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RESULTS OF MODELING AND EXPERIMENTAL MEASUREMENTS FOR THE DESIGN OF A NEUTRON SURFACE MOISTURE MEASUREMENT SENSOR (SMMS)

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Abstract: A neutron moderation-based moisture sensor has been designed and a prototype tested to measure the near-surface moisture concentration of tank waste.

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RESULTS OF MODELING AND EXPERIMENTAL MEASUREMENTS FOR THE DESIGN OF A NEUTRON SURFACE MOISTURE MEASUREMENT SENSOR (SMMS)

1.0 INTRODUCTION

A neutron-moderation-based probe has been designed to measure the moisture concentration near the surface of the underground wastes located in the Hanford Site tank farms. This report discusses the computer modeling and experimental prototype testing that has been performed to determine the baseline probe design of a neutron surface moisture measurement sensor (SMMS). This SMMS is designed to be placed in contact with the waste surface and to obtain information that may be interpreted as the moisture concentration profile in the top 10 to 15 cm of waste. Two documents that provide substantial background and technical bases for this surface moisture measurement effort are *Design Requirements Document (DRD) for the Surface Moisture Measurement System* (Stokes et al. 1995), and *Surface Moisture Measurement of Tank Waste Engineering Work Plan* (Stokes 1995).

The SMMS design work builds upon modeling and experimental development and testing performed for the design and construction of similar probes for application in the tank liquid observation wells (LOW) and probes designed for deployment in a cone penetrometer (Watson et al. 1994) (SAIC 1995). LOWs are pipes, closed on the bottom end, that are installed into the tank waste. The cone penetrometer is a smaller closed pipe that could be temporarily deployed in a tank. The LOW and penetrometer probes are designed to measure full depth moisture concentration profiles of the waste from within the cylindrical geometry of the LOW or penetrometer. Differences in the waste geometry (relative to the probe) between the surface and the LOW or cone penetrometer applications require a unique design for the surface probe to function as desired. The SMMS design geometry has been optimized to obtain measurements in a surface geometry.

The probe functions by emitting high energy neutrons that are moderated or slowed in the surrounding waste, primarily through interactions with hydrogen nuclei (Hearst and Carlson 1994). Thermal and epithermal neutron detectors, located within the probe, detect fractions of the moderated neutrons at rates related to the hydrogen concentration of the surrounding waste. Calibrations and modeling then are used to obtain estimates of the moisture concentration of the underlying waste.

A preliminary surface probe design has been created and a prototype of this design has been constructed to confirm the basic response predictions of the computer modeling. This design consists of a neutron source and three neutron detectors arranged and shielded in a manner that enables each to inspect different maximum depths below the waste surface. The prototype probe was tested using a matrix of simple moisture standards containing both uniform and stratified moisture concentrations. Comparisons of the computer modeling predictions and the experimental prototype measurements confirm that the design should be able to meet the requirements for the SMMS.

2.0 EXPECTED PROBE OPERATING ENVIRONMENT

The highly radioactive waste stored in the Hanford Site tanks usually produces a strong gamma-ray field throughout the tank volume. Measurements with thermoluminescent dosimeters and with passive gamma-ray detectors indicate that gamma-ray exposure rates near the waste surface typically range from about 0.5 to 1.0 grey/h. The maximum gamma-ray exposure rate in any tank with a LOW is estimated to be 3.8 grey/h near the bottom of a tank's waste (Parra and Watson 1994). Few, if any, of the tank gamma ray exposure rates are expected to exceed 2.0 grey/h at the waste surface. The tank gamma production is primarily from ^{137}Cs.

The temperature of the air or waste surface is expected to be below the maximum temperature of the tank contents for the tanks. The highest recent waste temperature reading of any organic or ferrocyanide watch-list tanks is 174 °F (79 °C) (Hanlon 1994). More than 95% of all Hanford Site tanks never reach above this temperature. The tanks of interest for immediate probe deployment have average temperatures of about 90 °F (32 °C).

The waste surface of tanks of interest are expected to be highly caustic. Typical compounds to be encountered could include sodium nitrate, sodium nitrite, sodium hydroxide, and sodium dichromate. These compounds are alkaline oxidizers that potentially could corrode or react with probe materials that contact the waste surface.

3.0 COMPUTER MODELING OF PROBE DESIGN PARAMETERS

To design a surface neutron probe that would meet the requirements of the *Design Requirements Document (DRD) for Surface Moisture Measurement (SMMS)* Stokes et al. (1995), computer modeling of many probe designs was performed.

[Note: For this discussion, a probe is an assembly of neutron detectors, neutron shielding and moderators, a neutron source, and a housing that contains these constituents.]

This modeling was used to predict the responses of the probe detectors to changes in moisture for various probe design configurations. The modeled probe design was changed in an effort to optimize probe sensitivity to changes in moisture concentration and probe ability to provide moisture information, as a function of waste depth, throughout the top 10 to 15 cm of waste.

The Monte Carlo N-Particle (MCNP) mathematical neutron transport modeling code was used to predict the responses of the neutron detectors to changes in device design or to changes in the surrounding conditions, such as moisture concentration (LANL 1993). Quality assurance qualification documentation for the Hanford Site implementation of this code is in existence (Carter 1995). The arrangement and shielding of the neutron source and neutron detectors within a probe housing were modeled for many different configurations. The model predicted detector responses were combined with model results for the depth of investigation to assess the suitability of a given design for meeting measurement needs.

Because the design of this probe builds on work done to develop neutron moisture probes for application in LOWs and cone penetrometers, initial surface probe design modeling began with similar probes. Westinghouse Hanford Company (WHC) drawings of the probes developed for LOW application (WHC 1995a, WHC 1995b), show long, cylindrical probes containing a neutron source on one end and two neutron detectors (one next to the source and one spaced more than 10 in. (25 cm) from the source). The detector placed near the source is referred to as a near-field detector and its response increases with increasing moisture concentration. The detector with the large source-to-detector spacing is a far-field detector and its response decreases with increasing moisture concentration. The near-field detector detects neutrons that, on average, have investigated a smaller volume and reduced depth of surrounding waste than the far-field detector. One of the LOW probes contains two epithermal neutron detectors and the other contains two thermal neutron detectors. The epithermal detectors differ in performance from the thermal detectors in primarily two ways: first, the signal is unaffected by the presence of any thermal neutron absorbers in the waste; and second, a smaller volume or depth of waste is investigated than with a counterpart thermal detector. These facts are known to apply to the geometry found in the LOW or penetrometer, where the waste completely surrounds the probe in a nearly cylindrically symmetric arrangement.

Practical considerations about surface probe size and deployment placed several constraints and design goals upon the geometry of modeled probe designs. The probe should be designed, if possible, to fit down a 4-in. riser. This constraint translates to a maximum outer probe diameter of 3.6 in. (9.1 cm). For ease in positioning the probe on the waste surface, an arrangement in which the probe simply could be lowered by a single cable to the surface is preferred. Modelers did not allow this mechanical preference to constrain the models considered. However, model geometries that would allow the probe to be placed easily and repeatably on the waste surface, so that all detectors would be in the same position relative to the plane of the waste surface, were preferred. For instance, each time the probe is placed upon the surface a given detector should automatically be at the same height above the surface. The required data collection time should be minimized by the probe design. This goal encourages the use of the largest volume detectors as possible to maximize the detector counting rates. Minimizing the data collection time will reduce field operations time and cost. The last major constraint was that the source and all detectors be packaged within a single housing so that all measurements could be made in a single deployment of a single probe through a given riser.

The simplest arrangement to model took the existing models of the two LOW probes and placed them horizontally on a flat waste surface containing given moisture concentrations. The results of this modeling produced some predictable results and some unexpected results. The near-field detector response was strongly correlated to the waste moisture concentration and the detector exhibited a medium depth of investigation (7 to 10 cm) at about 15 weight percent (wt%) moisture. The depth of investigation is defined as the depth from which about 90% of the detector signal returns. The calculation of this depth is based upon the moderation of the neutrons; the depths of neutron scattering locations where more energy are lost weighted more heavily in the calculation. The far-field detector exhibited a larger depth of investigation (10 to 14 cm), but its predicted response was nearly insensitive to changes in waste moisture concentration. While the depths of investigation for these two detectors was desirable, the lack of moisture sensitivity exhibited by the far-field detector was unacceptable.

Variations on the basic LOW design were modeled. Given the same basic cylindrical geometry, the horizontal center-to-center source-to-detector spacing for the far-field detector was varied from 2 to 38 cm (Figure 3-1). As the spacing was increased, the depth of investigation was increased, but the sensitivity to moisture was also decreased. Figure 3-2 shows the model predicted responses to changing moisture of a 4-cm-long detector placed at each of the 10 positions corresponding to the source-to-detector spacings shown in Figure 3-1. The detector responses, while related to moisture content of the waste, are not expected to have linear relationships with moisture concentration. Similar moisture sensitivity was obtained from a far-field epithermal detector model. It was postulated that neutrons streaming along the waste surface may have been contributing enough to the far-field response to reduce the moisture sensitivity. The model was changed to place thick (5 to 20 cm) iron, lead, or polyethylene plugs between the source and the far-field detector. The side of the plug nearest the detector also was lined with cadmium, a thermal neutron absorber, in some cases to shield the detector from neutrons moderated by the plug. None of these changes significantly altered the predicted response of the far-field detector to changes in moisture concentration.

Only the near-field thermal detector and the near-field epithermal detector exhibited both responses and depths of investigation that are desired for the surface measurement. Both exhibited high sensitivity to waste moisture changes. The near-field epithermal detector interrogated a shallower depth into the waste (5 to 7 cm) than the near-field thermal detector (7 to 10 cm). Both of these detectors were found to achieve the best performance when they were located as close as possible to both the source and the surface of the waste. Different arrangements were modeled in an attempt to find a configuration that would allow the probe to interrogate a greater depth while maintaining good sensitivity to moisture.

Because placing detectors further from the source along the waste surface did not give acceptable results, designers created models to investigate the effects either of locating the detector a given distance from the source and waste surface, or of placing both the source and detector above the surface. With the source near the waste surface, the vertical position of the neutron detector was varied in the model from 1.6 to 14.4 cm above the surface in 1.6 cm intervals (see Figure 3-3). The model results, shown in Figure 3-4, indicate that the detector sensitivity to moisture was reduced as the waste-to-detector spacing increased. For these arrangements, the sensitivity to moisture was improved for these arrangements over that predicted for the horizontal source-to-detector spacing, but the depth of investigation did not increase as the detector was spaced further from the source and waste surface. Locating both the source and the detector at varying distances above the waste surface produced even less encouraging results. Both the sensitivity to moisture and the depth of investigation were decreased further in these configurations.

