	255	206	123	356
^{131}I, ^{137}Cs,	1135	819	9555	9677	3180	--
^{134}Cs	68	40	164	186	154	--

a Pulse counter data.

b For each set of numbers the upper number is the average; the lower, the standard deviation.

The addition of ^{137}Cs and ^{134}Cs at levels projected[2] for a PWR 9A accident scenario resulted in a factor of three increase in the GM detector responses; a factor of two increase in the 489-55 response; and a factor of ~1.4 increase in the SPA-3 and RD-22 responses. For informational purposes, a combined ^{131}I, ^{137}Cs, and ^{134}Cs spectrum collected with the Ludlum 220/SPA-3 is shown in Figure 12. It shows the significance of compton contributions of the interfering nuclides to measurement of ^{131}I with a single 50 KeV channel centered on 364 KeV.

Of note, in Table 14 data collected with a pulse counter coupled to the phone jack of a CDV-700/6306 are presented. These one-time measurements were performed to evaluate the potential of pulse accounting, as suggested previously.[1,3] Results of the test indicate the difference

TABLE 15

20 GALLON TEST WITH LARGE INSERT
(Net cpm per μCi ^{131}I/L)

Solution	Detector							
	D-103 #1	D-103 #3	6306 #1	6306 #2	489-4	489-55	SPA-3	PD-22
^{131}I	139[a]	190	2975	3285	688	532699	177307	170000
	18	20	35	47	17	8996	40	663
^{13}I, ^{137}Cs	436	366	5111	5448	1262	685677	201809	185087
	15	49	235	219	89	2610	875	884
^{131}I, ^{137}Cs, ^{134}Cs	1015	671	7809	8500	2721	1033243	256529	221834
	43	36	249	69	107	13160	1262	1252

[a] For each set of numbers, the upper number is the average; the lower, the standard deviation.

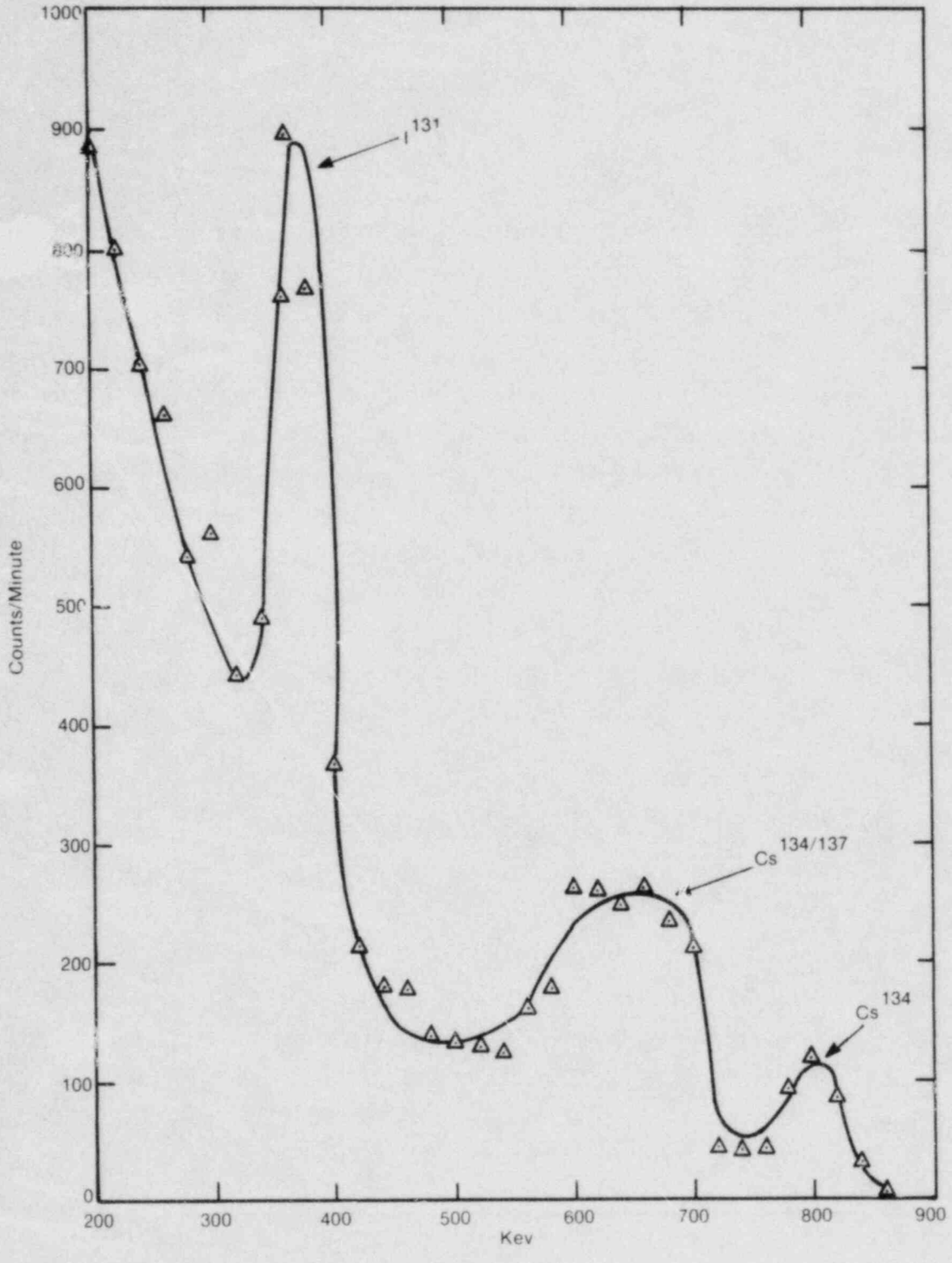


Figure 12. I^{131}, $CS^{134/137}$ Spectrum (LUDLUM 220/SPA-3)

between the pulse counter and the CDV-700 meter. Accordingly, discussions with FEMA personnel indicated a one to one correspondence between the phone jack and CDV-700 meter readings were not expected without special modifications. For reference, the pulse counter was manufactured by ENICO personnel (Appendix A) from readily available components. It required about $100 per parts and $400 for labor. Mass produced pulse counters should cost ~$100 each.

Table 16 shows the thirty-gallon drum data for the small and large inserts broken down into individual radionuclide responses, as obtained by measurements of the three different solutions. Separation into individual responses was accomplished by subtracting the ^{131}I response from the ^{131}I plus ^{137}Cs response to provide the ^{137}Cs response normalized to the ^{131}I content in microcuries per liter. Then, the normalized response was divided by the $^{137}Cs/^{131}I$ ratio of µCi/L to get the ^{137}Cs response in cpm per microcurie ^{137}Cs per liter. For ^{134}Cs, this response was multiplied by the $^{137}Cs/^{131}I$ ratio for the respective experiment, yielding the ^{137}Cs response normalized to ^{131}I. The sum of the ^{137}Cs value plus the ^{131}I response was then subtracted from the total response, giving the ^{134}Cs response normalized to the ^{131}I content. Lastly, this ^{134}Cs response was divided by the $^{134}Cs/^{131}I$ ratio to get the ^{134}Cs response in cpm per microcurie ^{134}Cs per liter.

Table 17 shows the responses for ^{131}I, ^{137}Cs, and ^{137}Cs extrapolated to an "infinite" source using values of 0.554, 0.519, and 0.53 for ^{131}I, ^{137}Cs, and ^{134}Cs, respectively. The values represent the fraction of an infinite source response for the tested geometry. The minimum detectable levels for ^{131}I alone in an "infinite" were then determined based on the respective instrument minimum detectable count rates and cpm per µCi of ^{131}I per liter values in bulk liquids; these values for the six instrument types were: D-103, 0.033; 6306, 0.007; 489-4, 0.036; 489-55, 4.27×10^{-4}; and RD-22, 1.60×10^{-4}.

The 6306 and all NaI(Tl) detectors are capable of detecting ^{131}I at the FDA proposed emergency and preventive Protection Action Guide

TABLE 16

DETECTOR RESPONSE TO DIFFERENT REDIONUCLIDES
IN 30 GALLON BARREL
(Net cpm per μCi)

Small Insert

	Detector				
Radionuclide	D-103 #1	D-103 #3	6306 #1	6306 #2	489-4
^{131}I	433	250	3120	3480	690
^{137}Cs	660	1100	19870	20700	6280
^{134}Cs	8000	5300	44610	39860	20270

Large Insert

	Detector							
Radionuclide	D-103 #1	D-103 #3	6306 #1	6306 #2	489-4	489-55	SPA-3	RD-22
^{131}I	320	190	2980	3280	620	532700	177300	170000
^{137}Cs	830	1250	15200	15400	4480	1085200	173800	107000
^{134}Cs	7500	3800	33200	37900	18600	4432700	697300	470100

TABLE 17

DETECTOR RESPONSE INSIDE TWENTY LITER-JUG
(Net cpm per µCi/L)

	Detector					
Radionuclide	D-103	6306	489-4	489-55	SPA-3	RD-22
^{131}I	620	5970	1250	961500	320000	306900
^{137}Cs	1700	39100	12100	2091000	334000	206000
^{134}Cs	12500	79700	38200	8364000	1316000	887000

(PAG) levels for milk: of 0.12 µCi ^{131}I/liter and 0.012 µi ^{131}I/liter, respectively; this is provided that there is no appreciable concentration of interfering nuclides.

2.7.2 Measurement of ^{131}I Collected on Anion Exchange Resin. The measurement of instrument response to radioiodine collected from milk onto an anion exchange resin proceeded in two stages. First, an iodine standard was generated for the BNL canister geometry to allow the determination of the activity collected on the resin after contact with the milk. Amberlite IRA-900C resin (0.45-55mm) was washed in distilled water, fined, and sieved using a 600 micron screen. Then 200 mL of resin in 200 mL of water in a beaker was added to the contents of a glass ampoule containing a known quantity of ^{131}I tracer in 5 mL of 0.05 M NaOH, 0.05 M NaI, and 0.05 M $NaHSO_3$. Verification of ^{131}I content was performed by gamma spectroscopy. Complete transfer of the activity in the ampoule was accomplished by washing with additional aliquots of 0.05 M NaOH until all activity had been transferred. A stirring bar was then placed in the beaker and the slurry was stirred for 180 minutes using a magnetic stirrer. The slurry was then carefully poured through an empty BNL canister, as designed by Distenfeld.[1]

The resulting eluate and all glassware were checked for residual activity. No appreciable activity was found. The eluate was allowed to drip into a beaker for ten minutes. Thereafter, the canister was placed in a polyethylene bag and the bag sealed. The canister was then analyzed by a calibrated gamma analysis system. The count rate was used to calculate a geometry factor for determining the activity present on the resin in ensuing experiments.

The second stage of the study measured the efficiency of the resin for adsorbing iodine from milk by Distenfeld's batch method[3] and the response of the selected radiological monitoring instruments to iodine sorbed on the resin was measured.

To accomplish this, glass ampoules containing known quantities of ^{131}I in 0.05 M NaOH, 0.05 M NaI and 0.05 M $NaHSO_3$ were quantitatively transferred to one gallon containers containing 3.4 liters of raw milk. Twenty-five mg of NaI carrier and 200 mL of Amberlite IRA-900C resin were added. The contents were mixed by rotating the container, top to bottom for one minute; the entire contents was poured through an empty BNL canister. After allowing the canister to drain for five minutes, it was placed in a polyethylene bag and the bag sealed with a heat sealer. The bagged canister was then analyzed for ^{131}I content with the same gamma ray analysis system used for the geometry calibration factor determination. After correcting for decay, the μCi content of the resin was compared to the activity added to determine the chemical yield.

Yields were 66.8 ± 0.6% for three canisters. Activity levels were approximately 0.18 μCi ^{131}I in each canister at the time of measurement. Free iodide in the milk as received was 3.8 ± 0.9 μg I^-/mL.

Subsequently, ten sets of measurements with each radiological instrument were made. First, the OCD-D-103 and 6303 detectors were located in the annulus of the BNL canister; later, they were positioned, as were the other detectors, with the active detector volume centered on and perpendicular to the axis of the canister. After the detector responses

were measured in the canisters, the resin was carefully transferred to one-liter plastic bottles by washing with water, and the detector responses were determined with the resin in a ~3.2-cm thick x 8.6-cm diameter geometry. Detectors were positioned so that the detectors' active volume was centered on and perpendicular to the axis of the bottles.

This sequence of resin measurements was performed in triplicate. Results of these measurements are given in Table 18 in terms of cpm per microcurie per liter and in Table 19 in terms of minimum detectable levels. For Distenfeld's method, assuming 67% recovery and a 3.4 liter sample, the 6306 GM tube inside the proposed air sampling canister and the three NaI(Tl) scintillation detectors are able to measure ^{131}I at the FDA preventive PAG level (0.012 μCi/L).

2.8 Mechanical Testing Effects

The purpose of the mechanical tests was to determine the effect of vibration and shock on the operation of the radiological instruments, including the CDV-715, 0-500 R/hr survey meter. Aluminum cases filled with foam padding were purchased from the Zero Corporation to encase the instruments during testing. The foam interiors were then cut to fit the various instruments.

Before each mechanical test, each instrument's response to a ^{133}Ba source and a mixed ^{133}Ba, ^{137}Cs, and ^{134}Cs source was measured. Each instrument was then subjected to each of the five mechanical tests below:

1. Transported over fifty miles of gravel road

2. Dropped from 2 ft onto grass cover ground

3. Dropped from 2 ft onto barren soil

TABLE 18

AVERAGE DETECTOR RESPONSE FOR ^{131}I ADSORBED ON RESIN FROM MILK - WITH 67% RECOVERY
(Net cpm per μCi/L)

	Detector					
Detector Position	D-103	6306	489-4	489-55	SPA-3	RD-22
Inside BNL Canister	116	3960	--	--	--	--
Outside BNL Canister	ND[a]	1670	260	135600	90800	84700
Outside 1-L Bottle	ND	1890	270	177000	109900	105600

[a] Not detected

TABLE 19

MINIMUM DETECTABLE QUANTITIES OF ^{131}I ADSORBED ON RESIN WITH 67% RECOVERY
(μCi/L)

	Detector					
Detector Position	D-103	6306	489-4	489-55	SPA-3	RD-22
Inside BNL Canister	0.180	0.011	ND[a]	--	--	--
Outside BNL Canister	ND	0.025	0.170	0.0030	0.00054	0.00056
Outside 1-L Bottle	ND	0.022	0.170	0.00230	0.00045	0.0046

[a] Not detected

4. Dropped from 4 ft onto grass covered ground

5. Dropped from 4 ft onto barren soil

After each mechanical test the instrument responses were again measured with the two radionuclide sources.