With the source at the waste surface, designers postulated that a detector located a distance above the waste was receiving much the same information that a near-field detector would receive, except that the information was diluted by the extra distance and by neutrons returning from scattering along a greater area of the surface. This idea led modelers to investigate an arrangement that would place the detector a medium distance above the waste surface, but that would shield the detector from neutrons returning from directly below the source. The neutrons returning from directly below the source would be many of the same ones that could contribute to the near-field response and therefore would provide little additional information. A model was devised that placed the source near the waste surface, a thin cadmium disk (OD ≈ 7 cm) above the source, and the detector placed horizontally a few centimeters centered above the cadmium disk. The cadmium disk shields the detector from the thermal neutron flux exiting the waste surface under the disk. Modeling results for the detector in this configuration showed both an improvement in the moisture sensitivity of the detector and an increase in the depth of investigation. The increased depth of investigation was likely because that thermal neutrons reach the probe by travelling a through a large and often deeper volume of waste before reaching the detector. In order to reach the detector, thermal neutrons must exit the waste surface at a relatively large radial distance from the probe so they may reach the detector without encountering the disk-shaped cadmium shield. Figure 3-5 shows a sketch of a path for a typical neutron that is detected by the detector for this arrangement. The spacing of the cadmium above the source and of the detector above the cadmium were varied in the models in order to obtain the deepest interrogation volume while maintaining a strong moisture sensitivity.

Practical information about available neutron detector and source sizes was needed to assemble a single realistic estimate model of the most promising detector arrangements. Boron-10-lined neutron detectors were chosen as the type of detector to use in the surface probe. This choice was made primarily because of the results of tests performed for the design of the cone penetrometer neutron probe (SAIC 1995). These tests showed that this type of neutron detector could function in the widest range of gamma-ray fields and temperature conditions while providing acceptable sensitivity to thermal neutrons. Several ^{10}B lined detector manufacturers recommended using tubes that have an active length at least twice that of the diameter to achieve good charge collection characteristics. A detector that could fit horizontally within a 3.6 in. (9.1 cm) OD housing would need to be less than 3 in. (7.6 cm) long. For an overall detector length of 2.75 in. (7 cm), the maximum active length producible is only about 1.25 in. (3.2 cm). The tube diameter must not exceed about 0.625 in. (1.6 cm) for this geometry. An encapsulated Californium-252 neutron source capable of containing enough ^{252}Cf to meet the needed neutron emission rate is available with a 0.25 in. (0.64 cm) diameter and a length of about 0.5 in. (1.3 cm).

The three types and placements of detectors that seemed to provide the best moisture sensitivity and range of depths of interrogation were assembled into a model of a single probe. Figure 3-6 shows a cross-sectional view of the geometry of the probe model that was constructed. Because the range of source-to-detector spacings possible for a near-field epithermal detector is shorter than that allowed for a near-field thermal detector, the design places the near-field epithermal detector (detector 1) nearest the source. The near-field thermal detector will not fit horizontally in the probe housing bottom in the remaining space without greatly reducing its size or both its size and the size of the near-field epithermal detector. Reducing the size of either or both of these detectors would increase greatly the expected counting times needed to achieve good counting statistics. As a compromise between optimal moisture sensitivity and reasonable data collection times, the detector size was maintained for the near field thermal detector (detector 2) by placing it vertically on the housing bottom as near to the source as possible. The thermal detector (detector 3) above the cadmium disk was changed to a vertical placement so that it could use a larger active region. Model results predicted good sensitivity to moisture for each of the detectors in this arrangement. The depth of investigation predicted for each probe at a moisture concentration of 10 to 15 wt% was as follows: detector 1, 5 to 7 cm; detector 2, 7 to 9 cm; and detector 3, 9 to 11 cm.

Minor refinements to the basic model described above have produced the baseline design for a neutron surface moisture sensor. The results for depth of investigation were considered too similar for detectors 2 and 3. The model was refined by placing an ultra thin cadmium shield (0.005 cm thick) around detector 2 in order to reduce the average depth of investigation for that detector. The shape of the polyethylene around the detector 1 was altered to reduce the fraction of the signal it receives that comes from the source without entering the waste. The cadmium and polyethylene shields around detectors 1 and 2 function to remove some or all of the thermal neutrons from the neutron flux traveling toward the detector and to also moderate the remaining neutrons to increase their probability of being detected. The cadmium absorbs some fraction, depending upon its thickness, of the thermal neutrons passing through it, but allows most epithermal and higher energy neutrons to enter the polyethylene. The polyethylene is thick enough to slow many of the epithermal neutrons down to thermal energy before they reach the detector which increases their interaction probability with the boron in the detector.

Figure 3-6 shows a cross sectional view of the geometry of the model for the current baseline surface neutron probe design. Each of the three detectors is designed to interrogate a slightly different maximum depth of waste below the probe, while exhibiting good sensitivity to changes in the underlying moisture concentration. The range of moisture concentrations of most interest are from 0 to about 30 wt% water. The depth of interrogation for each detector will vary as a function of moisture concentration through this range of moisture. The greater the moisture concentration, the shallower the average depth of investigation will be for each detector. Figure 3-7 shows computer model estimated depths of investigation for each of the three detectors as a function of waste moisture. More moisture increases the interaction probability with hydrogen nuclei in the waste, causing the average neutron path length before thermal or epithermal energies are reached to shorten.

Figure 3-8 shows the predicted response of each detector to changes in waste moisture concentration. Each detector is expected to have a strong signal that is proportional to the moisture concentration in the underlying waste. Detector 3 is predicted to experience the highest count rates, both because it is not wrapped with thermal neutron absorbing material and because it has a larger active region than the other two detectors. Detector 1 is expected to exhibit the lowest counting rates because of the thick thermal neutron absorber, cadmium, completely surrounding the detector.

Figures 3-9, 3-10, and 3-11 show the calculated scattering locations of neutrons that the model predicts will be detected in detector 1, 2, or 3, respectively, for 15 wt% waste moisture concentration. The scale on the left side of each of these figures shows both the depth in the waste and the estimated fraction of the detector signal contribution that comes from a given depth or higher. For instance, in Figure 3-10, 78% of the signal reaching detector 2 is correlated to scattering events that occur above a depth of 5 cm below the waste surface.

For the calculated estimates of signal contributions in Figures 3-9, 3-10, and 3-11, all scattering events are not weighted equally. Scattering events where a larger fraction of the neutron's energy is lost are weighted more heavily in the calculation of depth of signal return. The calculation uses the following weighting scheme to determine the average depth of investigation for each neutron:

$$Depth\_avg_n = \frac{\sum\limits_{\substack{scattering \\ locations_n}} \frac{E_i - E_f}{E_i} * Z}{\sum\limits_{\substack{scattering \\ locations_n}} \frac{E_i - E_f}{E_i}}$$

where n refers to a specific neutron, E_i is the neutron energy before each scattering event, E_f is the neutron energy after each scattering event, and Z is the depth of the neutron scattering location (with Z=0 at waste surface). In these figures, the percent of the depth of investigation (DOI%(Z)) up to a given depth, Z, is given by

$$DOI\%(Z) = \frac{\sum\limits_{Z=\infty}^{Z} Contribute(Z)}{\sum\limits_{Z=\infty}^{-\infty} Contribute(Z)} * 100\%$$

where Contribute(Z) is a function defining the portion of the detector contribution from a given depth. Contribute(Z) is a function that is the sum of the contributions from all neutrons with $Depth\_avg_n$ equal to Z and may be expressed as:

$$Contribute(Z) = \sum_{neutrons} TallyWeight_n(Z)$$

where $TallyWeight_n(Z)$ is the MCNP weight calculated for a given neutron contribution to a detector tally (response). $TallyWeight_n(Z)$ is assigned to $Depth\_avg_n$ for each neutron and is therefore equal to zero unless Z equals $Depth\_avg_n$ for that neutron. The MCNP weight for each neutron which enters a detector is proportional to the probability that it will be absorbed or detected.

The depth of investigation, calculated in this manner, is not the equivalent of the fraction of the infinite media signal that would be received by the detector if the waste were only a given thickness. This is primarily because increasing the thickness of waste not only will increase the signal from scattering events below the original waste thickness, but also will increase the signal contribution from scattering events occurring at shallower depths as the neutron returns to the detector.

4.0 EXPERIMENTAL PROTOTYPE PROBE TESTS AND COMPARISONS WITH MODELING PREDICTIONS

A prototype probe has been assembled and tested using a matrix of simple moisture standards to confirm the basic modeling predictions for the baseline probe design. This prototype probe, used available size and type detectors (BF_3) and a similar neutron source, enabled us to produce a configuration very similar to the detector arrangement modeled in the baseline design. A simple computer model of this prototype configuration was developed to make better comparisons with the experimental data.

4.1 PROTOTYPE GEOMETRY, DETECTORS, AND ELECTRONICS

Figure 4-1 shows a dimensional sketch of the detector configuration used in the experiments. Figure 4-2 is a photograph showing the actual detector configuration used in the tests. The configuration used in the tests is based upon the modeled baseline design. Each detector is a BF_3 gas-filled tube. Detectors 1 and 2 are each 1 in. (2.54 cm) in diameter with a 1.5 in. (3.81 cm) active length and are filled with a gas pressure of 400 torr (53300 Pa) (absolute). Detector 3 is 1.5 in. (3.81 cm) in diameter with a 4 in. (10 cm) active length, the top half being covered with 0.021 in. (0.053 cm) thick cadmium. Detector 1 is positioned horizontally at the bottom of the detector stand and is surrounded with 0.66 cm of polyethylene (CH_2) and 0.112 cm of cadmium. Detector 2 is positioned vertically on the bottom of the detector stand and was surrounded by either 0-, 0.0051-, or 0.013- cm-thick cadmium for the tests. Detector 3 is positioned vertically directly above the center of detector 1 and above a 3-1/8-in. (7.94 cm)-diameter, 0.066-cm-thick cadmium disk. A 10 μgm ^{252}Cf neutron source was used in all of the tests. Care was taken to ensure that each of the detectors remained in the same positions in the test stand during the measurements.

The electronics for the detectors are contained within a single NIM bin and are shown in the photograph in Figure 4-3. Each of the detectors is connected to a Tennelec preamplifier that sends its output signal to a Tennelec amplifier. The pulse-height discriminator for each amplifier was set about three times higher than the electronic noise and about twice as high as the largest gamma-ray pulses from a 1 mCi (3.7×10^7 Bq) ^{137}Cs source placed against each detector. Each of the detectors was biased to +1150 volts through the preamplifiers. The scalar pulse (5 volts high and 0.5 μs wide) from each amplifier was sent to a scalar that records the number of pulses in a fixed time and prints the results to a small printer also located within the NIM bin. During the tests, all detectors were operated and counts were recorded from each of the three detectors simultaneously. Figure 4-4 shows the detector configuration placed on one of the tubs in a typical measurement.

4.2 MOISTURE STANDARD TEST BED MATRIX

The test bed matrix was comprised of 10 nearly cylindrical laundry tubs (galvanized steel, 55 cm diameter, 28 cm high) setup for the tests. Figure 4-5 shows a wide angle view of the entire test bed matrix and the detector configuration with electronics. Figure 4-6 is a photograph of the test bed matrix from another angle. Various moisture concentrations and stratifications using sand/gravel/aluminum oxide trihydrate mixtures are in the tubs. The exact moisture concentration of the standards has some uncertainty associated with the fact that small unknown amounts of either adsorbed or hydrated water could have been present in the constituents. Most tubs rest on a concrete floor except for the tubs filled with thin 14 wt% layers and the tub filled entirely with 14 wt% moisture (see Figure 4-7). Thin cadmium sheets (0.053 cm thick) were placed between the floor and the raised tubs. For the 4 cm thick, 14 wt% water case, the worst case, detector 3 experienced a 5% (+-0.9%) increase in count rate with the cadmium removed. Detector 1 was affected least by the cadmium and experienced a change of 1.5% (±0.4%) in its count rate. Detector 2, covered with 0.013 cm of cadmium, experienced a 3.6% change. The following is a list of the waste simulant in each of the ten tubs with the moisture concentrations indicated by weight.

- 26 wt% moisture throughout entire tub.
- 21 wt% moisture throughout entire tub.
- 14 wt% moisture throughout entire tub.
- 14 wt% moisture in top 3 cm; 21 wt% moisture next 3 cm; 26 wt% in the remainder.
- 14 wt% moisture in top 3 cm; 21 wt% moisture in the remainder.
- 10 wt% moisture in top 3 cm; 14 wt% moisture next 3 cm; 21 wt% moisture in the remainder.
- 21 wt% moisture with boric acid (H_3BO_3) added (2.08 mg/cm^3).
- 14 wt% moisture, 4 cm thick only.
- 14 wt% moisture, 6 cm thick only.
- 14 wt% moisture, 9 cm thick only.

The composition and density of the water/sand mixtures are as follows.

26 wt% - 100% 3/8 inch rock (pea gravel) screened with 1/4 inch wirescreen (called a "1/4-inch hardware cloth") for removing the fine portion of the gravel. Density = 1.92 g/cm^3.

21 wt% - 1 volume of 20 mesh washed silica sand and 1 volume of 60 mesh washed silica sand. Density = 1.86 g/cm^3.

14 wt% - 1 volume of 20 mesh sand, 1 volume of 60 mesh sand, and 2 volumes of screened 3/8 inch pea gravel. Density = 2.12 g/cm^3.

10% wt - 1 volume of $Al_2O_3 \cdot 3H_2O$ fine powder (aluminum oxide trihydrate, by itself the density=1.34 g/cm^3), 1 volume 20 mesh sand and 1 volume 60 mesh sand. Density = 1.59 g/cm^3.

Approximately 30 Hanford Site waste tanks on a critical list for surface moisture inspection were researched to determine the amount of neutron absorbing material within the tanks. Of these tanks, tank S-111 is expected to contain the greatest amount of neutron-absorbing material. The neutron absorption properties of the waste in this tank are dominated by nitrogen and very small amounts of cadmium. Nitrogen is a weak thermal neutron absorber, but large concentrations of this material are present. Boric acid was used in the tub (No. 7) with 21 wt% moisture in an amount that provided the same amount of neutron absorption as in tank S-111. Less than one-tenth of the neutron absorber concentration found in S-111 is expected for about 50% of the tanks, and less than about one-half of the S-111 absorber concentration is expected for 80% of the tanks.

The thermal neutron attenuation through the pea gravel was checked against that for the sand to determine if the gravel contained any significant quantities of neutron absorbing materials. Equal thicknesses (about 7.1 g/cm^2 or 5 cm) of the pea gravel and sand were used and polyethylene was placed around the neutron source to moderate the neutrons emitted from the 10 μgm ^{252}Cf source. The attenuation of the neutrons through the pea gravel was 4.2% less than for that through the sand. The amount of neutron absorbing material in the pea gravel is negligible and, therefore, would not affect the results of these tests.

4.3 PROTOTYPE EXPERIMENTAL MEASUREMENTS

For each measurement using a tub, the detector was placed in four different locations near the center of the tub to help check and average out any potential systematic effects caused by variations in the moisture concentration directly below the detector configuration. At each location on the tub, three or four 50-second-long measurements were made simultaneously using each of the three detectors. The variation in the total counts in a fixed location should relate primarily to statistical phenomena, but by making four independent measurements, we could check for any possible systematic affects associated with the detectors or electronics (for example, gain shift problems). The average systematic error in the count rates determined from measurements over the four different locations was 1.2% (one standard deviation), and the average statistical error in the count rates is about 0.6% (one standard deviation). Therefore, the combined average total error was approximately 1.4%.

The 21 wt% moisture tub (No. 2) was tested with and without a cadmium sheet placed between the tub and the concrete floor to determine the influence of the concrete on the readings. There was no statistical difference in the measured count rates with and without the cadmium sheet in place. For initial measurements, each of the tubs containing 14 wt% moisture (full and thin layers) was raised 38 cm off the concrete floor, using concrete blocks at the tub edges, and a thin cadmium sheet (0.053 cm) placed below the tub to absorb any neutrons thermalized in the concrete and returning to the detectors. This initial arrangement produced measurements in the thin-layer tubs that were in poor agreement with computer model predictions of the detector responses. The thin layer tub experimental measurements produced greatly enhanced detector responses compared with expected results. The tubs were later moved to a location that was about 110 cm above the concrete floor, supported by a thin aluminum plate, and far from any other materials such as adjacent tubs or walls. All tests using the 14 wt% moisture tubs were repeated with the tubs in this configuration and the measured detector responses were significantly reduced, giving better agreement with modeled predictions.

The detector support structure is constructed of aluminum, but the final deployable probe will be fabricated from stainless steel. Therefore, the affect of the stainless steel on the detector count rates was determined by counting alternately with a 1/4 inch (0.64 cm) thick stainless steel plate placed under the detector stand, and then with an aluminum plate of the same thickness. The steel plate did show some absorption, a reduction in the count rate of about 17%. The steel construction of the actual surface probe will reduce the detector count rates, requiring longer measurement time intervals. However, this will not affect the general responses demonstrated with these tests, which were meant to serve as a test bed for the calculations. Furthermore, the final configuration will be calibrated using controlled moisture test standards.

Measurements were made in each tub with all three detectors counting and with a 0-, 0.0051-, and 0.013-cm thick cadmium sheet placed around detector 2. The amount of background events caused from neutrons entering the detectors directly from the source or scattered from the material within the detector configuration was checked occasionally by counting with the detector configuration located away from the floor and tubs and with the neutron source placed in the probe. These background counts (which can be 10% or more of the counts caused by neutrons thermalized in the waste) were subtracted from the simulant-measurement counts for each and every measurement, as they are not simulant-related neutrons.

The influence on the count rate in each of the three detectors by a small 1 cm deep cavity in the sand mixture was tested by measuring the count rates at several positions over and near the cavity. The cavity was in the form of a long V-shaped trench with a 90-degree angle between the sides at the bottom of the trench. All count rates measured with the small cavity near the detector configuration were within 1.1 standard deviations of the count rates with no cavity nearby. This demonstrates that small cavities of this size have a negligible influence on the response for any of the three detectors.

4.4 TEST RESULTS

The results of the counts measured (and corrected for direct-source-neutron background) in each counter in 50 seconds in the different thicknesses of 14% moisture layers are displayed in Figure 4-8. For these measurements, detector 2 was surrounded by 0.013 cm of cadmium. The counts for each detector are normalized to those measured with the same detector on the tub filled entirely with a 14 wt% moisture mixture (28 cm). The plot indicates that there is a significant difference in the depth inspected by each of the detectors. For example, 60% of the signal occurs at depths of 4.5 cm, 7 cm and 10 cm for detectors 1, 2 and 3, respectively. For detector 1, 84% of the signal is from 9.0 cm; and for detector 2, 70% of the signal is from interactions 9.0 cm within the waste; and for detector 3, the corresponding value is 55%. To get a better estimate of the normalized count rates above the 9 cm mark, a fit (such as to 1-exp[-ax] where x is the layer thickness) to the curve could be performed.

Figures 4-9, 4-10, and 4-11 are plots of the results corrected for background with 0-, 0.0051-, and 0.013-cm thick cadmium surrounding detector 2. A particular detector is represented by a particular symbol (e.g., detector 1 is represented by an open square). Data points which are connected are for measurements in tubs filled entirely with one moisture concentration. Data points which are not connected are for measurements made in the tubs with various moisture layers. Data points from stratified measurements are plotted so that the bottom layer, which is the bulk of the tub, is represented on the moisture axis.

The measured response of each detector increases significantly as a function of the moisture concentration for the moisture range tested. In general, the largest change and, therefore, greatest sensitivity occurs in going from 14 to 21 wt%. This is important because the critical moisture concentration is 20 wt% according to the safety screening requirements (Meacham et al. 1995). Detector 2, with no cadmium surrounding it, has the same response for the higher concentrations (i.e., above 21%) as does detector 1, so no new information is really gained (except that the depth profiles may be different). As the cadmium thickness is increased on detector 2, the count rates in the other detectors change slightly, probably because of a shielding effect caused by the cadmium on detector 2. The plots also indicate that thin, dry layers (3 cm thick) on the 21 wt% or 26 wt% moisture mixture significantly influence the detector responses.

Ratios of count rates between the detectors (1 to 2, 1 to 3, and 2 to 3) were calculated to determine how closely the detector responses followed each other as a function of moisture and for the stratified tests. In almost all cases including those with different cadmium thicknesses, the ratio of counts in detector 2 to detector 3 were flat, that is, independent of moisture concentration and any variation in the moisture profile. Count rate ratios for detectors 1 to 2 and detectors 1 to 3 showed the largest change in going from 14 to 21 wt%, the most important moisture concentration range, even for the cases where the 21 wt% had thin, dry layers on top of the bulk moisture concentration. Furthermore, these ratios (1:2 and 1:3) did vary with the different dry layers placed on top of the main medium. This indicates that the count rate in combination with the ratios of count rates could be used to determine, to some extent, the moisture profile just below the surface.

As a simplified example of how the readings could be interpreted, suppose the number of counts in all three detectors are measured in one location on the waste surface. The time of each measurement is 50 seconds and Detector 2 is surrounded by 0.013 cm of cadmium. If, on the average, detector 1 counted about 27,000 events, then according to Figure 4-11, we then know that the very top of the waste is 14 wt%. Using only this count rate value, it would not be known if the top of the waste is entirely 14 wt% or if it is 14 wt% (3 cm) and the remainder 21 wt% or if it is 14 wt% (3 cm), 21 wt% (3 cm), and the remainder 26 wt%. If the ratio of 1:2 is 4.3, this would mean that the depth profile may be similar to 14 wt% (3 cm)/21 wt% (3 cm)/26 wt% (remainder) because for only 14 wt% (entire) the ratio of 1:2 is about 4.9 (significantly higher) and only 4.0 for a 14 wt% (3 cm)/21 wt% (remainder) profile.