Damage was indicated by a change in instrument response. To this end, ratios of the source responses were calculated as in Section 2.4 to determine the effect of vibration and shock. The cases used for the 489-55, 489-4, SPA-3 and RD-22 and their associated instrumentation provided good protection with essentially no change in detector response. In regard to the other instruments, one CDV-700/6306 failed due to a meter malfunction, one CDV-700/6306 exhibited no damage, and the two CDV-700/OCD-D-103 meters tested showed minimal change in responses. As the CDV-700/OCD-D-103 and the CDV-700/6306 were tested using the same cases, the former appear to be more sensitive, exhibiting the one observed failure as well as the largest change (14%) in ^{133}Ba response. (The response change for these two CDV-700/OCD-D-103 instruments are shown on bar charts in Figures 13 and 14).

In conjunction with these tests, the two CDV-715, 0-500 R/hr survey meters were tested for effects of vibration and shock in a 150 R/hr gamma radiation field before and after the same series of mechanical tests above. In these tests, the instruments were also enclosed in a padded aluminum case. Although the zero of the instruments appear somewhat sensitive to shock and required adjustment before measurement, the unit itself was otherwise unaffected when dropped in a padded case.

2.9 Other Experimental Observations

Early in the testing program, two 6306 GM tubes failed at different times for no apparent reason. When one of these units was sectioned for investigation, the glass seal holding the anode wire to the end of the tube was not in place and the anode wire was burned into two sections.

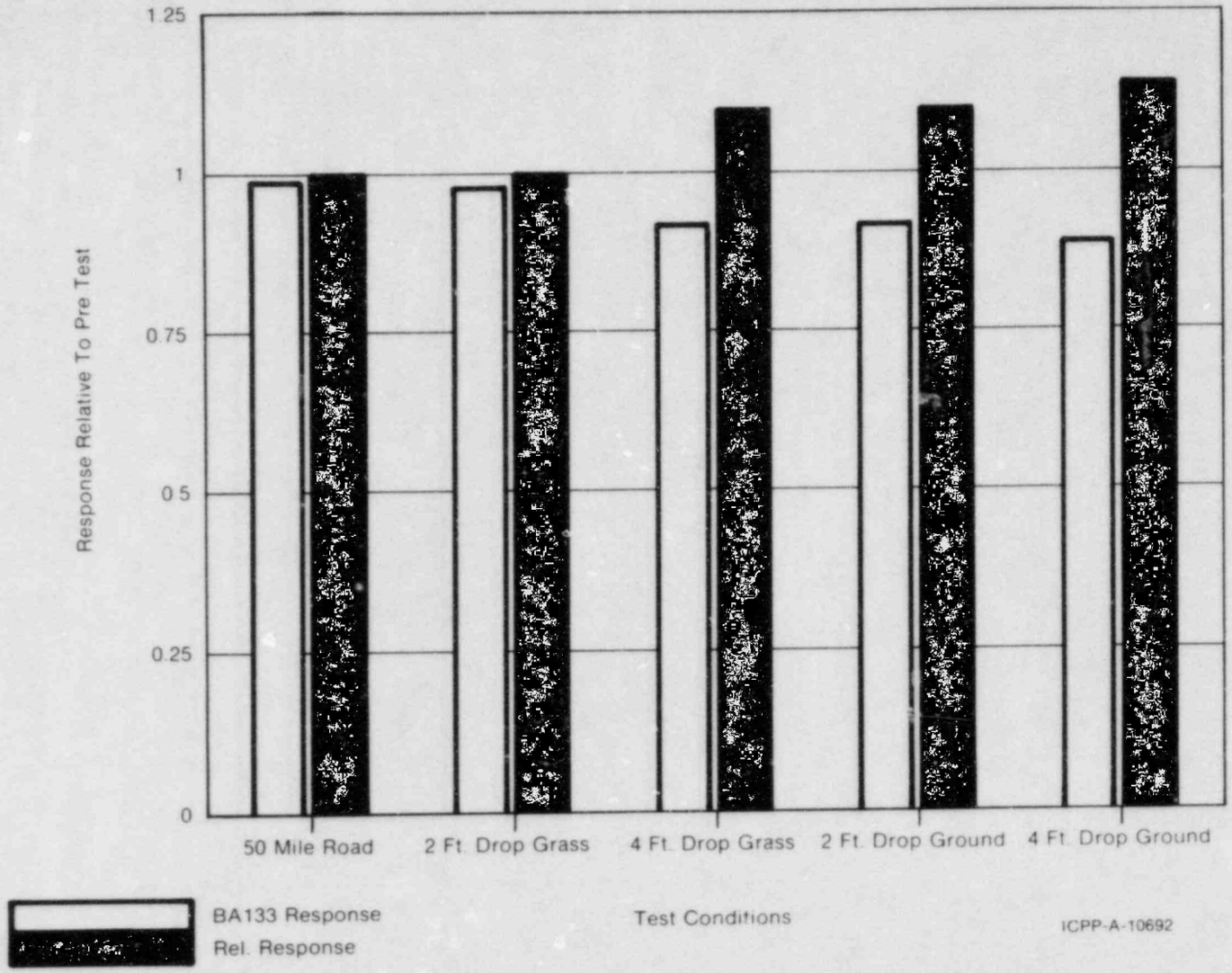


Figure 13. Mechanical Testing Of CDV 700/OCD-D-103#1

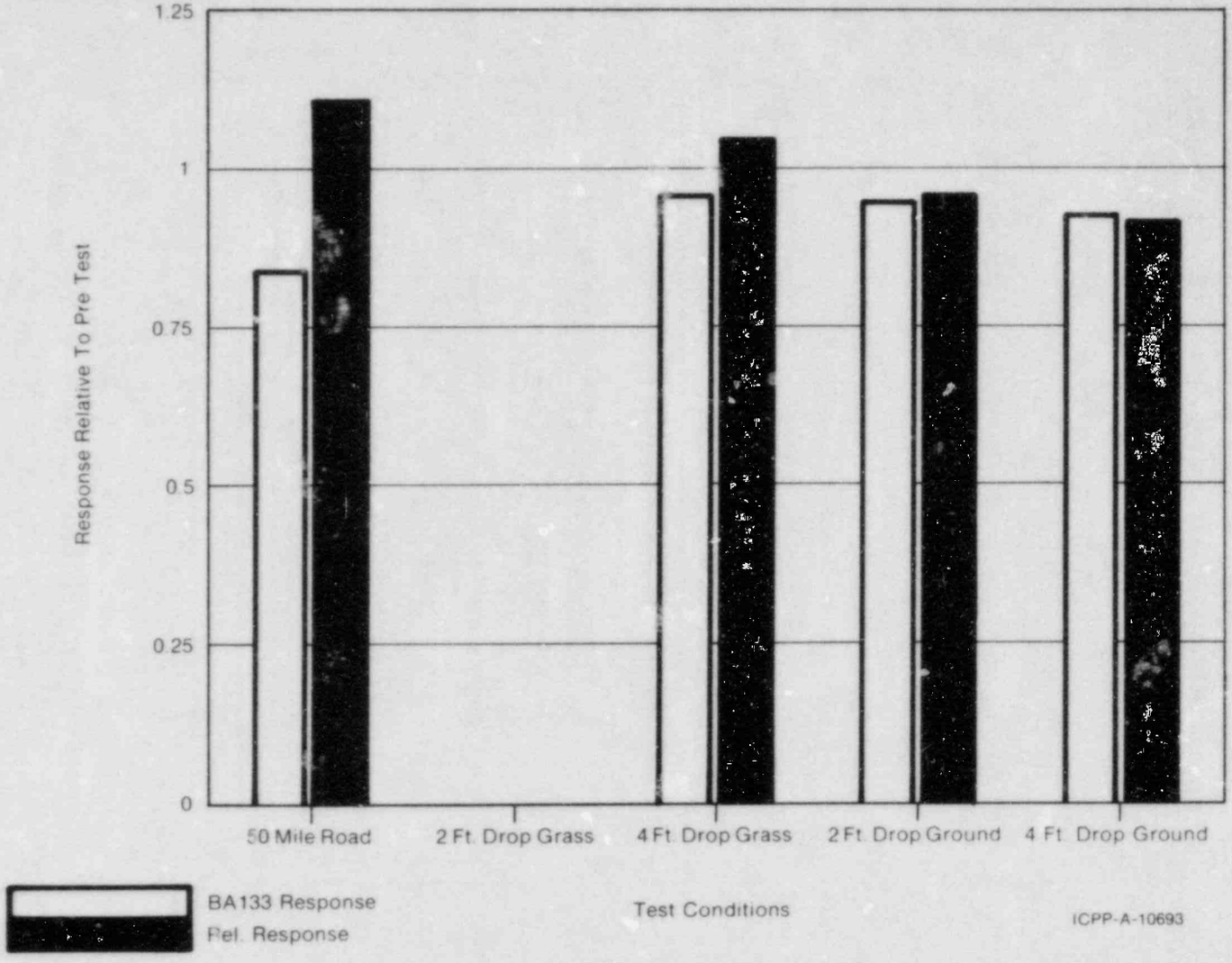


Figure 14. Mechanical Testing Of CDV 700/OCD-D-103#2

It is most likely that the seal failed first, allowing the anode wire to short against the tube wall. No failures were experienced in the second group of 6306 tubes purchased and tested in the program.

In addition to instabilities observed in the low temperature environmental chamber testing, the SAM II evidenced high voltage drift on two separate occasions. Efforts to determine a cause for the drift were unsuccessful. It cannot be determined without testing a group of these units whether the instabilities seen in this unit are characteristic of SAM II's in general. However, the instabilities are likely due to the limited temperature range (40-140°F).

3. CONCLUSIONS AND RECOMMENDATIONS

The following items summarize the results of the evaluations of the six instruments proposed for emergency measurement of ^{131}I and of the CDV-715 0-500 R/hr survey meter. An overview of the results is presented in Table 20.

1. Scintillation detectors have the highest sensitivity toward 364 KeV gamma rays produced by ^{131}I. The 6306 GM tube shows higher response for 364 gamma rays than the other GM tube probes tested.

2. Operation in the range of 0 to 110°F with 90% RH showed changes of <16% in absolute and relative response for all instruments except the SAM II/RD-22. An increasing loss in response was observed with the SAM II/RD-22, probably due to drifting high voltage.

3. Operation at -20°F resulted in changes up to 26% change in the GM detector and the 489-55 scintillation detector responses. The SPA-3 showed a 40% loss. The SAM-II/RD-22 showed a 99% loss, correctable to a 40% loss by adjusting the high voltage ~50 volts out of ~750. The drift for the RD-22 SAM II is unexpected because it is supposedly "stabilized" by design. It is not known whether this is a defect in the instrument design or only in the individual instrument tested.

4. All instruments returned to their initial responses when retested at 70°F, with the exception of the THYAC III/489-4. It showed a 34% loss in response, the cause for which is not known.

5. The CDV-715, 0-500 R/hr survey meters showed minor (10-30%) changes in response when exposed to the range of environments from -20 to 110°F with 90% RH.

6. Scintillation detectors showed the highest sensitivity for measurement of ^{131}I in bovine thyroid models, with the SPA-3 and RD-22 able to detect ∿7 nanocuries and the 489-55 able to detect ∿20 nanocuries. The minimum detectable level for the shielded 6306 GM tube was ∿300 nanocuries, for the 489-4 GM ∿1.4 microcurie, and for the OCD-D-103 GM ∿600 nanocuries.

7. Scintillation detectors had the lowest detection level for ^{131}I in human thyroids; the SPA-3 and RD-22 were able to detect radioactivity levels equivalent to a 9 millirem dose commitment for two year olds; the 489-55 was able to detect radioactivity levels equivalent to a 56 millirem dose commitment for the two year olds. The shielded 6306 detected 330 millirem; the 489-4, 1.5 rem; and the OCD-D-103, 1 rem dose commitment for two year olds. Measurable dose commitments for five year old children and adults were factors of approximately 2 and 10 lower.

8. Only the scintillation detectors were able to detect ^{131}I on fields and pastures at the FDA preventive PAG level of 0.14 $\mu Ci\ ^{131}I/m^2$.

9. Both scintillation detectors and shielded 6306 GM tubes were able to detect ^{131}I in bulk liquids (milk or water) at the FDA preventive PAG of 0.012 $\mu Ci\ ^{131}I/L$.

10. The presence of ^{134}Cs and ^{137}Cs in milk, at levels postulated for a PWR 9A accident scenario, increased the response of the GM detectors by a factor of three. The response of the 489-55 was increased by a factor of ∿2; the responses of the SPA-3 and RD-22 were increased by a factor of ∿1.4. The presence of other nuclides would increase the amount of overestimation of ^{131}I when determined by direct measurement of bulk liquids.

11. When 67% recovery of the ^{131}I in milk was collected on 200 mL of Amberlite IRA-900C resin and located in an BNL canister, the scintillation detectors and the 6306 GM tube were able to detect less than the 0.012 µCi ^{131}I/L FDA preventive PAG level.

12. Mechanical testing showed no instrument damage associated with vibration.

13. Two foot and four foot drop tests of the instruments in padded cases caused a failure of one CDV-700/6306 instrument. No other instruments were affected.

14. The CDV 715, 0-500 R/hr survey meters were not affected by mechanical and drop tests, other than requiring an adjustment of the instrument zero.

15. Two 6306 GM tubes failed in the early phase of the program. One was sectioned and found to have a broken cathode wire and a glass seal separated from the end of the tube. Another CDV-700/OCD-D-103 failed for no apparent reason. None of the failures noted can be attributed to test parameters.

TABLE 20

SUMMARY OF RADIOLOGICAL INSTRUMENTS COMPARISON

Meter-Detector	Sensitivity				Radiological Interference Factors (Increase)	Environmental Effects (% Change)		Mechanical Effects
	Thyroid[a] (mRem)	Liquid[b] (μCi/L)	Resin[c] (μCi/L)	Field[d] ($\mu Ci/m^2$)		(0°F)	(-20°F)	
CDV-700 OCD-D-103	1000	0.03	ND	ND	3	<16	<25	POOR
CDV-700 6306	330	0.007	0.02	0.5	3	<16	<25	GOOD
THYAC III 489-4	1600	0.04	0.2	1.7	3	<16	<25	GOOD
THYAC III 489-55	60	4(-4)	2(-3)	0.07	2	<16	<25	GOOD
Ludlum 2200 SPA-3	10	2(-4)	4(-4)	0.02	1.4	<16	<40	GOOD
SAM II RD-22	10	2(-4)	4(-4)	0.02	1.4	>90	99	GOOD

a Two year old thyroid data. For comparison, the preventive PAG is 1.5 REM.

b Bulk Liquid infinite source data. For comparison, the preventive PAG is 0.012 μCi/L.

c Outside one liter bottle, 67% recovery of radioiodine.

d One meter source to detector distance. For comparison, the preventive PAG is 0.14 $\mu Ci/M^2$.

4. REFERENCES

1. Distenfeld, C., and Klemish, J., An Air Sampling System for Evaluating the Thyroid Dose Commitment Due to Fission Products Released from Reactor Containment, NUREG/CR-0314/BNL-NUREG-50881 (December 1978).

2. U.S. Nuclear Regulatory Commission, Reactor Safety Study, Appendix VI, WASH 1400 (1975).

3. Distenfeld, C., and Klemish, J., Environmental Radioiodine Monitoring to Control Exposure Expected from Containment Release Accidents NUREG/CR-0315/BNL-NUREG-50882 (December 1978).

4. ICRP Report No. 23., Report on the Task Group on Reference Man, Pergamon Press (New York 1975).

5. Radiological Health Handbook, U. S. Department of Health Education and Welfare, Public health Service, Superintendent of Documents, U. S. Government Printing Office, Washington D. C. (1970).

6. H. Cember, Introduction to Health Physics, Pergamon Press, New York, p. 158 (1980).

7. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50," Appendix I.

APPENDIX A

EXPERIMENTAL DRAWINGS

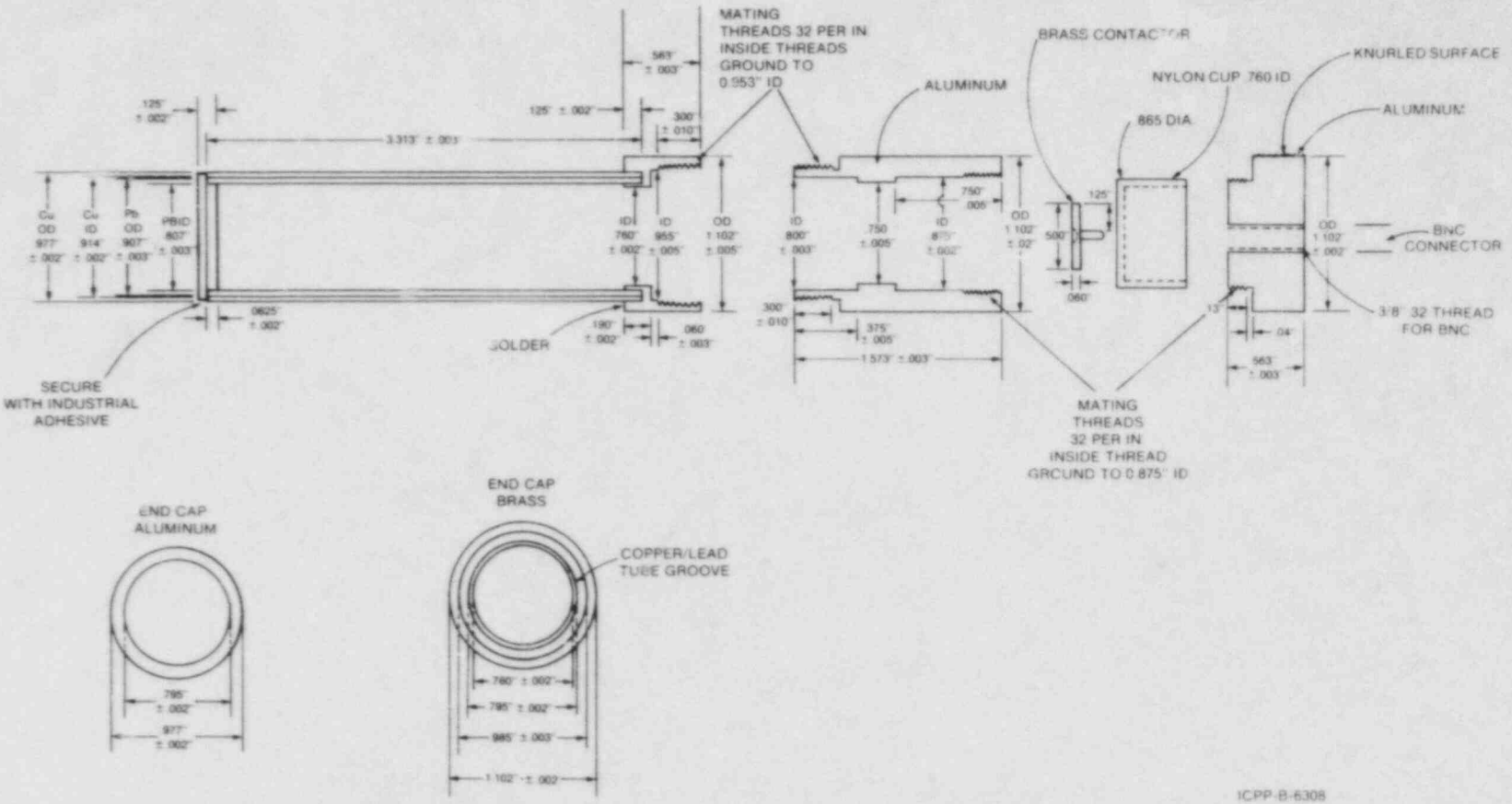
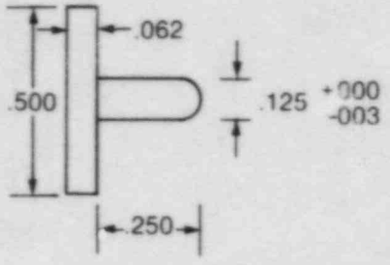
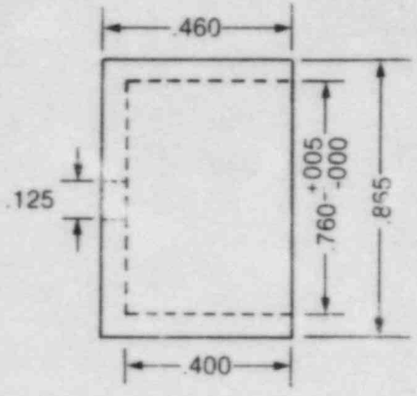


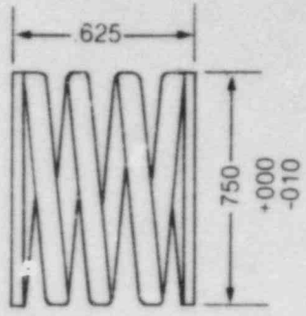
Figure A.1. 6306 Probe Shield and Connector



BRASS CONTACTOR
1 REQ



NYLON CUP
1 REQ



COMPRESSION
SPRING
.041 Stainless Wire

ICPP-A-6306

Figure A.2. 6306 Probe Detail

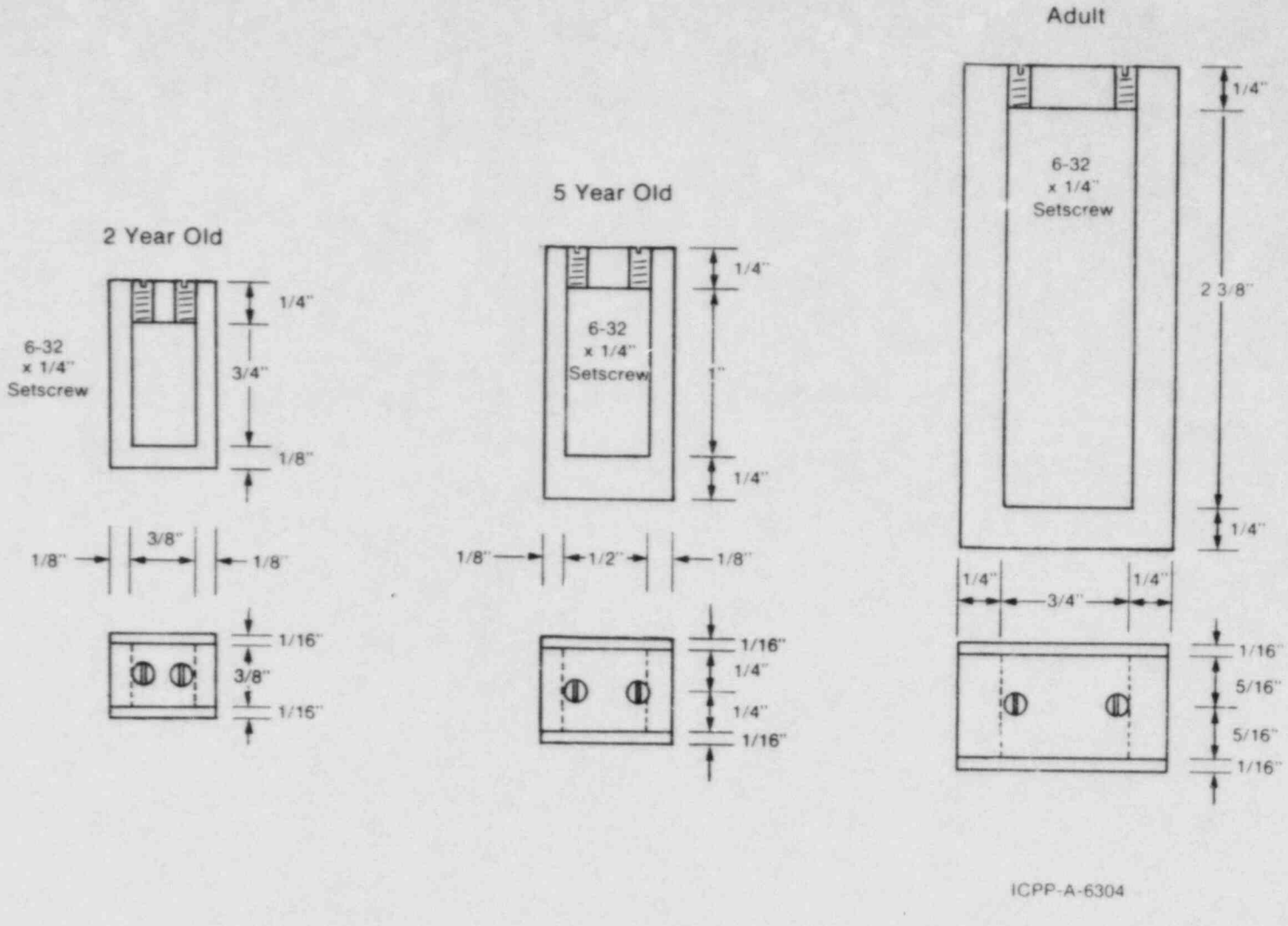
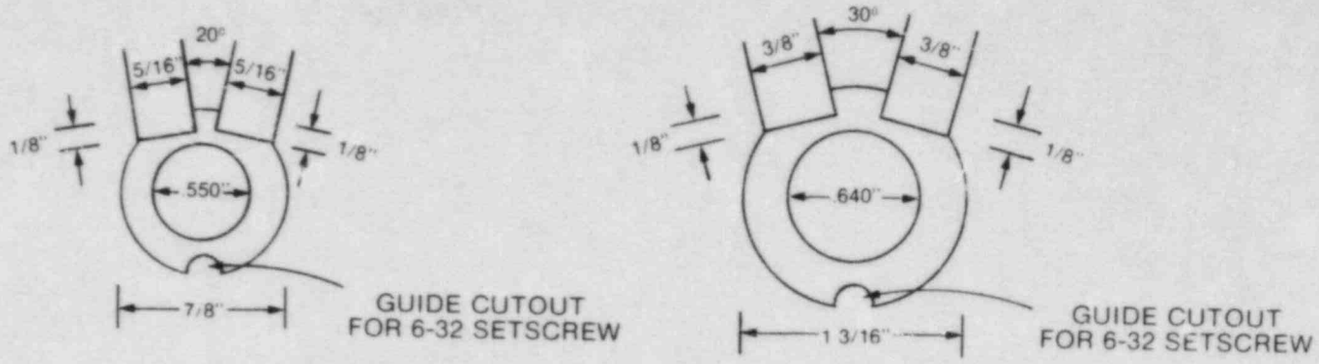


Figure A.3. Thyroid Bodies



ICPP-A-6305

Figure A.4. Mounting Rings For Thyroid Body*

* NOTE 1/2" PLEXIGLAS

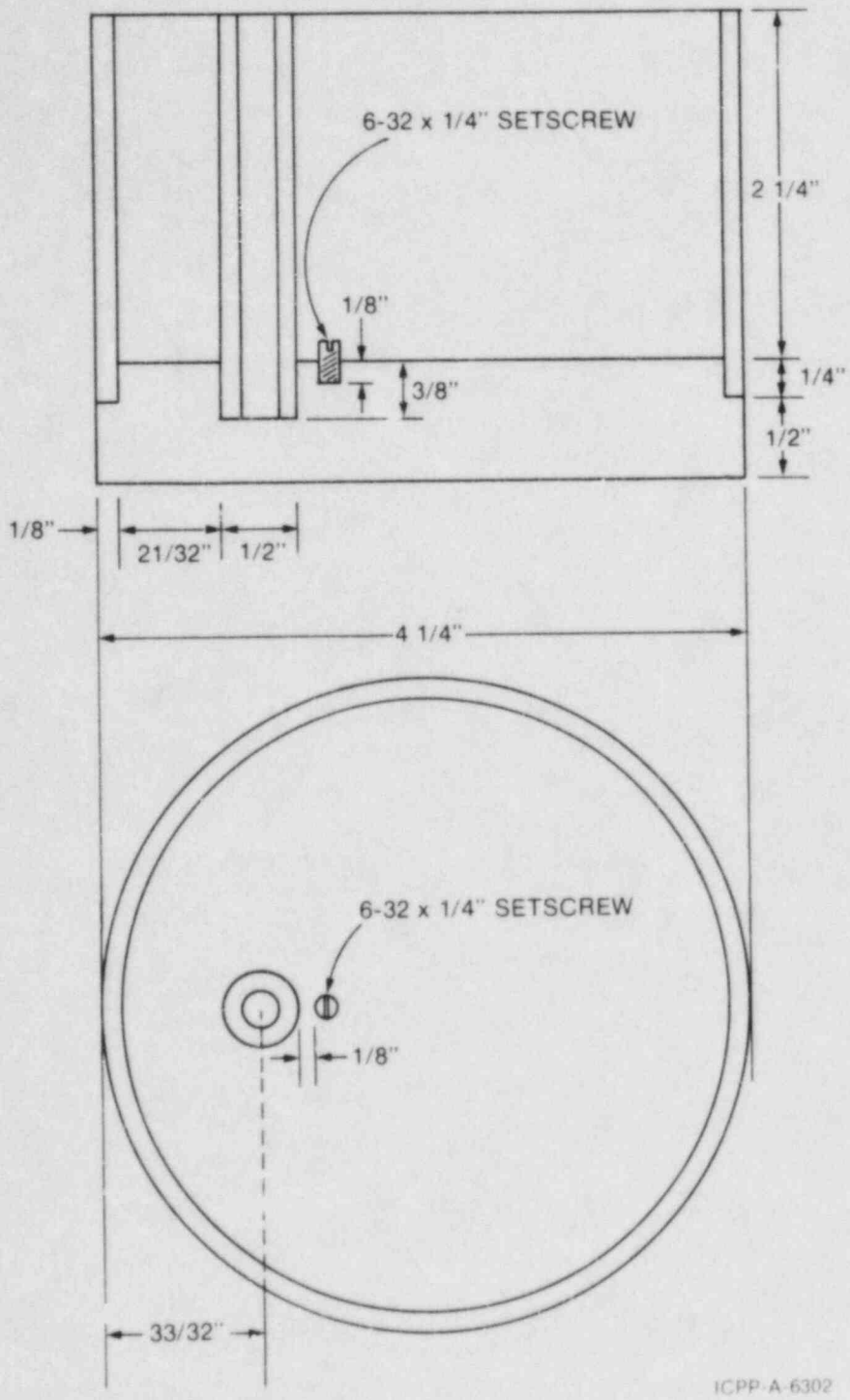


Figure A.5. Neck/Trachea Assembly (2 Years Old)