The results of the measurements with the 21 wt% tub with boric acid are shown in Figures 4-12, 4-13, and 4-14 for detector 2 with 0-, 0.0051-, and 0.013-cm of cadmium covering the detector. Included in these plots are the responses for the clean tubs (i.e., no boron in the mixture) filled entirely with only one moisture concentration. In all of these cases, detector 1 proved to be the least influenced by the amount of contamination in the water/sand mixture. Detector 2 became less sensitive to the effects from neutron absorbers as the cadmium thickness was increased. This happens because the cadmium absorbs thermal neutrons which are affected by the neutron absorbers in the waste much more than the epithermal neutrons. With 0.013 cm of cadmium on detector 2, there is almost no change in its count rate as compared to a clean tub. The amount of neutron absorbers can be determined in the following way, if 0.013 cm of cadmium is used on detector 2. Because it is reasonable to expect that layers of waste closest to the surface are the driest, then if, for example, detectors 1 and 2 show a moisture reading of 21 wt%, but detector 3 reads low for that concentration, there are neutron absorbers within the waste. To study how well the probe can determine the amount of neutron absorbing material within the waste, further testing with more tubs and/or additional calculations would need to be performed.

4.5 COMPARISONS OF EXPERIMENTAL AND MODELED PROTOTYPE RESULTS

A simple MCNP model of the prototype probe was made in order to demonstrate a reasonable level of agreement between the model predicted and experimentally measured results. The relative agreement obtained between these are not indicative of the best agreement possible between model and experiment. It is expected that, during model comparisons with calibration measurements, refinements in the exact geometry and materials in the computer model will lead to more precise agreement.

Figure 4-15 shows a comparison of the measured and modeled detector responses to the homogeneous moisture content standards. The overall magnitude of the predicted count rates for each detector have been scaled by a single constant factor, after subtracting background, so that the average count rate for the modeled results is equal to that of the experimentally measured results. While the absolute values of the results do not match precisely, the general trends between the modeled and measured responses are in agreement. Both the modeled and measured results show strong, nearly linear, correlations between each detector response and the moisture content of the simulant.

Figure 4-16 shows a comparison of the measured and predicted responses of each detector to simulant of varying thickness. The responses in the figure are normalized to the appropriate infinite media response, either predicted or measured, for each detector. The model predicted results are in agreement with the measured results. Some systematic uncertainties in the model and/or the experiments may cancel in these comparisons of response ratios, giving particularly good agreement.

Figure 4-17 shows comparisons of the measured and computer modeled responses of the prototype detectors to four special tests standards, three with multiple moisture layers and the one containing added boron. The model predicted detector responses have been adjusted using the same constant factors used to obtain the agreement with measured values used in Figure 4-15. Using these same constants, nearly all of the model-predicted results are in excellent agreement with measured results. The predictions for detectors 2 and 3 for the boron-loaded tub seem to exhibit a small systematic offset from the measured data. For this standard, model estimates of responses for both of these detectors are noticeably lower than were observed. Detectors 2 and 3 have either a thin cadmium thermal neutron shield or no shield, making their responses more susceptible to changes in the thermal neutron absorption properties of the test bed matrix. Since these absorption properties were changed in a known way, the model should be able to predict the proper change in detector responses. This apparent discrepancy may indicate that the uniformity of the distribution of the added boron may be uncertain. More tests will be needed to determine how these differences may be reconciled. These tests could include multiple boron concentration standards and should use standard where the uniformity of the boron distribution is better controlled.

4.6 PLANNED INTERPRETATION METHOD FOR IN-TANK DATA

Data quality will be assessed in field measurements with the aid of calibration check standards and by collecting analog signals from the detectors that can be both qualitatively and quantitatively checked for consistency with expected signals. Both before and after the probe is deployed in a tank, the detector count rates will be measured with the probe placed in a check standard. These measurements will verify that the probe is producing the same responses to a standard surrounding material as were measured during the calibration.

Detector signals will be transmitted to the data acquisition system in analog form. The spectra from each detector will be displayed by a multichannel analyzer (MCA). These signals will serve three purposes that are related to the verification of data quality. The spectrum of responses from each detector will provide information that qualitatively allows one to assess the operating performance of each detector and its associated signal processing electronics. A spectrum, characteristic of the detector, will be expected. A lower level electrical discriminator must be used to delete electrical noise and gamma-ray induced signals from the neutron capture signal in each detector. The spectrum will be used to set the lower level electrical discriminator. The spectrum will enable an operator to set the discriminator repeatably with respect to a feature, such as a peak, in the spectrum. One will be able to verify that significant interfering electrical signals have been excluded from the counts used for tank property analyses. The analog spectrum provides the raw data that could enable corrections to be made to measurement results if, for example, the electrical gain were to shift during a series of measurements.

Waste properties, primarily surface moisture, will be determined from the neutron count rate above a certain threshold energy (on the MCA), along with detector temperature data provided by probe thermistors. Interpretations of measured data will most likely be performed with the aid of an automated computer interpretation routine, TMAD (Finfrock 1995). This routine will compare measured data from each of the detectors with benchmark (theoretical) responses produced using a calibrated computer model. Eventually, benchmark responses may be available for different:

- moisture concentrations,
- moisture gradients as a function depth in the waste,
- thermal neutron absorber concentrations,
- waste bulk densities,
- probe-to-surface offset distances,
- and other waste/probe parameters.

However, testing will be initiated with benchmark libraries for moisture concentrations and gradient, only. The TMAD code will only consider moisture concentration and one other material parameter at a time, but different benchmark libraries that assume different absorber concentrations, for example, can be created.

The TMAD routine uses second order curve fits to the modeled data to produce solution curves, but, because two variables are assumed (moisture concentration and gradient), a simple equation relating count rate to moisture is not possible. Curves will be in families of count rates for each detector versus moisture concentration for different moisture gradients. In principle, there could be separate families of curves for each different neutron absorber concentration or for each value of waste bulk density, for example. Measurements are then compared with these solution curves to locate the best (lowest error) solution. For a set of measured count rates from the SMMS, the TMAD routine will determine the best-fit values of surface moisture and gradient. Alternately, the best-fit values of surface moisture and bulk density, or any of other variables.

Either assumptions must be made concerning some of these waste parameters or additional information will be needed to determine which of the possible moisture values are appropriate. Information could come from sources such as tank history databases, prior sampling, or video evidence. For initial testing and data interpretation, three primary assumptions are planned; (1) the moisture concentration does not decrease with depth in the investigated waste volume, (2) the investigated waste volume does not contain significant amounts of thermal neutron absorbers, (3) the waste bulk density is a given constant ($\approx$1.5 g/cm^3). The moisture concentration is not expected to decrease with depth in salt cake wastes. Strong thermal neutron absorbers, like cadmium, known to be in the tanks are not expected to be found in salt cake wastes. Under these assumptions, fewer benchmark computer models will need to be run to initiate testing and evaluation of the instrumentation. Each pair of detector count rates will be used to determine a moisture and gradient. Because TMAD employs second order curve fits, between zero and four solutions points may be obtained for each pair. These potential solution points will be grouped into clusters with each cluster representing one possible solution derived from the three count rates. If the solution points in a cluster are essentially equal, as determined statistically, the moisture and gradient will be known. A more detailed description of the way that the TMAD code operates may be found in the *System Design Description for the TMAD Code* (Finfrock, 1995). Otherwise, additional benchmarks will need to be generated to correctly interpret the results.

5.0 CONCLUSIONS AND CONTINUING WORK

Based on the modeling calculations and waste tank safety data needs, a detector configuration for determining the surface moisture in underground waste tanks at the Hanford Site was designed; and a lab prototype was built and tested. A test bed matrix was built of wash tubs and water/sand/gravel/ aluminum oxide trihydrate mixtures to simulate both different uniform moisture concentrations and surface moisture gradients. Both the test results and the modeling predictions, performed to date, confirm that the baseline surface moisture probe design is capable of meeting the sensor design criteria. The design provides for three distinct moisture signals that will exhibit good sensitivity to surface moisture concentration. Tests confirm that each detector will investigate a different maximum depth of waste, all in a range from about 5 to 16 cm below the waste surface, depending upon waste moisture concentration. Results suggest that data obtained from all three detectors will provide information that will lead to an interpretation of the surface waste moisture concentration and an estimate of the moisture concentration gradient as a function of depth within the top 10 to 15 cm of waste.

Given the favorable results of modeling and tests, work will continue with a first field unit probe, based upon the baseline modeled design, being fabricated and assembled. This probe will need to undergo similar experimental tests that can be compared with very precise computer model results of the test configurations. It is expected that agreement (agreement better than 5%) can be obtained between predicted and absolute measured detector count rates. Once this level of agreement is obtained between modeled and measured results, calculations can be used to generate a database of detector responses to different moisture concentrations and other physical situations for the purpose of interpreting the in situ measurements. Interpretations will include estimates of moisture concentration and moisture gradient as a function of depth in the waste at each location where a measurement is made. Work is being completed on an computer routine for comparing such a model-produced calibration database with measured data to obtain best estimate interpretations. The detectors used in the probe will need to undergo simple radiation exposure tests and environment chamber tests to determine the amount, if any, that their responses are affected by gamma radiation or changes in temperature. Results of these tests will be used to make any needed corrections in the measured results before they are compared with the calibration benchmark libraries.

6.0 FIGURES

Figure 3-1. Sketch of the Horizontal Surface Probe Geometry Modeled During Development of Design.

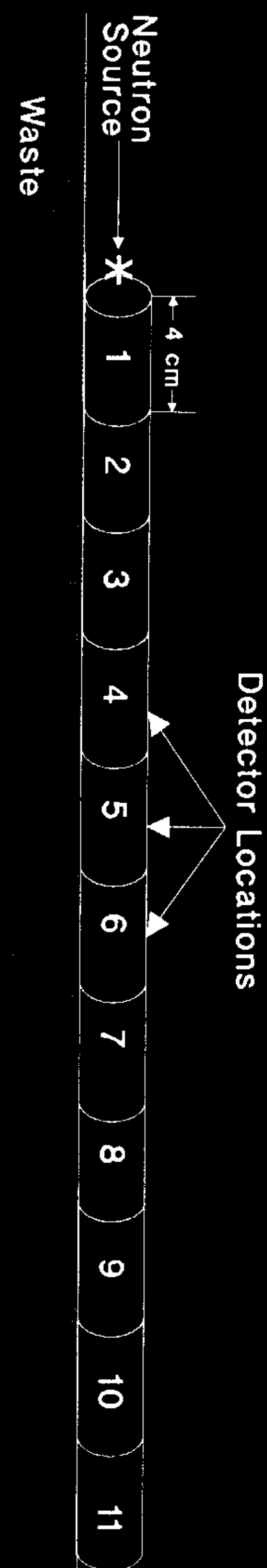


Figure 3-2. Predicted Responses of the Horizontal Placed Surface Neutron Detectors Shown in Figure 3-1 to Changes in Moisture.