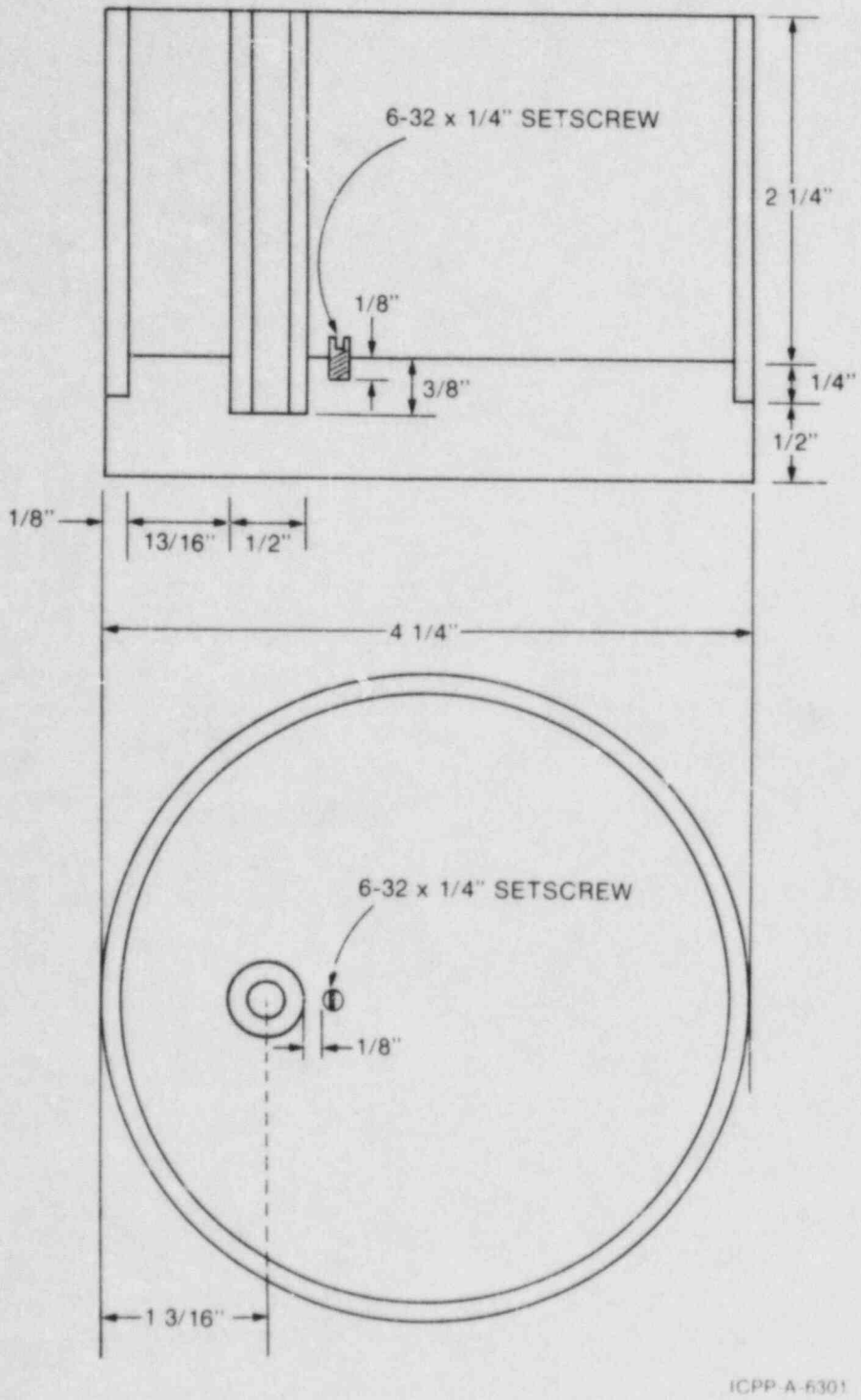


Figure A.6. Neck/Trachea Assembly (5 Year Old)

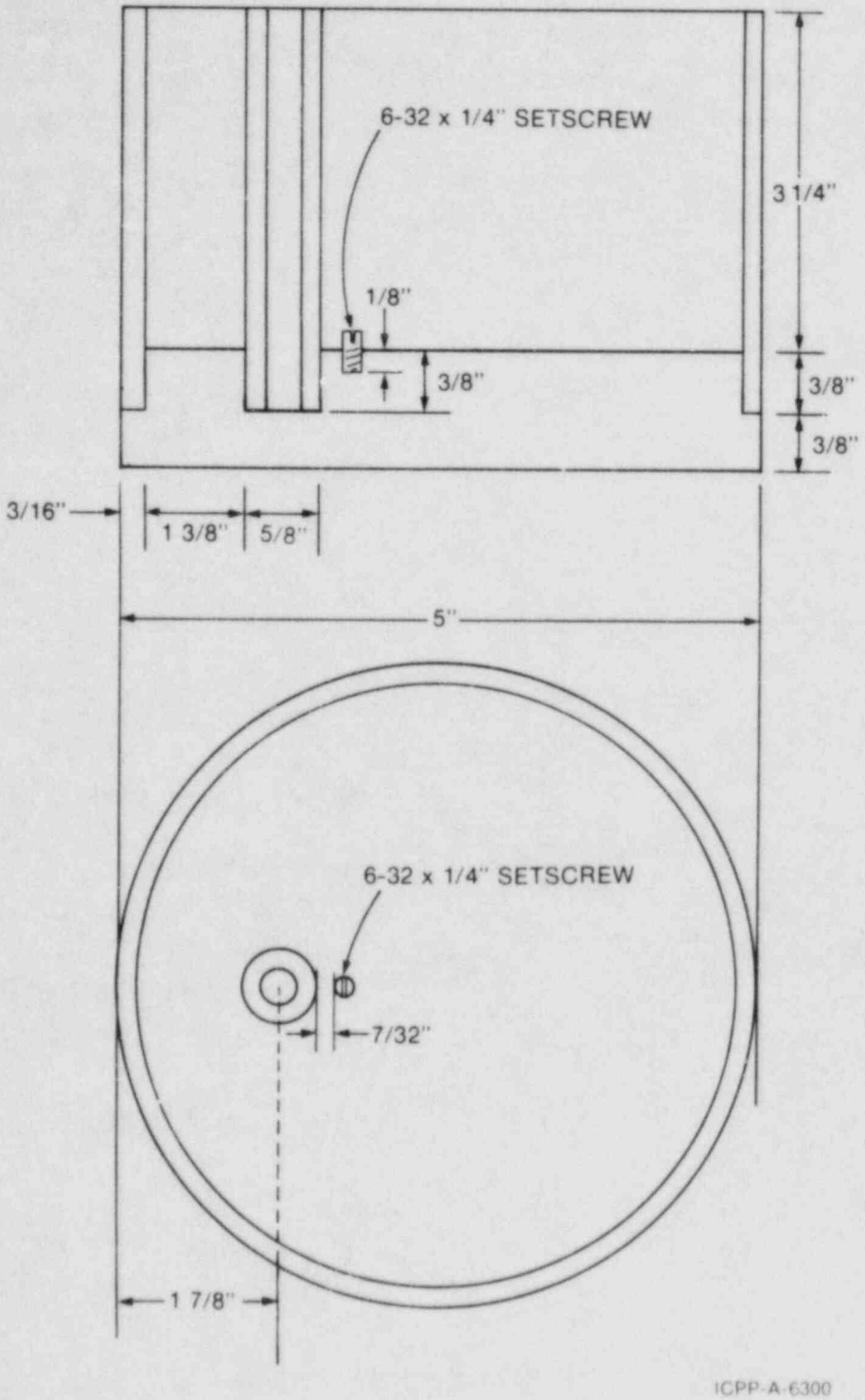


Figure A.7. Neck/Trachea Assembly (Adult)

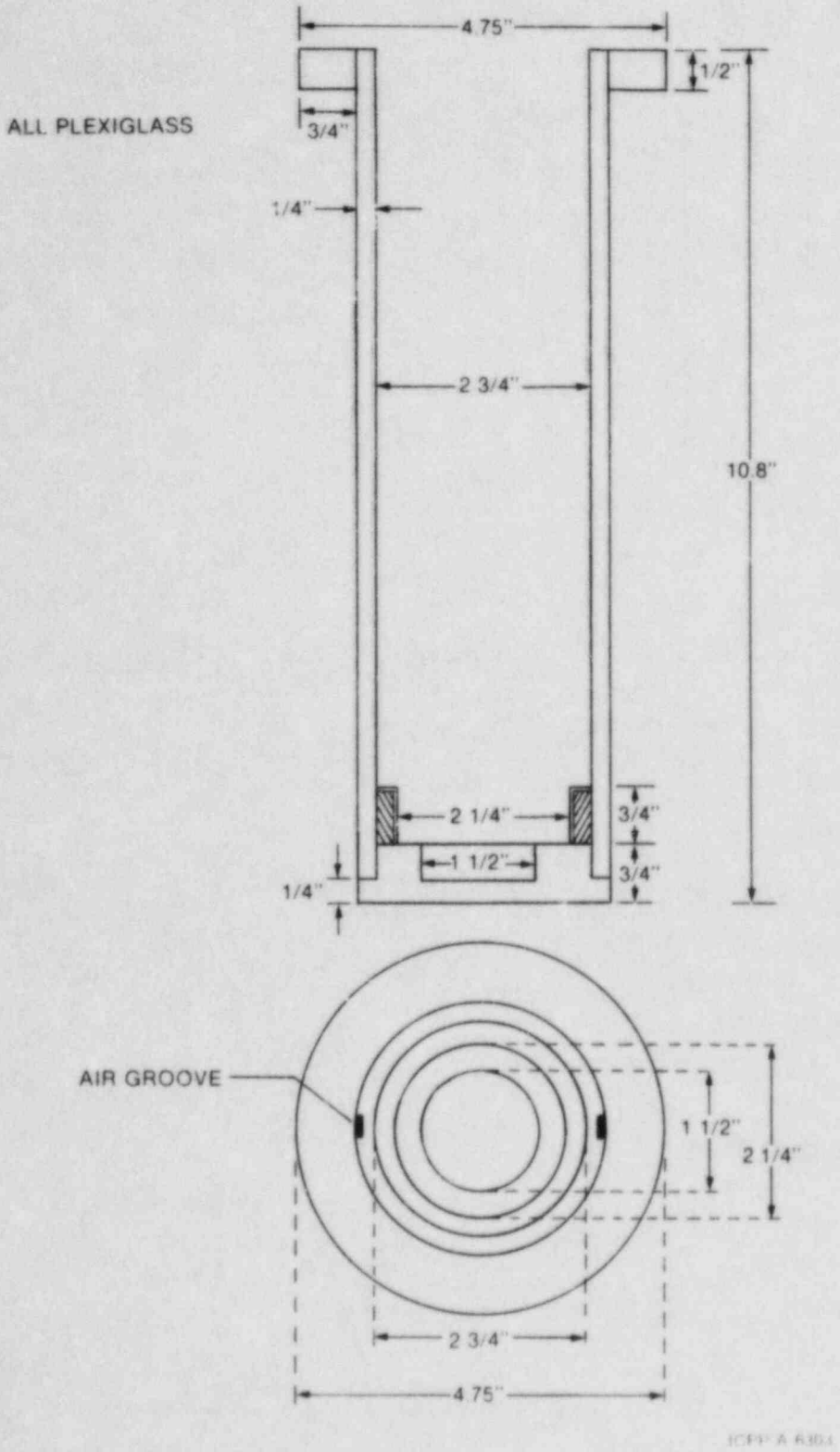


Figure A.8. Large Insert

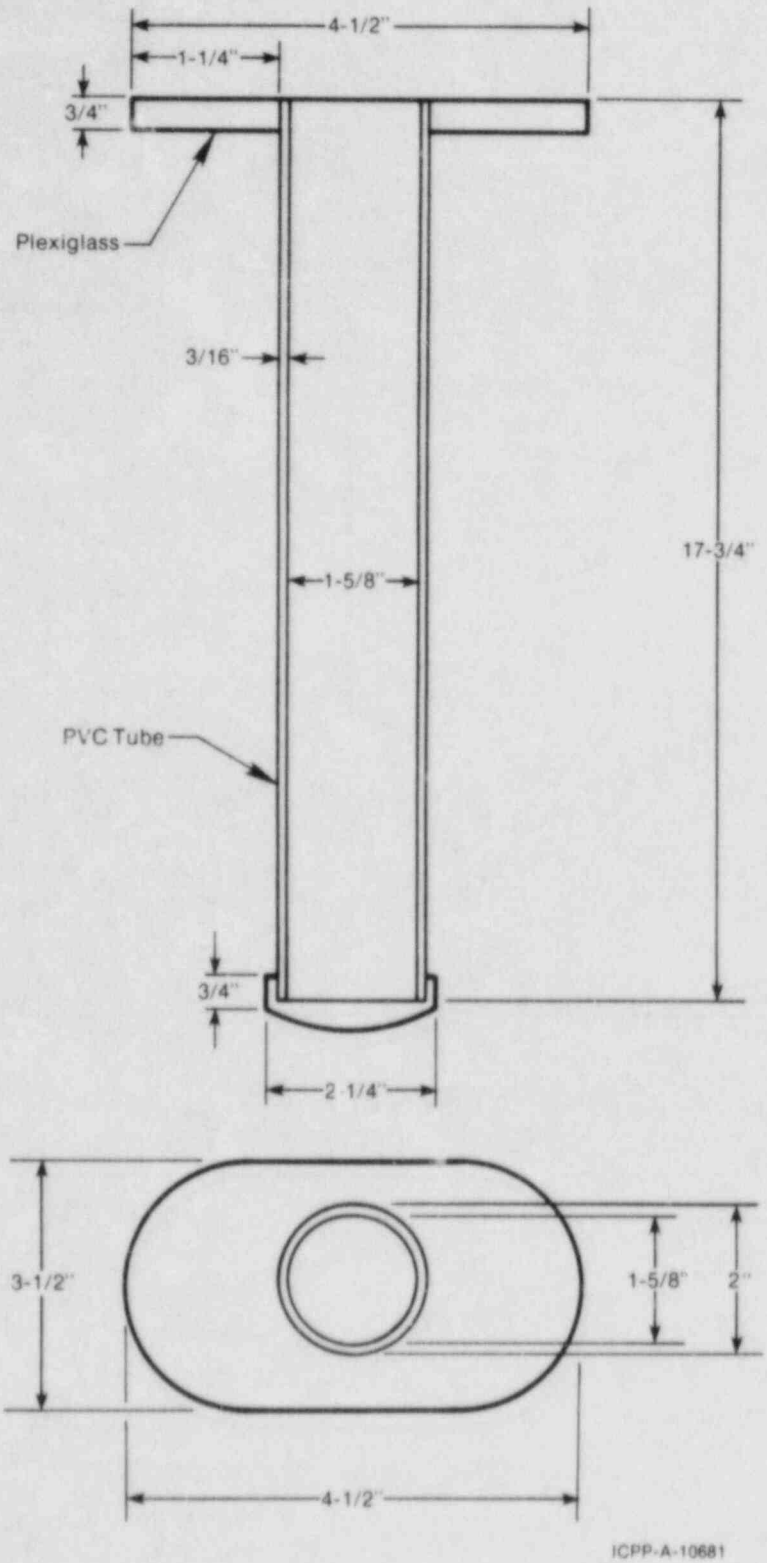


Figure A.9. Small Insert

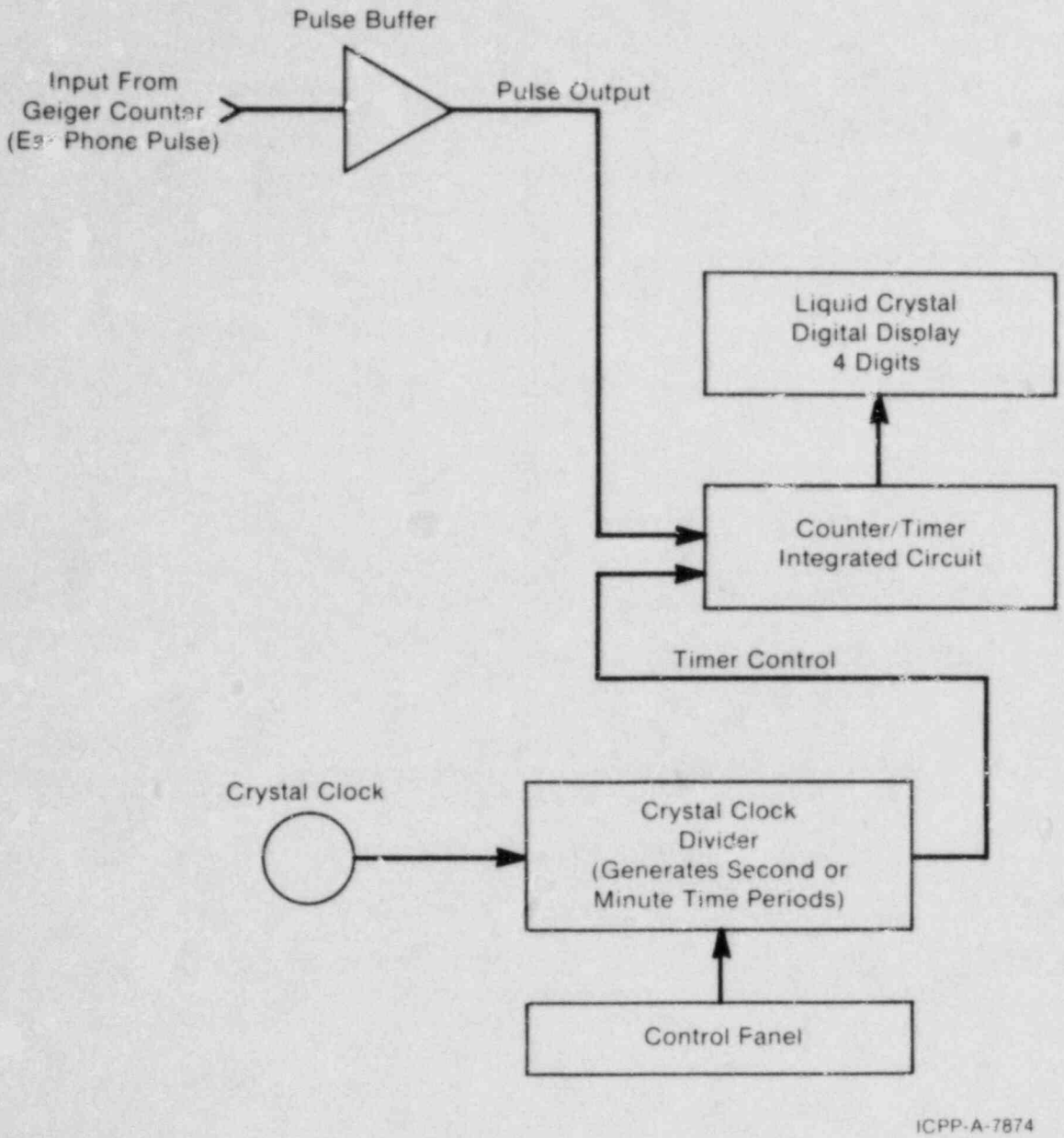


Figure A.10. Block Diagram For Portable Timer/Scaler

Timer/Scaler Components

IC #	Type	+VCC	GND	
U-1	ICM 7224	1	35	4 1/2 Digit Counter Decoder/Driver
U-2	ICL 8260	16	9,13	Programable Timer/ Counter
U-3	ICL 8260	16	9,13	
U-4	ICL 8250	16	9	
U-5	MM 5369	8	7, 11	OSC/Divider
U-6	MC 14049	1	8	Buffered Hex Inverter

SK-1 Component Mount

SK-2 Ribbon Cable Connector (Switches)