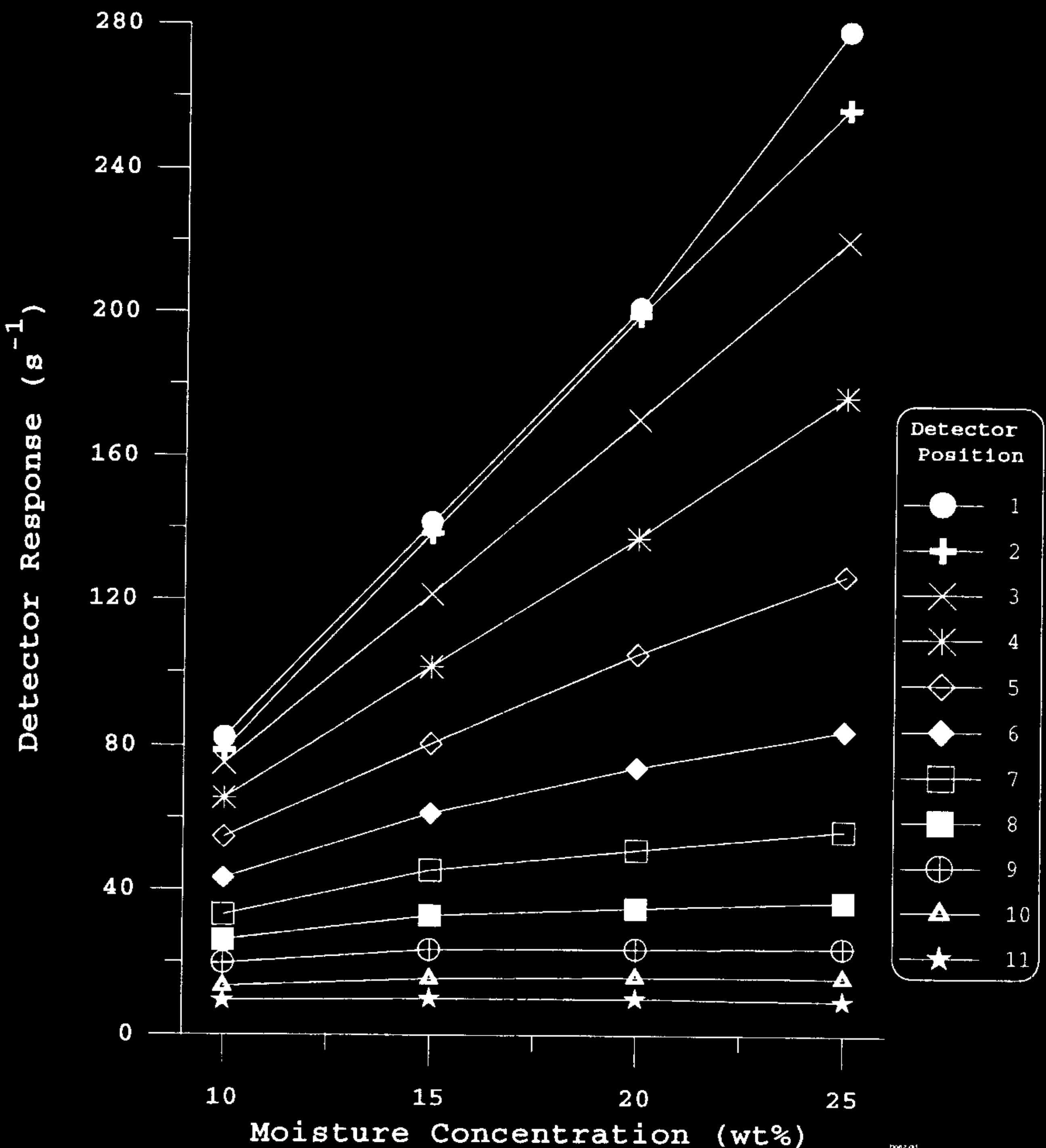


Figure 3-3. Sketch of the Vertical Surface Probe Modeled During Design Development.

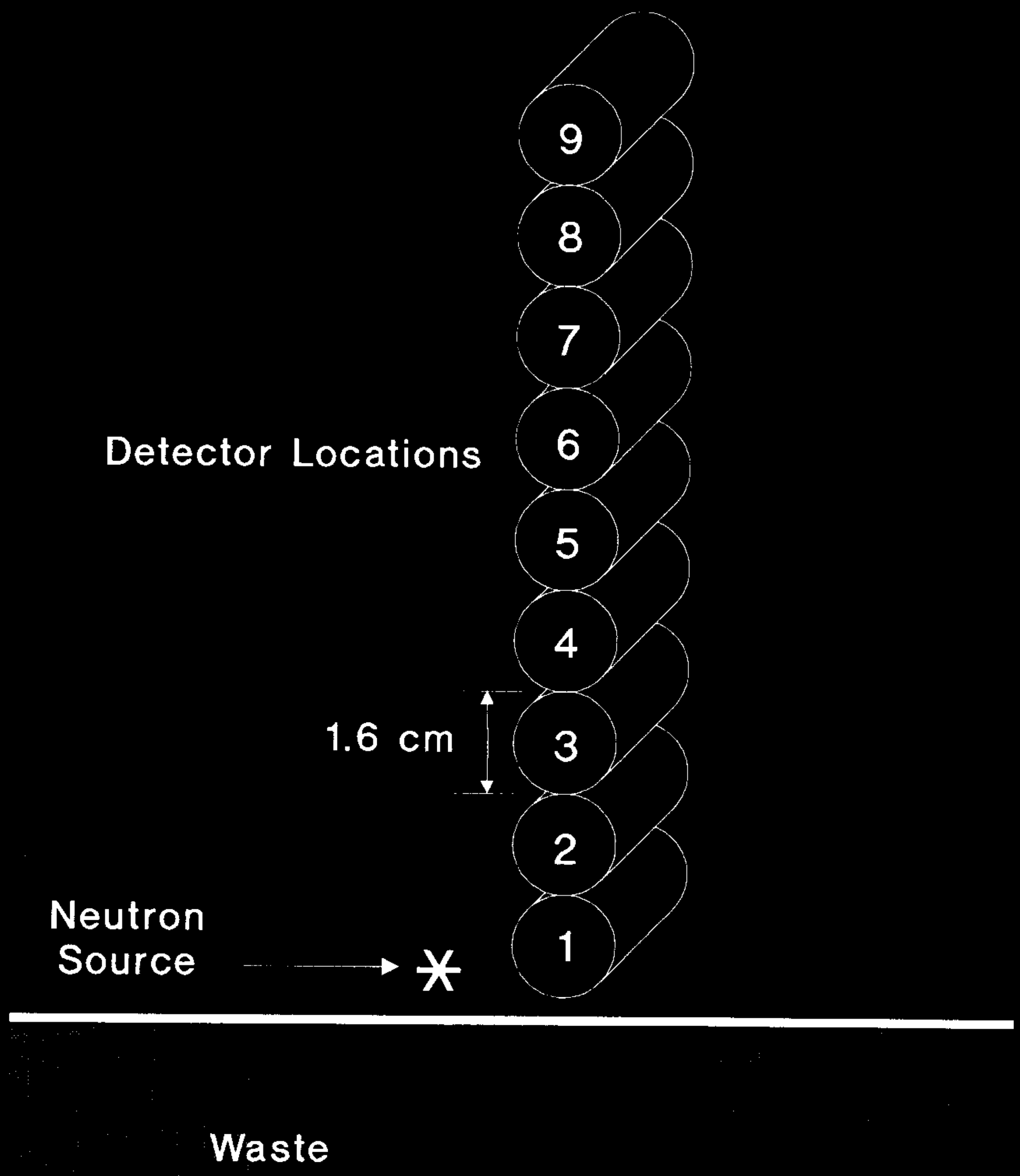


Figure 3-4. Predicted Responses of Vertical Geometry Surface Neutron Detectors Shown in Figure 3-3 to Changes in Moisture.

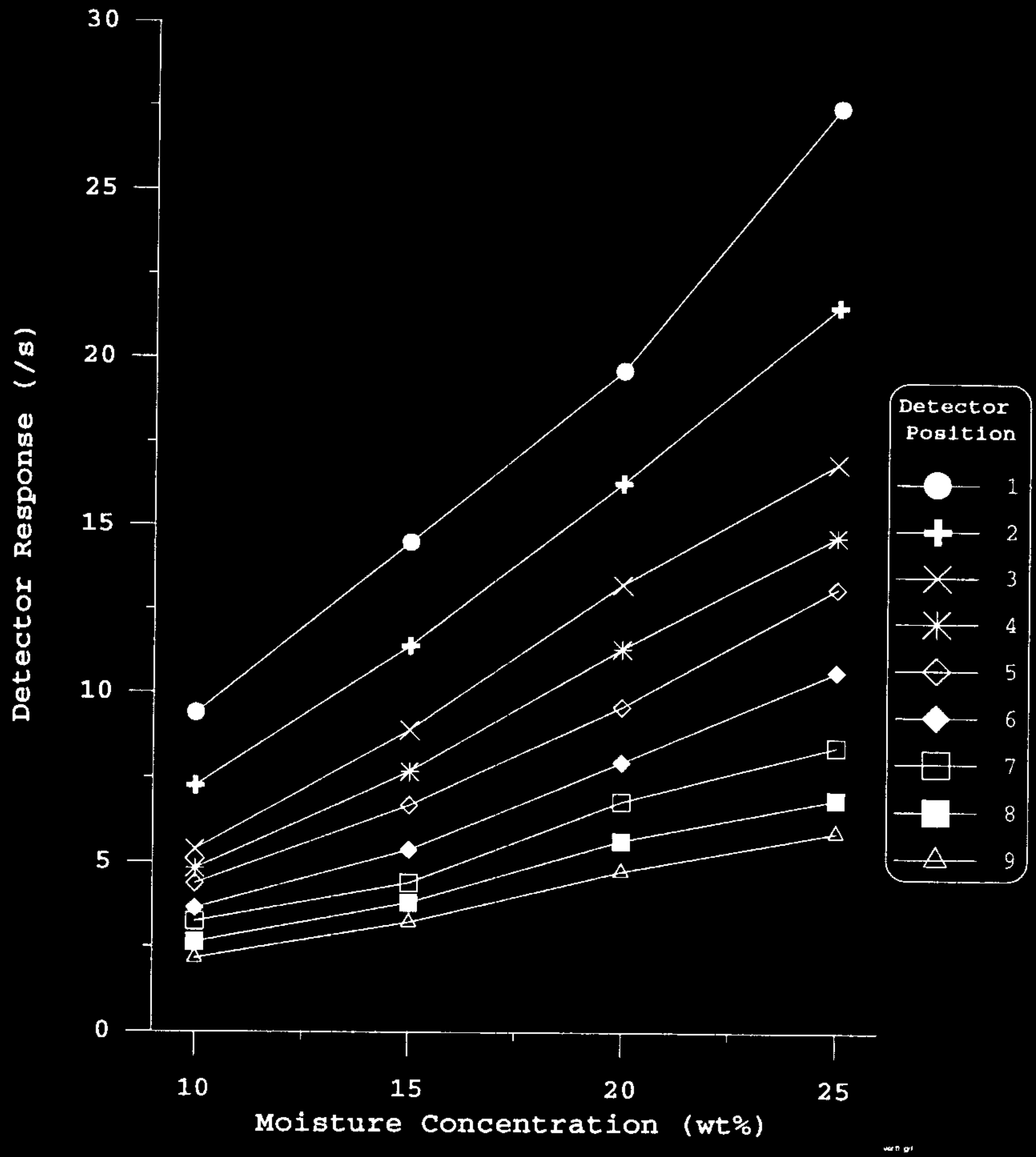


Figure 3-5. Sketch Showing a Typical Path that Might be Followed by a Neutron that is Eventually Thermalized and then Detected.

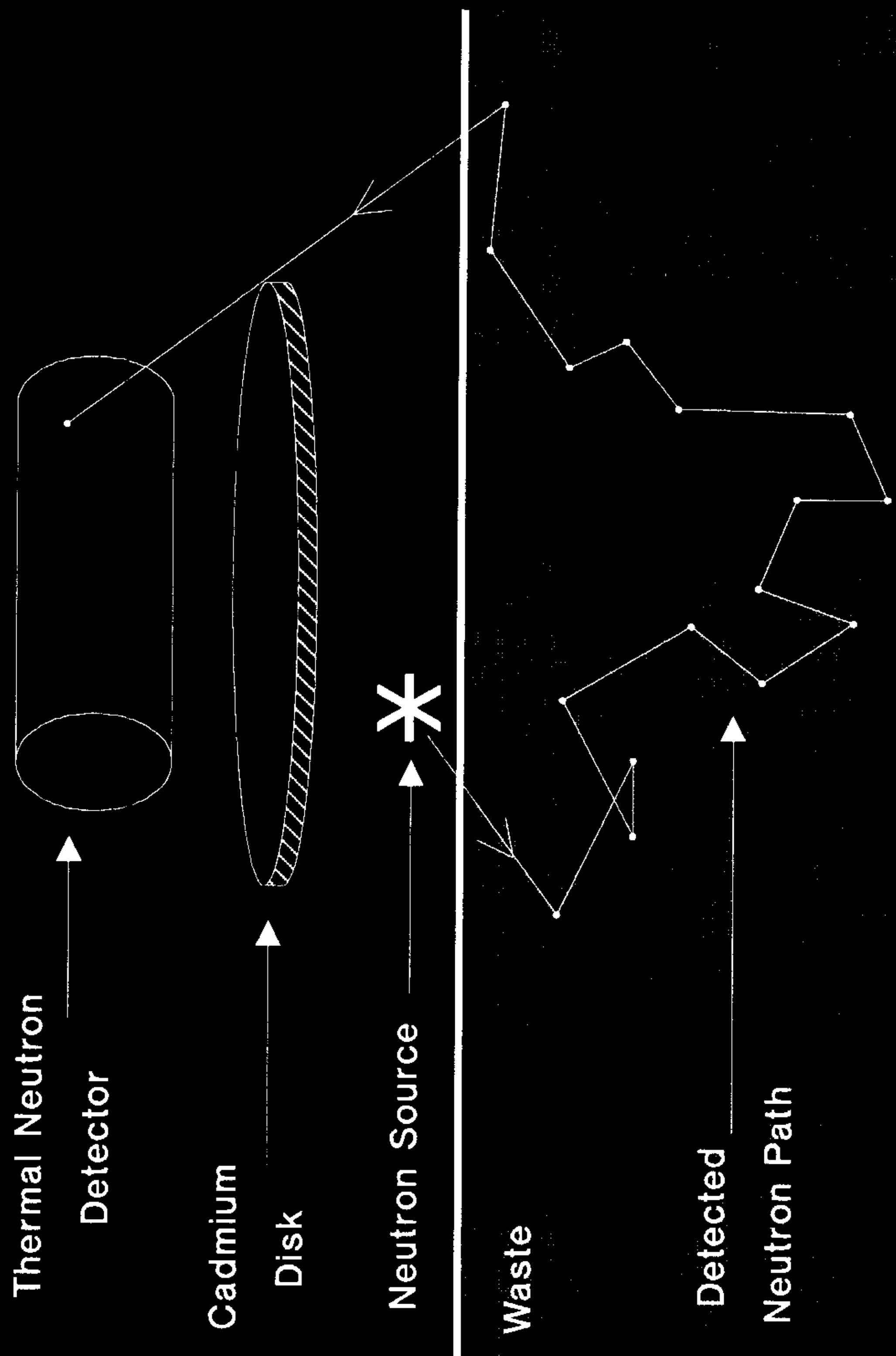


Figure 3-6. Sketch of the Geometry Used in the Computer Modeled Baseline Surface Probe Design.

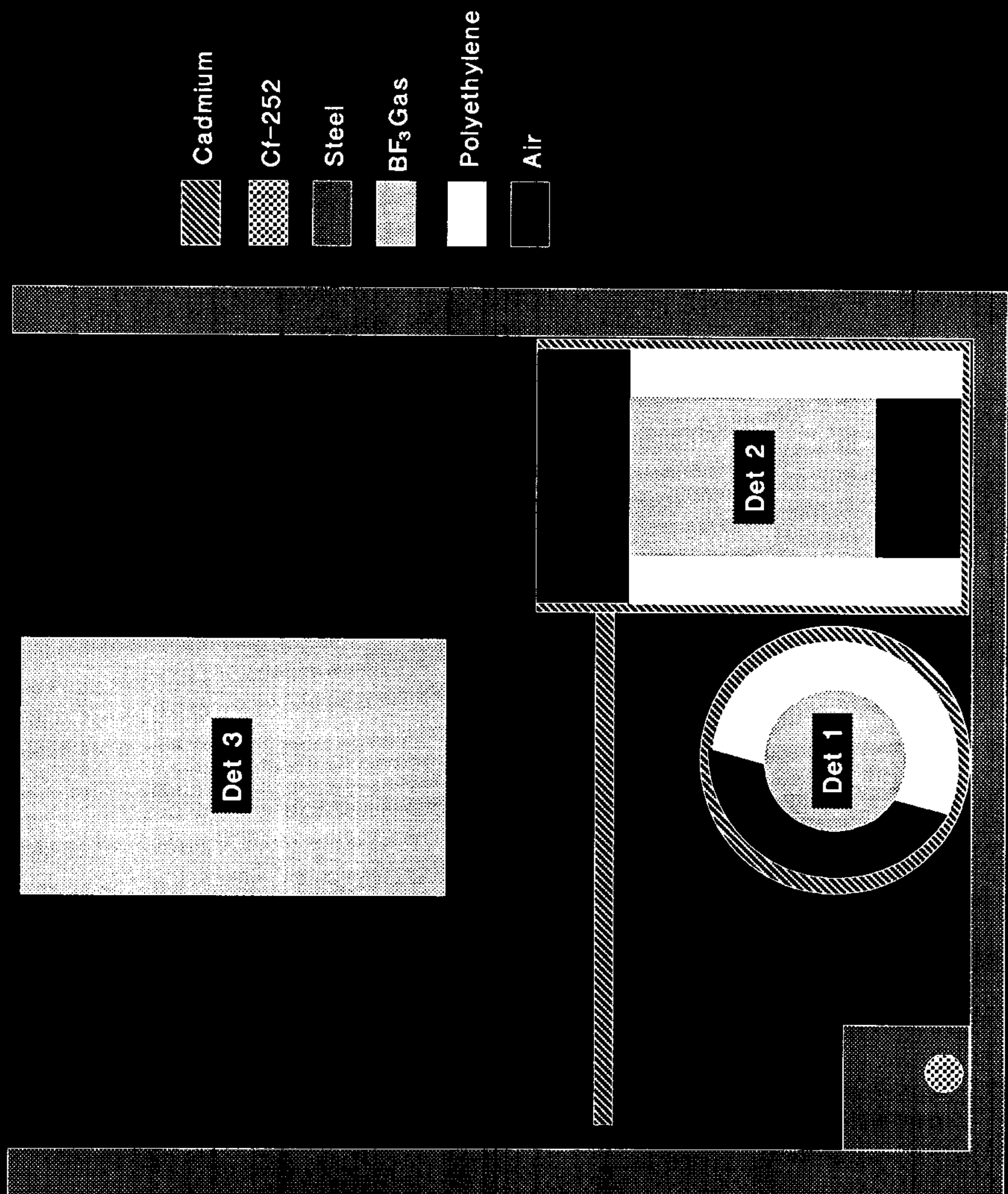


Figure 3-7. Predicted Depth of Investigation for Each Detector as a Function of Uniform Waste Moisture Concentration. (Investigation Depth is Depth Above Which 90% of Total Detector Signal Returns)

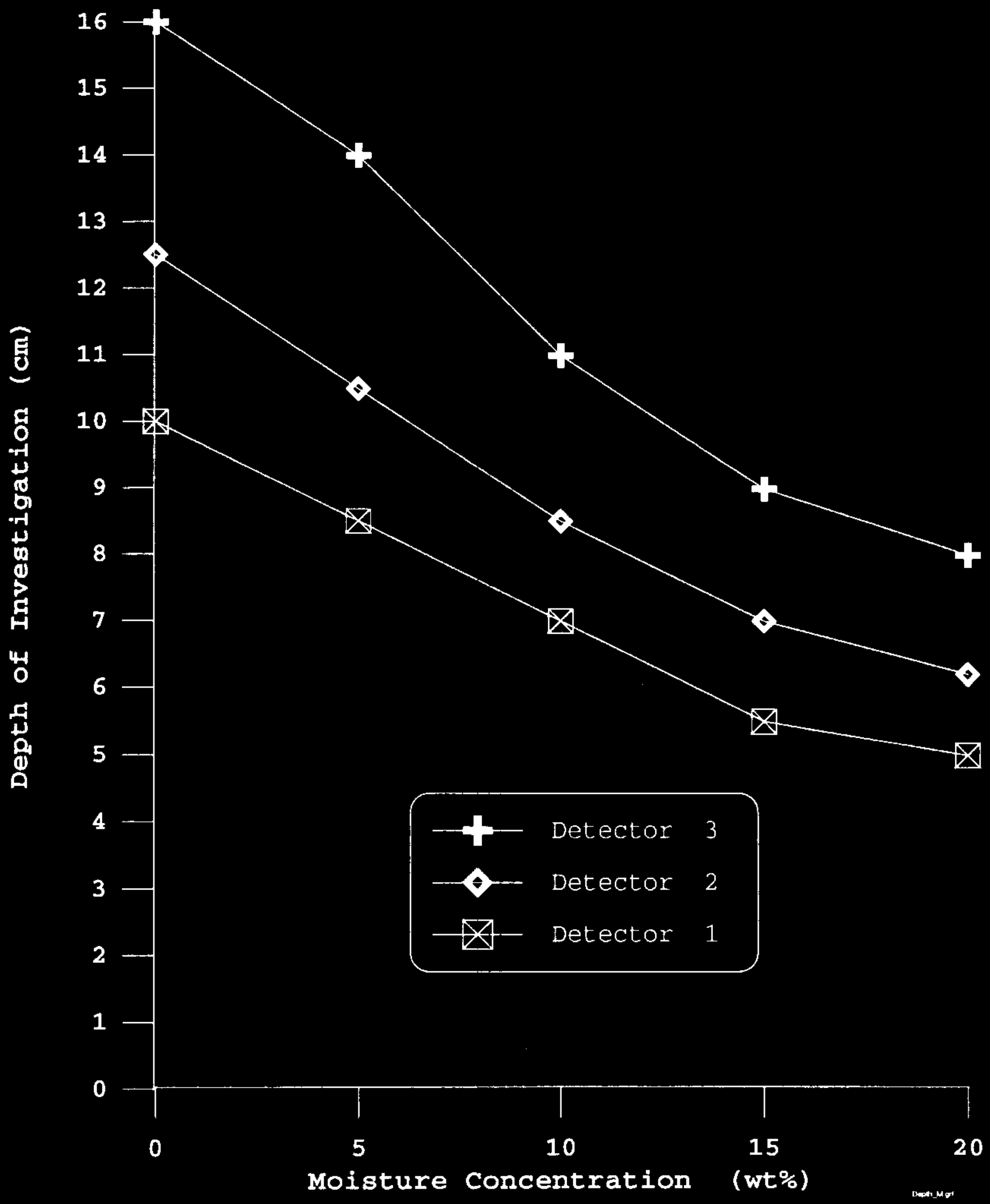


Figure 3-8. MCNP Predicted Detector Responses to Surface Moisture Content for Baseline Probe Design.