SK-3, SK-4, SK-5 Ribbon Cable Connectors for Display Chip

ICPP-A-7875

Figure A.11. Timer/Scaler Components

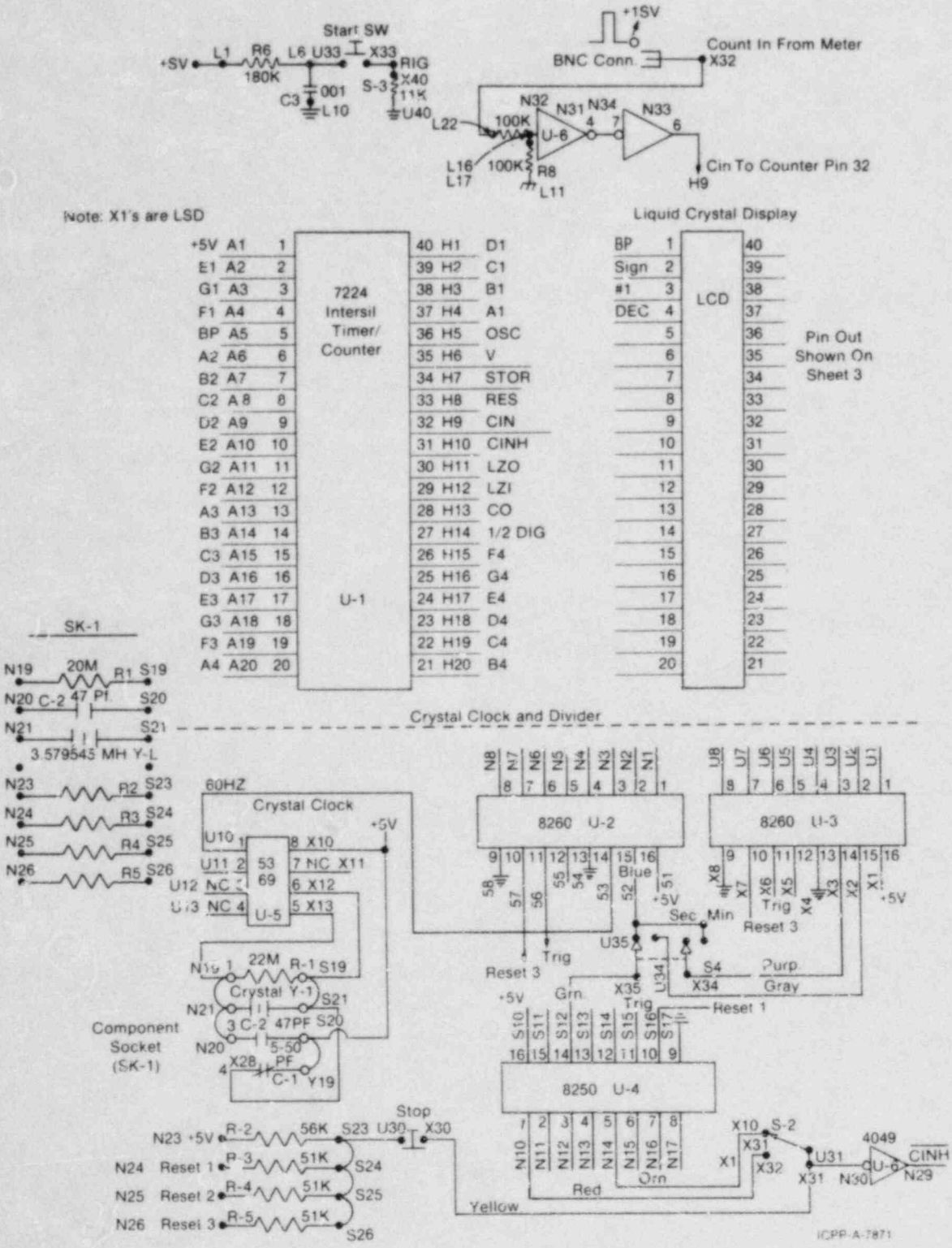


Figure A.12. Timer/Scaler Schematic

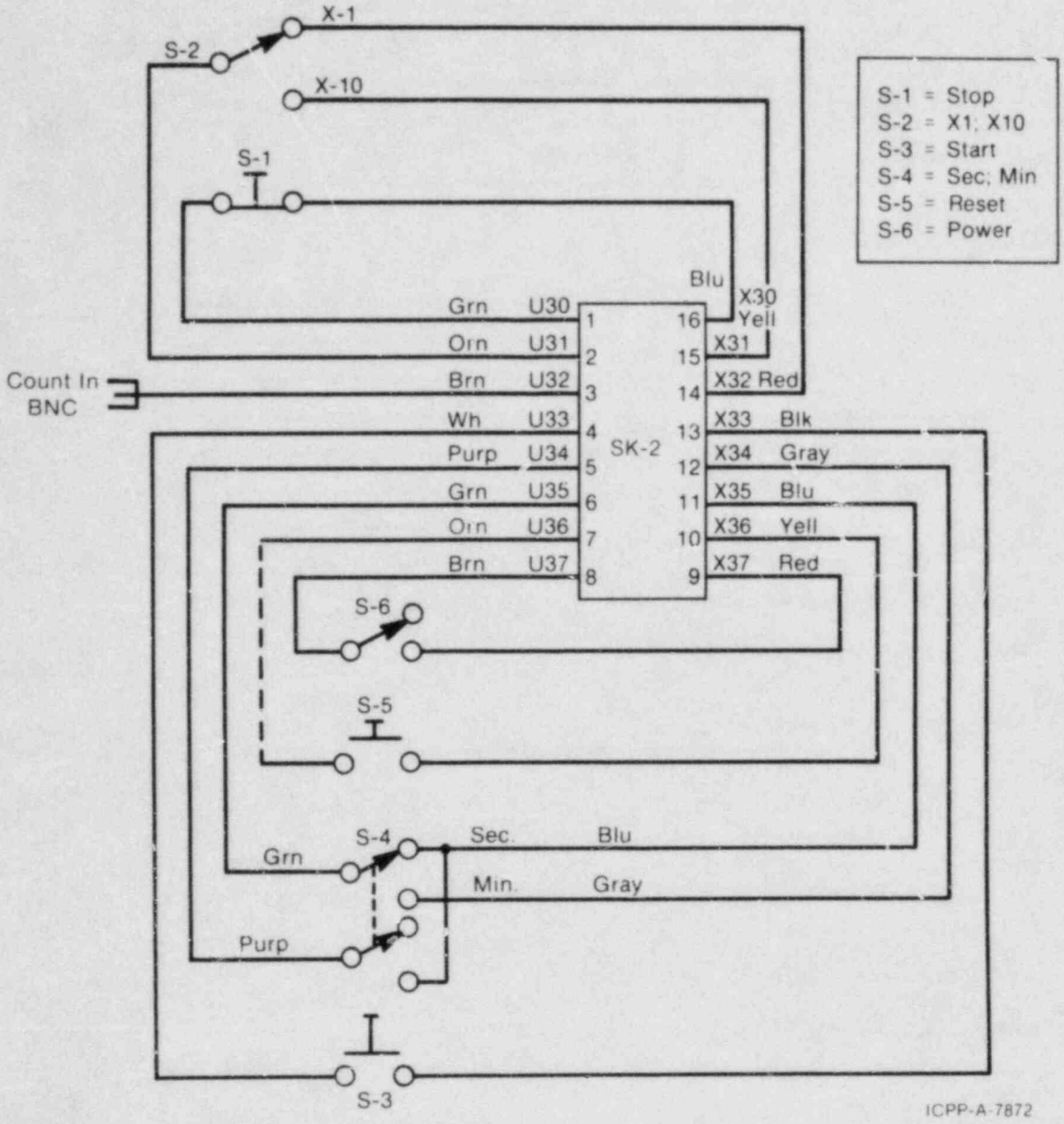


Figure A.13. Timer/Scaler Panel To Board Connections

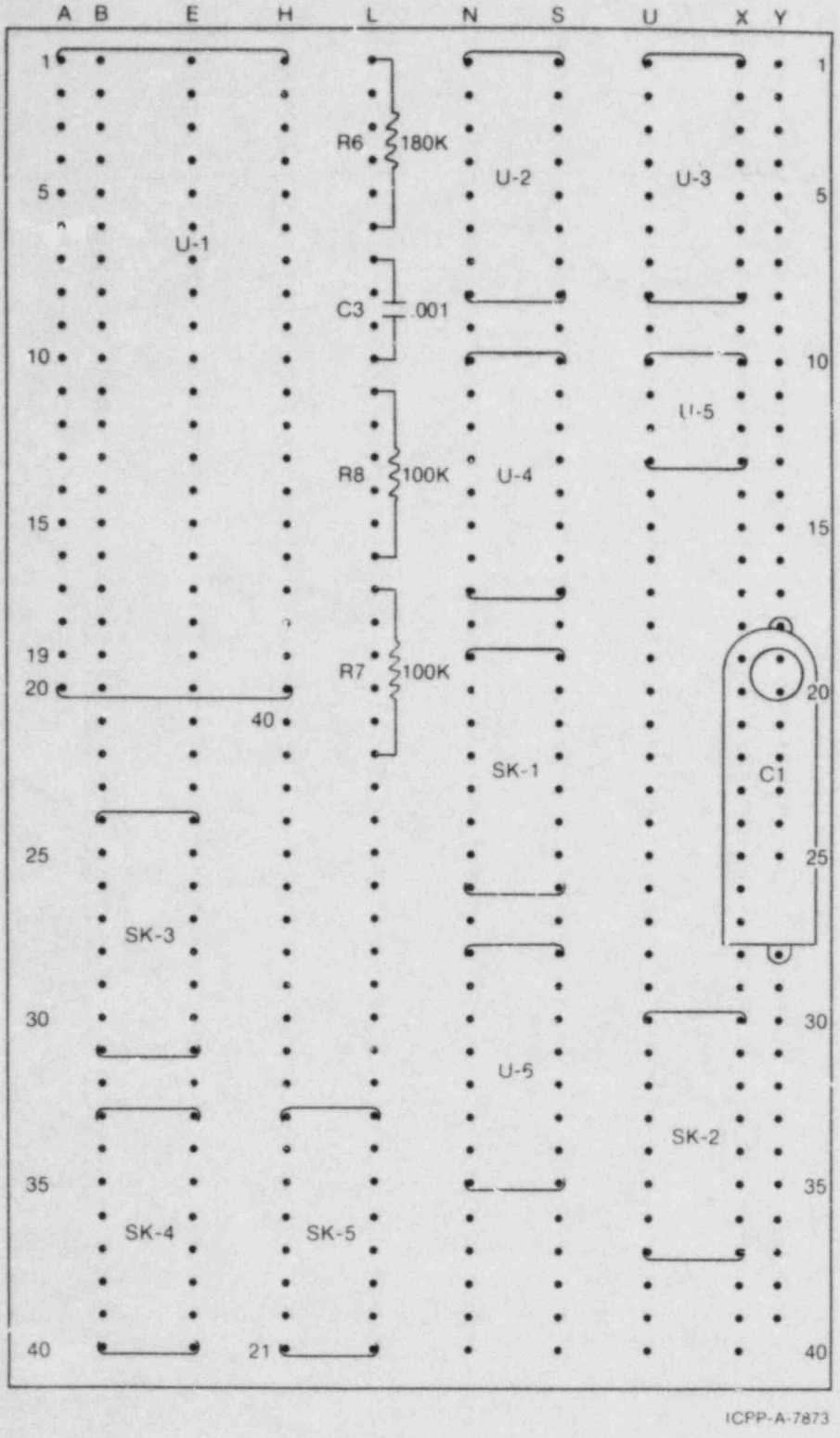


Figure A.14. Timer/Scaler Component Layout and Wirewrap Board

Signal Desig.	LCD Pin #	Ckt. Board Pin #	ICM 7224 Pin #	Ckt. Board Pin #
Backplane	1	A-21	5	A-5
Neg. Sign Seg.	2	A-22		
1/2 Digit Seg. (#1)	3	A-23	27	H-14
Units Decimal	4	A-24		
Seg. E-1	5	A-25	24	H-17
Seg. D-1	6	A-26	23	H-18
Seg. C-1	7	A-27	22	H-19
Tens Decimal	8	A-28		
Seg. E-2	9	A-29	17	A-17
Seg. D-2	10	A-30	16	A-16
Seg. C-2	11	A-31	15	A-15
Hundreds Decimal	12	A-32		
Seg. E-3	13	A-33	10	A-10
Seg. D-3	14	A-34	9	A-9
Seg. C-3	15	A-35	8	A-8
Thousands Decimal	16	A-36		
Seg. E-4	17	A-37	2	A-2
Seg. D-4	18	A-38	40	H-1
Seg. C-4	19	A-39	39	H-2
Seg. B-4	20	A-40	38	H-3
Seg. A-4	21	H-40	37	H-4
Seg. F-4	22	H-39	4	A-4
Seg. G-4	23	H-38	3	A-3
Seg. B-3	24	H-37	7	A-7
Seg. A-3	25	H-36	6	A-6
Seg. F-3	26	H-35	12	A-12
Seg. G-3	27	H-34	11	A-11
Semicolon	28	H-33		
Seg. B-2	29	H-32	14	A-14
Seg. A-2	30	H-31	13	A-13
Seg. F-2	31	H-30	19	A-19
Seg. G-2	32	H-29	18	A-18
Semicolon	33	H-28		
Seg. B-1	34	H-27	21	H-20
Seg. A-1	35	H-26	20	A-20
Seg. F-1	36	H-25	26	H-15
Seg. G-1	37	H-24	25	H-16
Overflow (→)	38	H-23		
Pos. Sign Seg.	39	H-22		
Backplane	40	H-21	5	A-5

NOTE: X-1 are MSD
X-4 are LSD

ICPP-A-7876

Figure A.15. Timer/Scaler Signal List

APPENDIX B

DETECTOR ENERGY RESPONSE CURVES

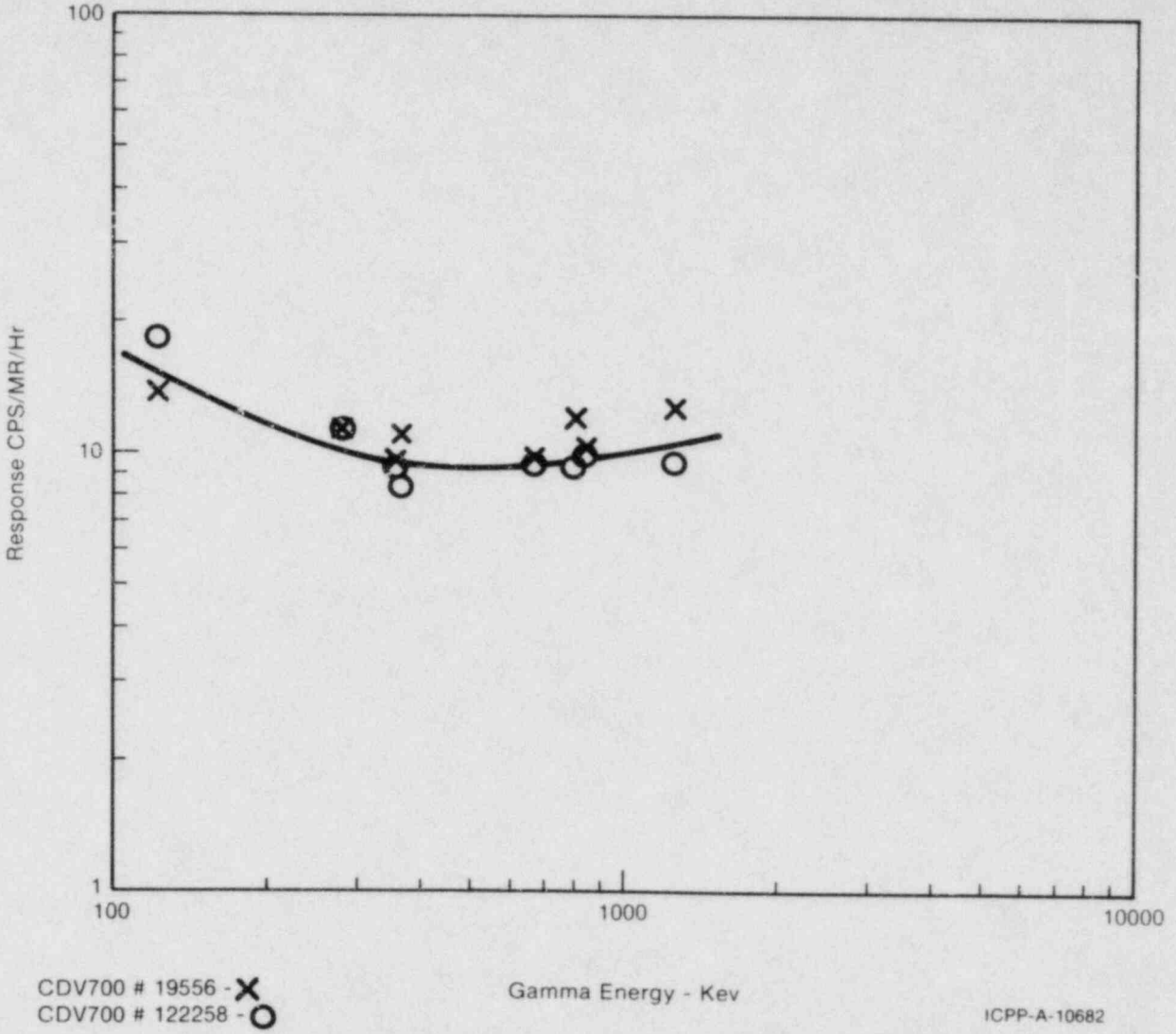


Figure B.1. Detector Energy Response--OCD-D-103

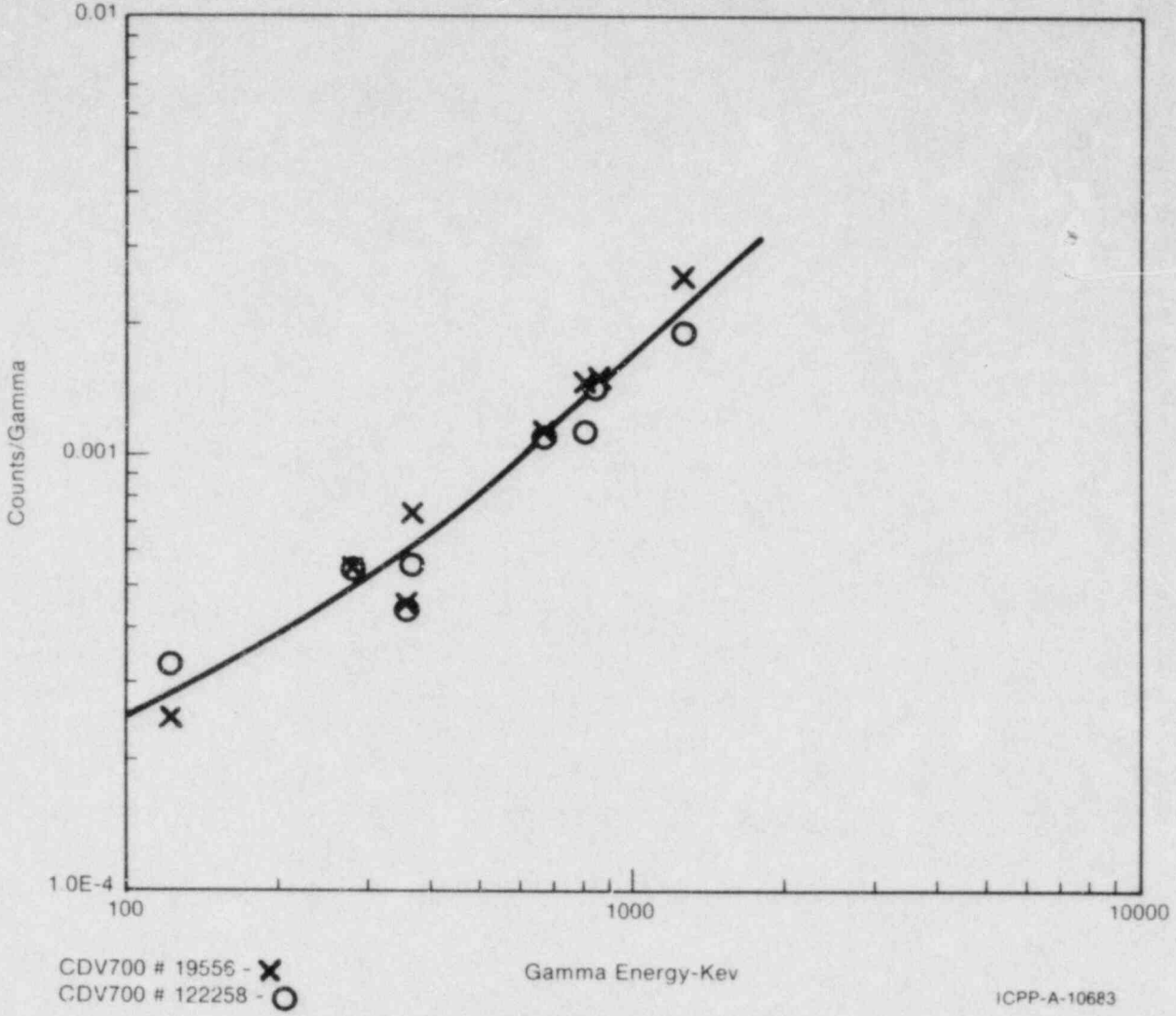


Figure B.2. Detector Energy Response--OCD-D-103

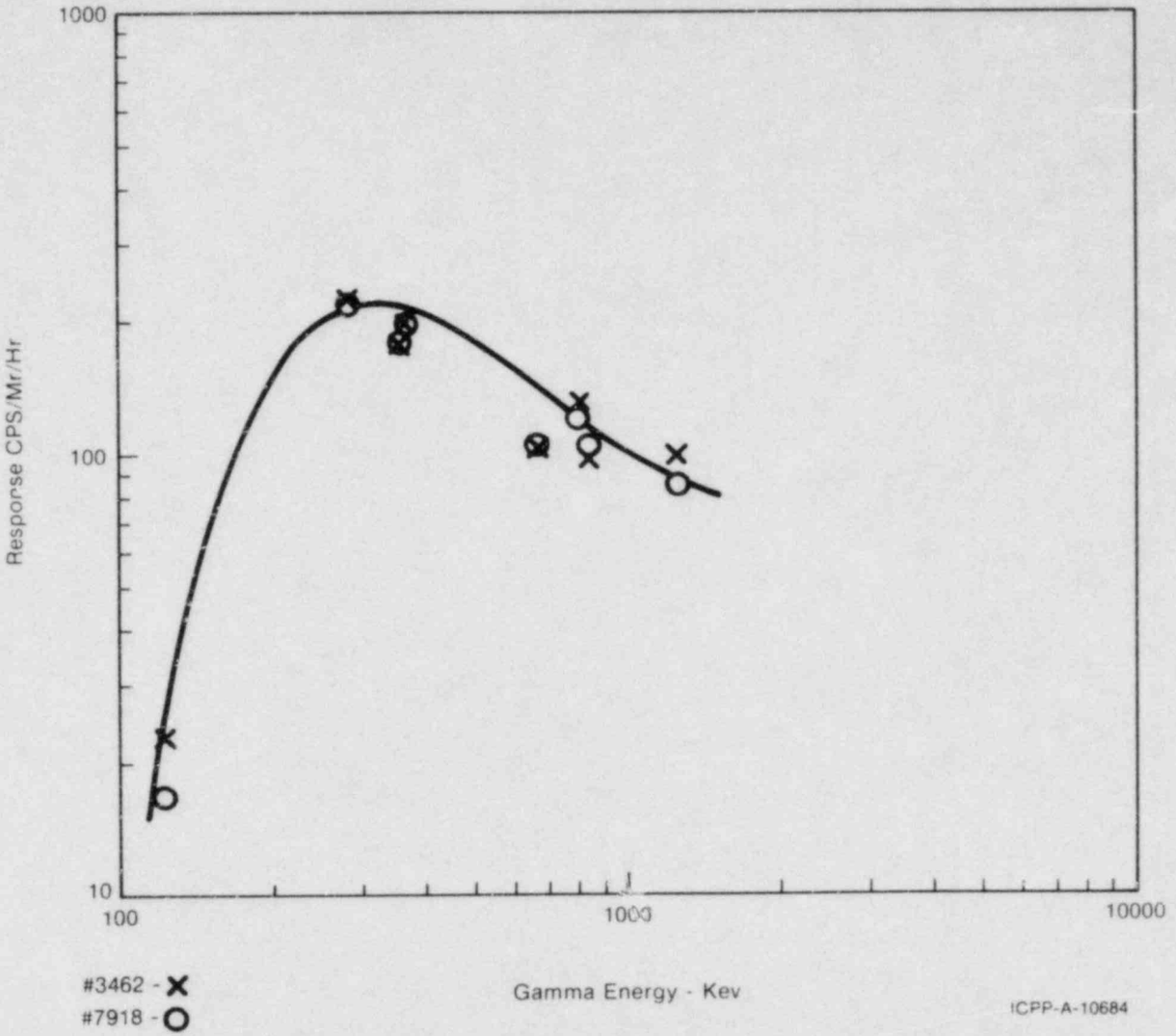


Figure B.3. Detector Energy Response Shielded 6306 0.12cm PB + .08cm CU CDV 700 Ratemeter