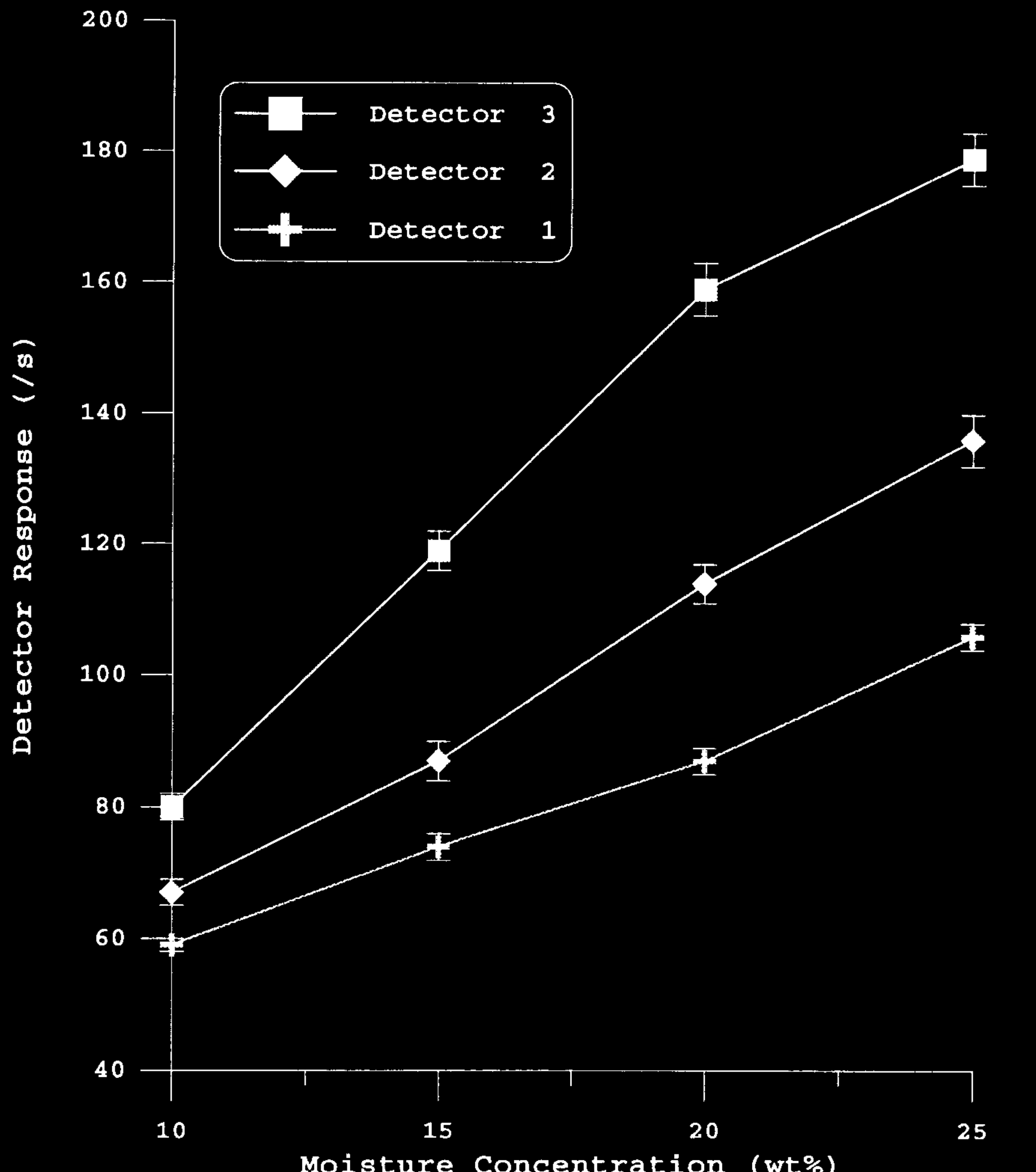


Figure 3-9. Model Predicted Neutron Scattering Locations for Neutrons that Contribute to Detector 1 Response. Graph Shows Calculated Depth from which Neutron Moderation Signal Originates. Scale Shows Percentage of Total Signal Coming from a Given Depth or Above. Color Corresponds to Neutron Energy at a given Scattering Location.

Detector 1, 15 wt% Moisture Waste
90% Depth: 5.5 cm
Average Depth: 2.1 cm

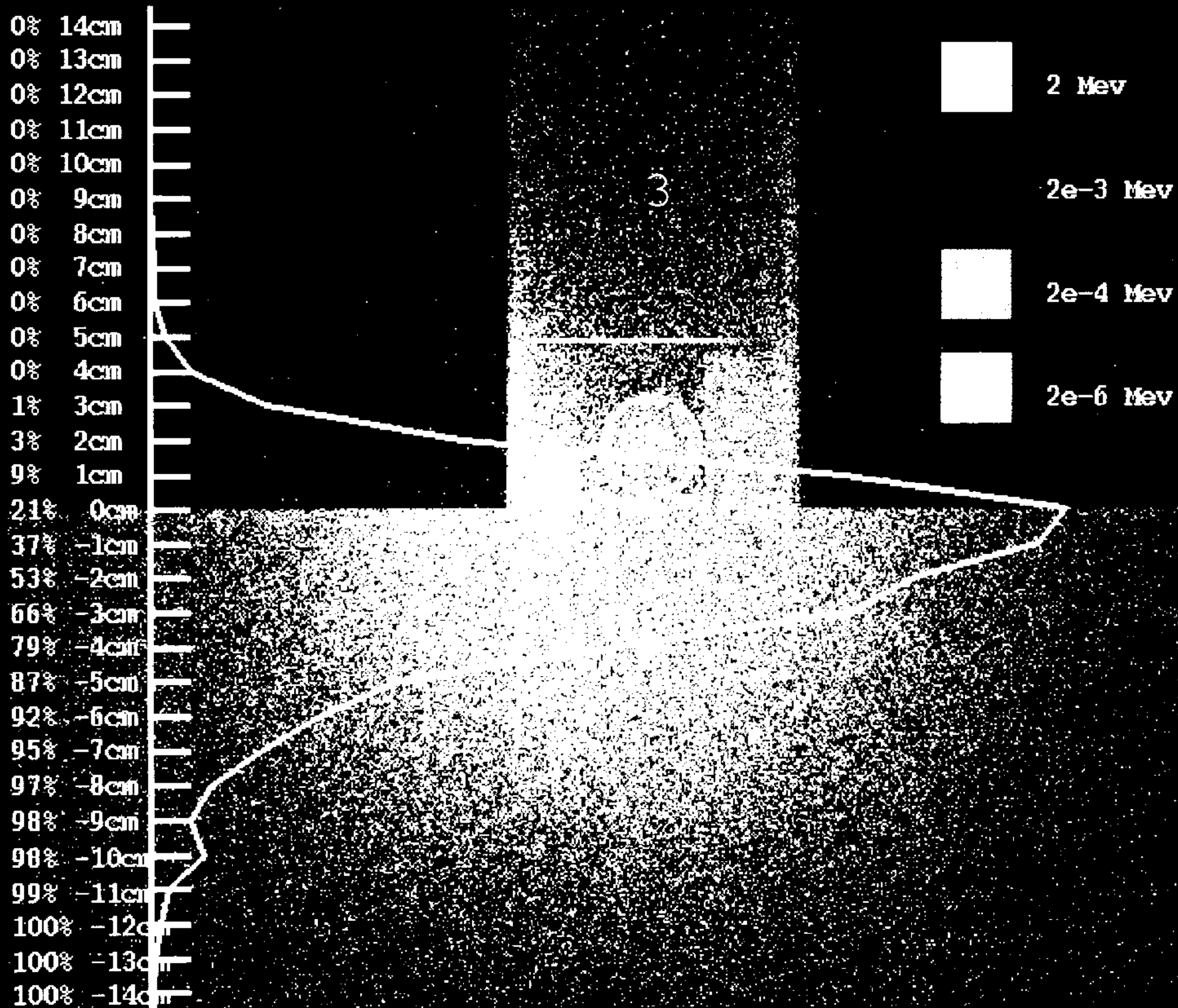


Figure 3-10. Model Predicted Neutron Scattering Locations for Neutrons that Contribute to Detector 2 Response. Graph Shows Calculated Depth from which Neutron Moderation Signal Originates. Scale Shows Percentage of Total Signal Coming from a Given Depth or Above. Color Corresponds to Neutron Energy at a given Scattering Location.