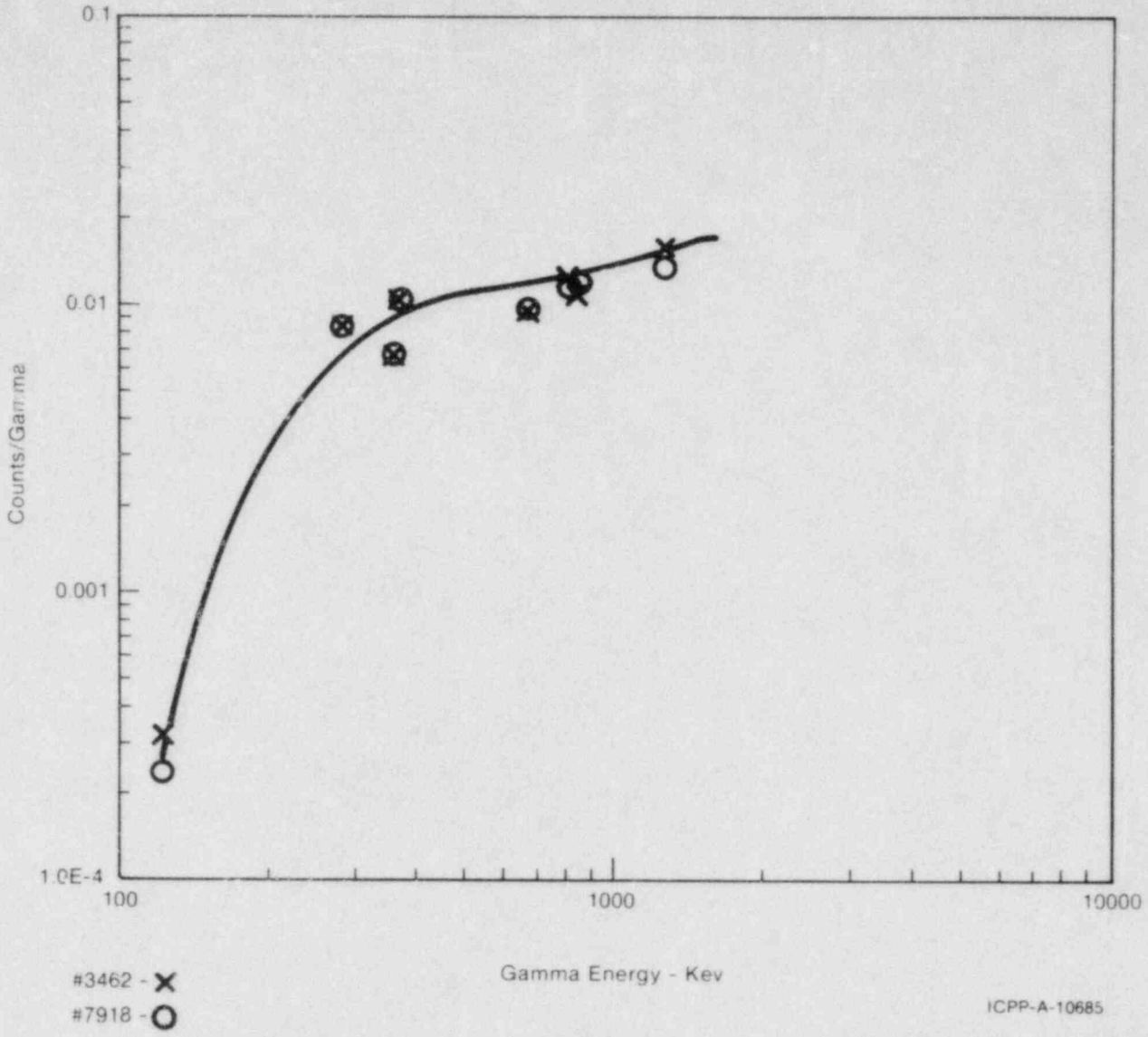


Figure B.4. Detector Energy Response Shielded 6306 0.12cm PB + .08cm CU CDV 700 Ratemeter

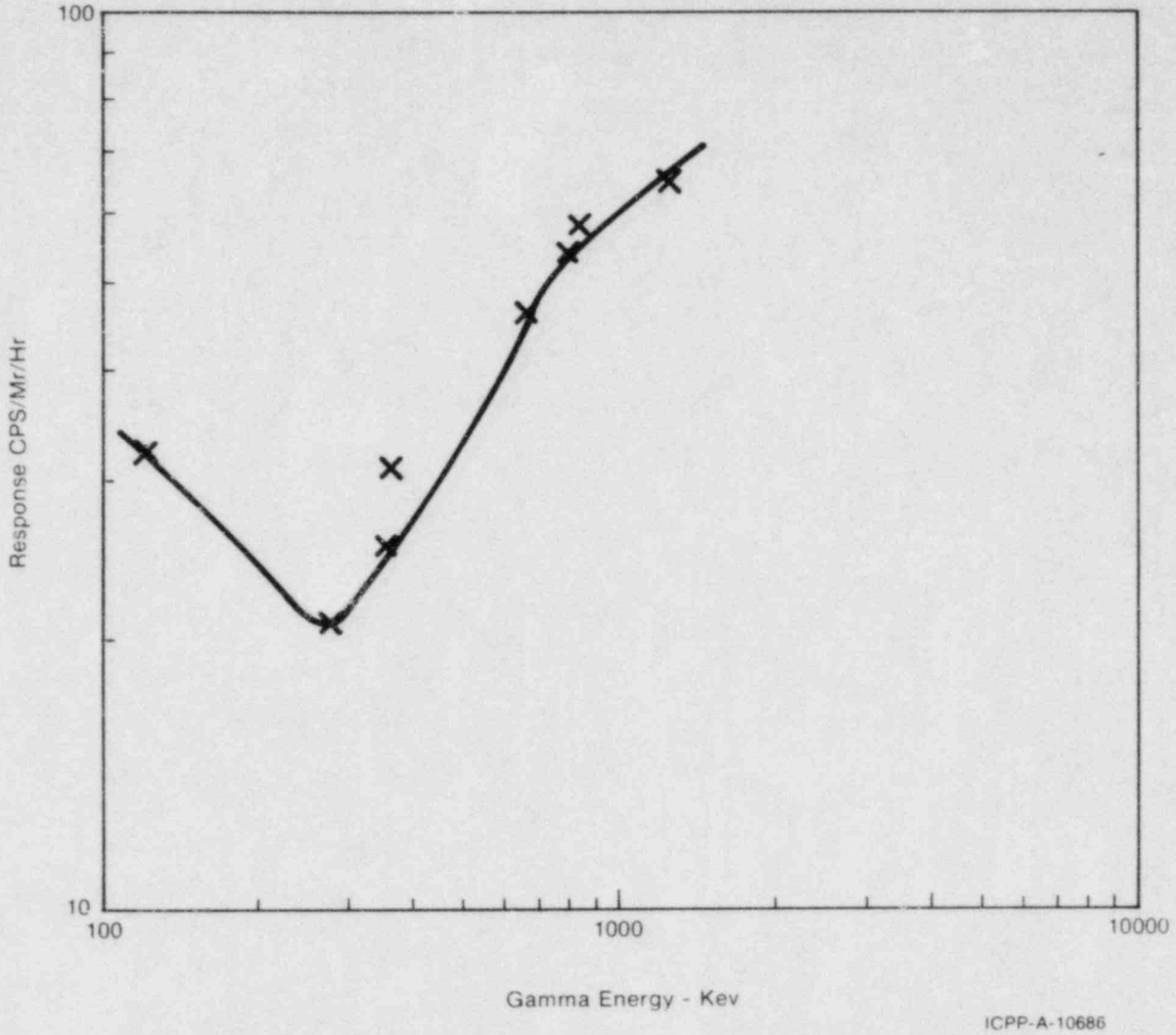


Figure B.5. Detector Energy Response 489-4 Model 390 THYAC III Ratemeter

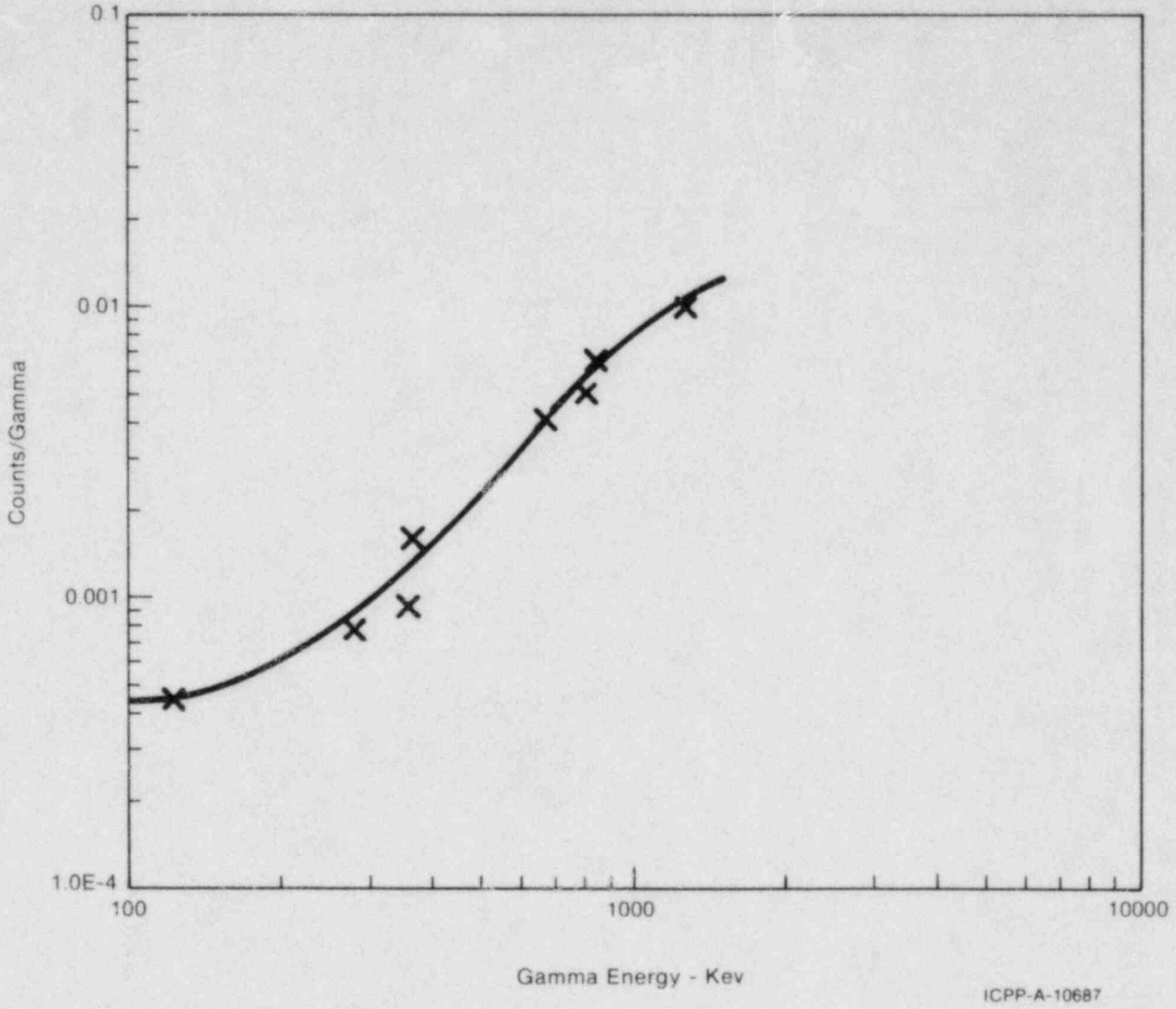


Figure B.6. Detector Energy Response 489-4 Model 390 THYAC III Ratemeter

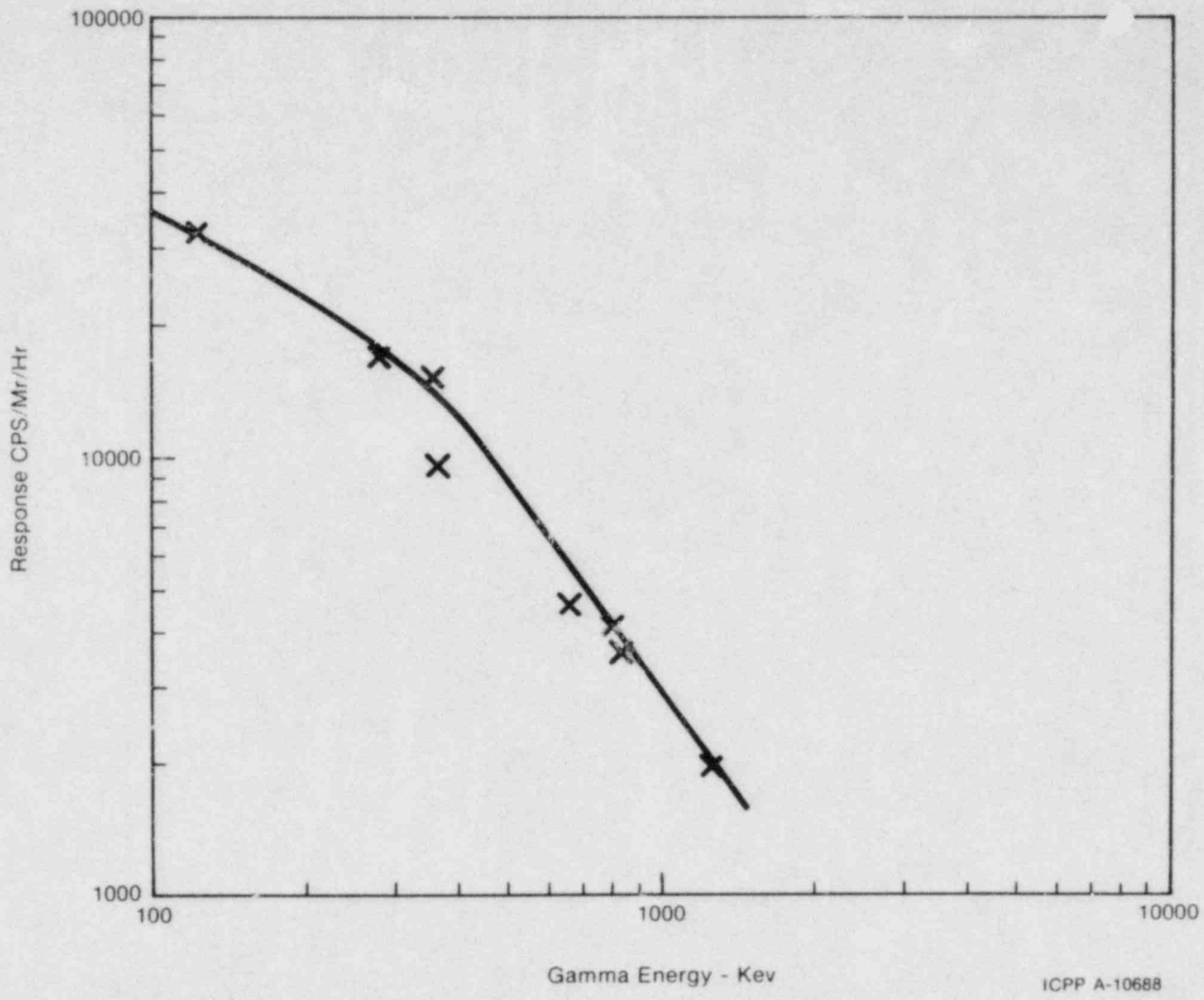


Figure B.7. Detector Energy Response 489-55 NaI(Tl) Model 490 THYAC III Ratemeter

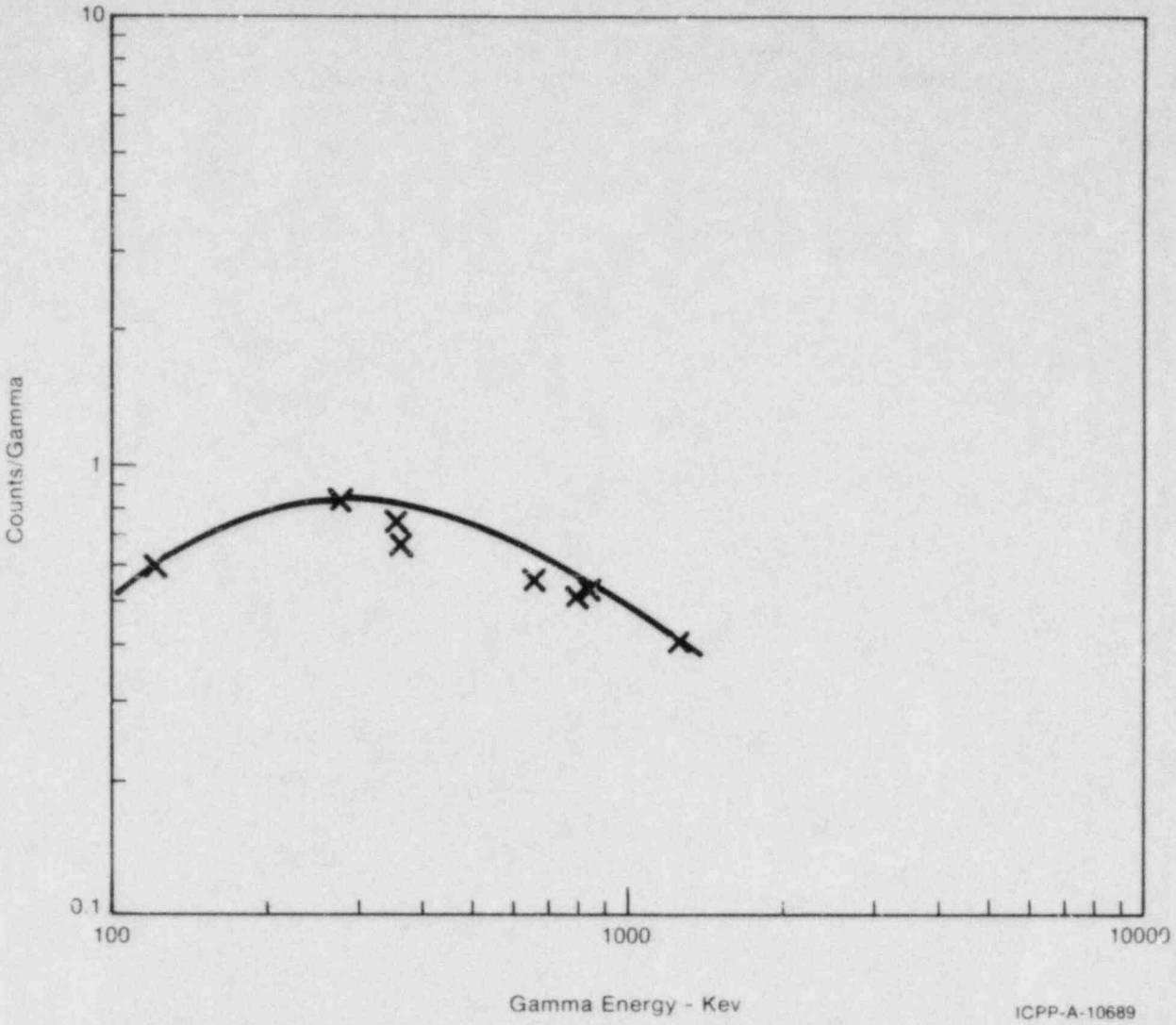


Figure B.8. Detector Energy Response 489-35 NaI(Tl) Model 490 THYAC III Ratemeter

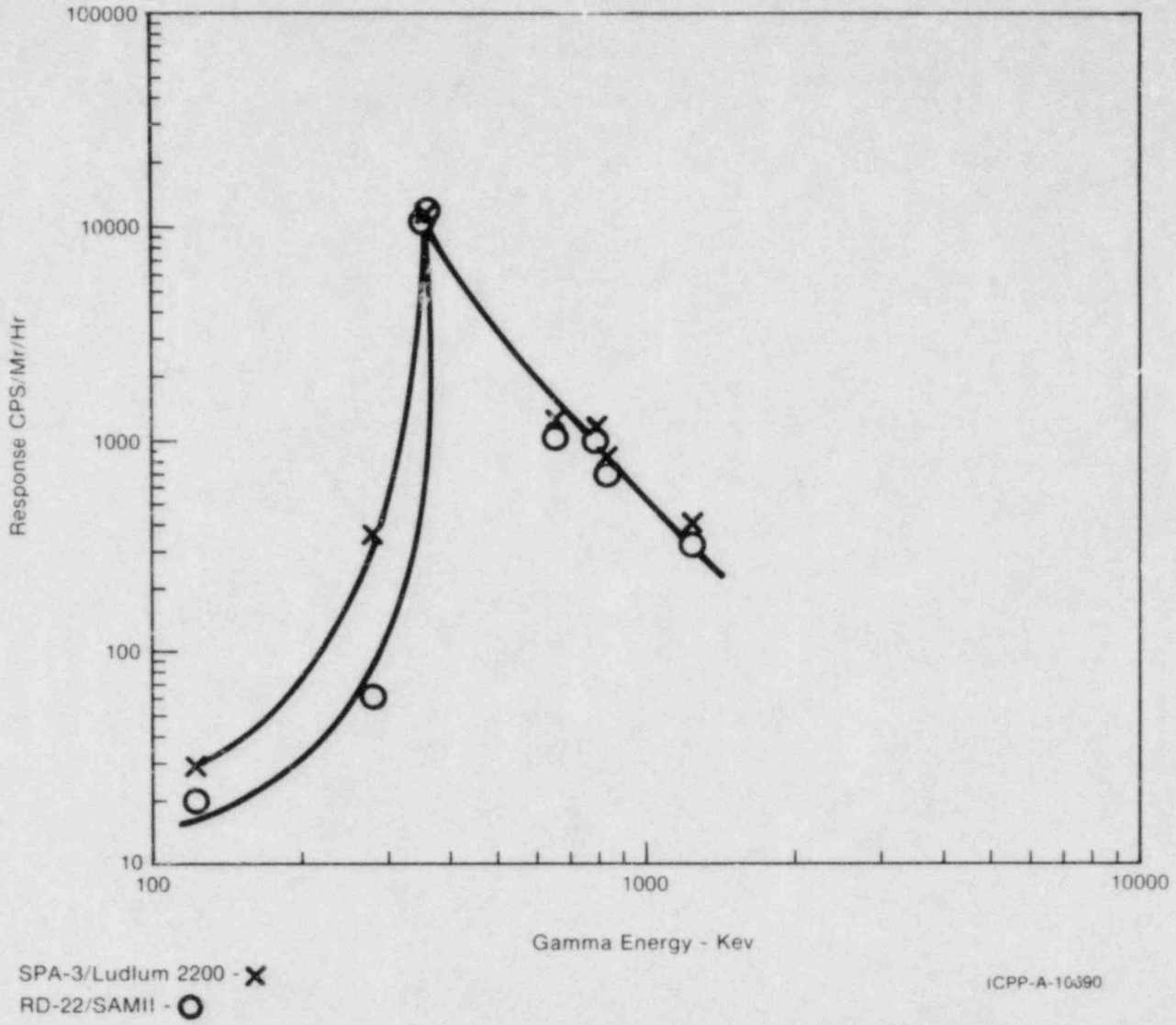


Figure B.9. Detector Energy Response 2"X2" NaI(Tl) Single Channel Analyzer 50 KEV Window Peak @ 364 KEV

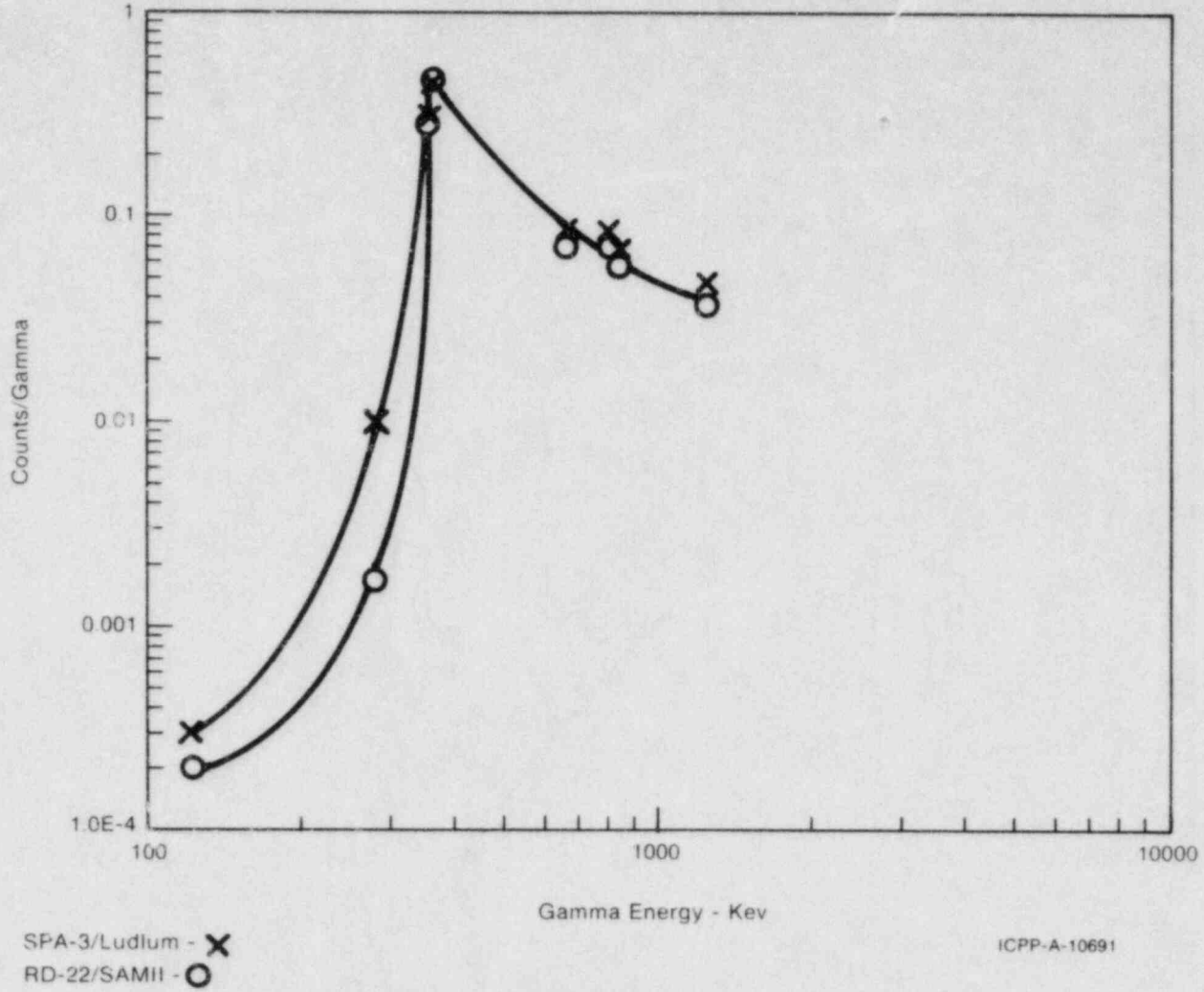


Figure B.10. Detector Energy Response 2"X2" NaI(Tl) Single Channel Analyzer 50 KEV Window Peak @ 364 KEV

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In the event radionuclides are released to the environment following an accident at a commercial nuclear power facility, measurement methods are required to assess the potential radiological hazards to the surrounding populace. Reported are the results of a study to evaluate the relative ability of selected portable radiological instruments to measure: ^{131}I in milk, on barren and grass covered ground, and in human and bovine thyroid phantoms. The study of the three GM and three scintillation, (NAI(Tl), instruments entailed evaluations of their sensitivities, accuracies, energy responses and performance characteristics in simulated environmental conditions of temperature and relative humidity and upon mechanical shock and vibration.

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