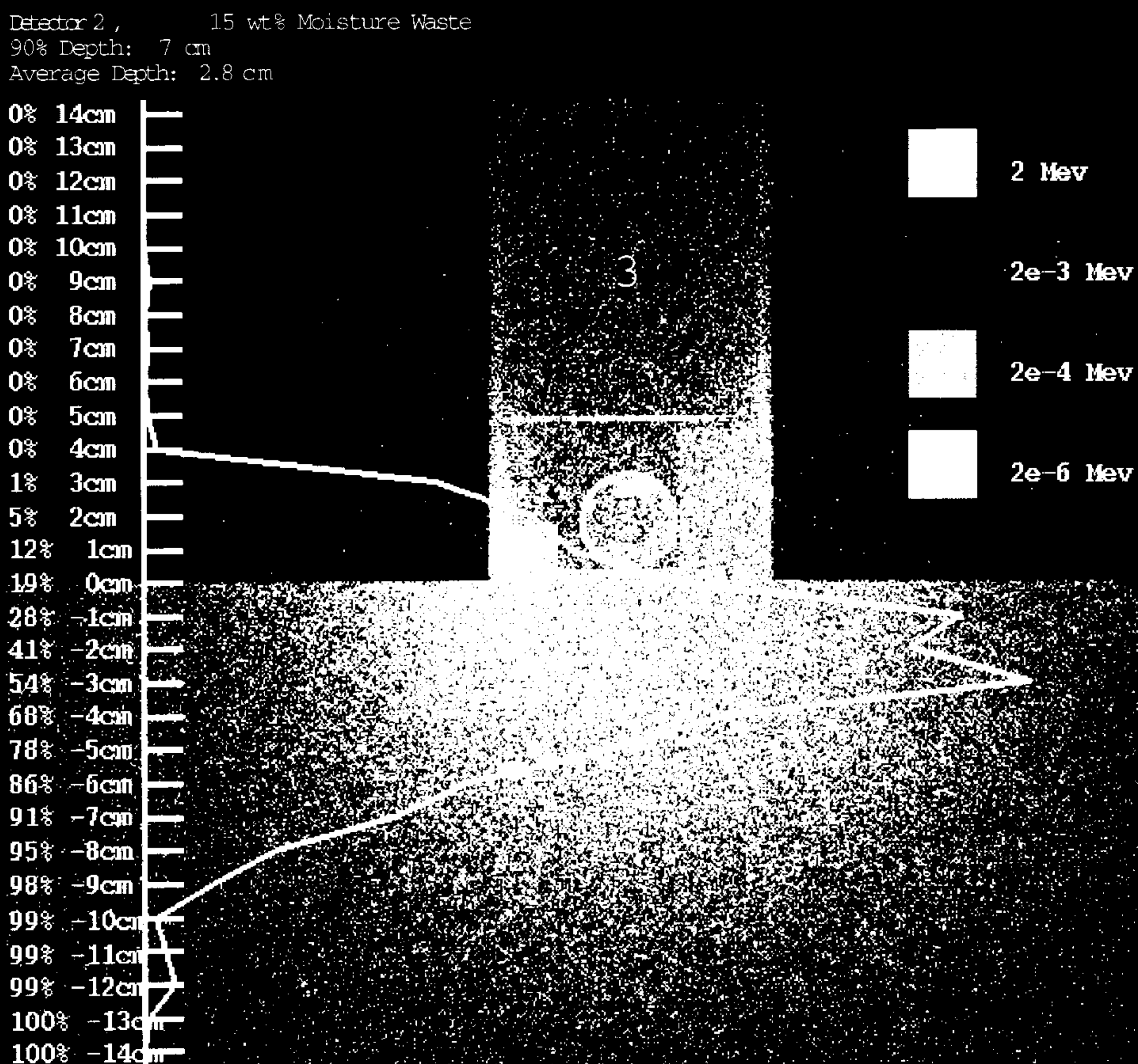


Figure 3-11. Model Predicted Neutron Scattering Locations for Neutrons that Contribute to Detector 3 Response. Graph Shows Calculated Depth from which Neutron Moderation Signal Originates. Scale Shows Percentage of Total Signal Coming from a Given Depth or Above. Color Corresponds to Neutron Energy at a given Scattering Location.

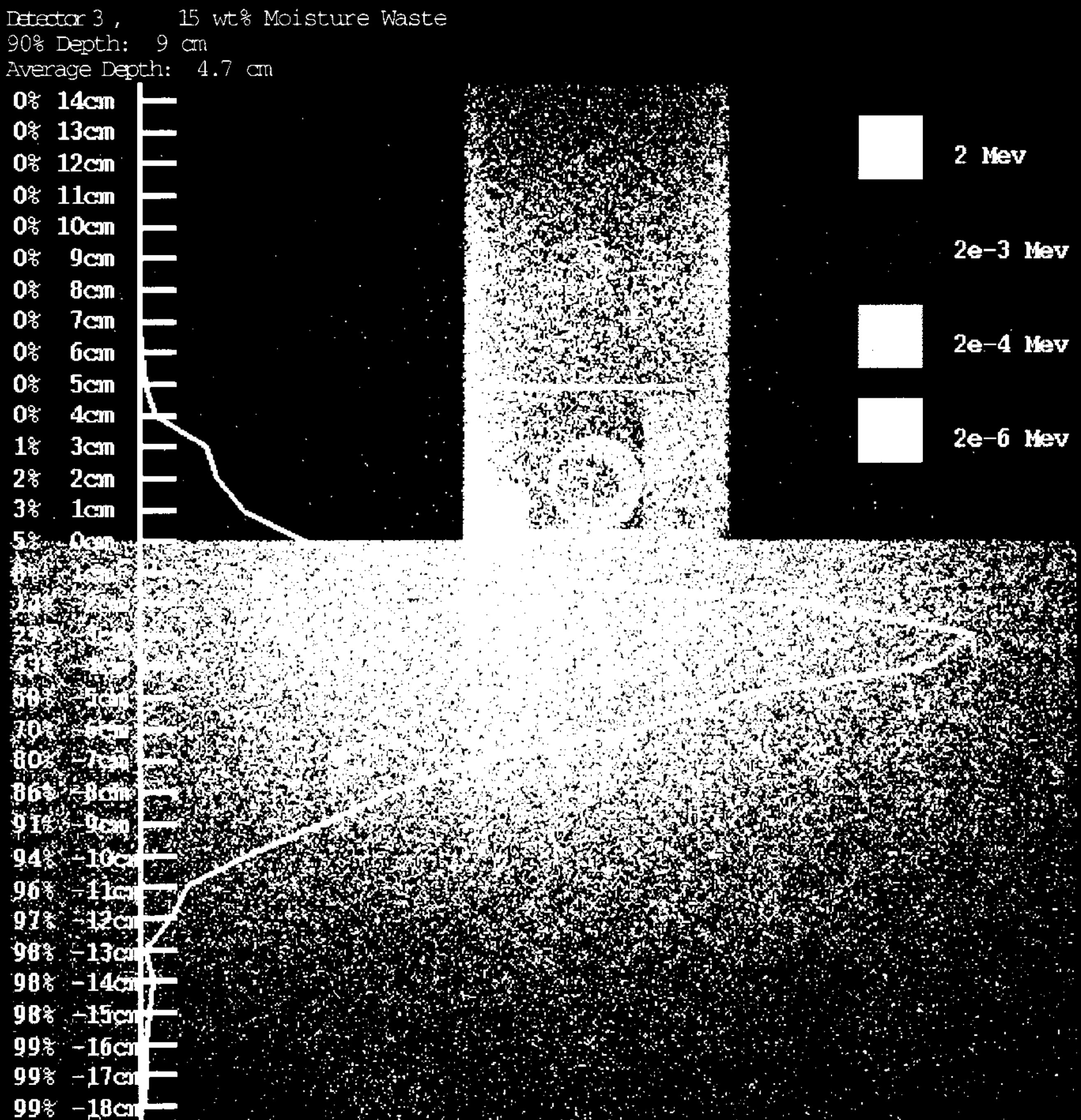


Figure 4-1. Schematic drawing of detector configuration used in the tests. All detectors are BF3 type neutron counters. Dimensions are given in inches and in centimeters (shown in parenthesis).

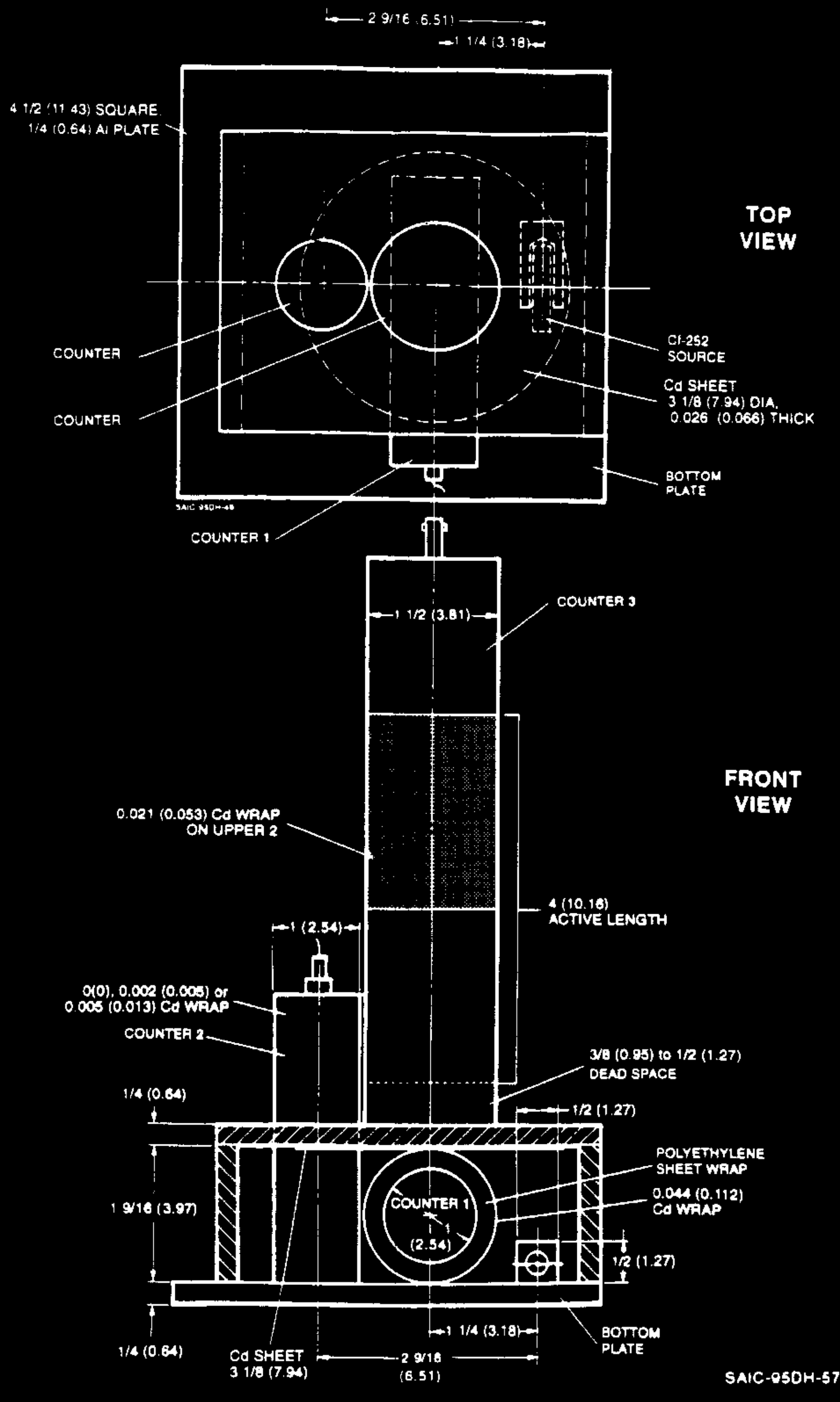


Figure 4-2. Photograph of the detector configuration used in the tests.

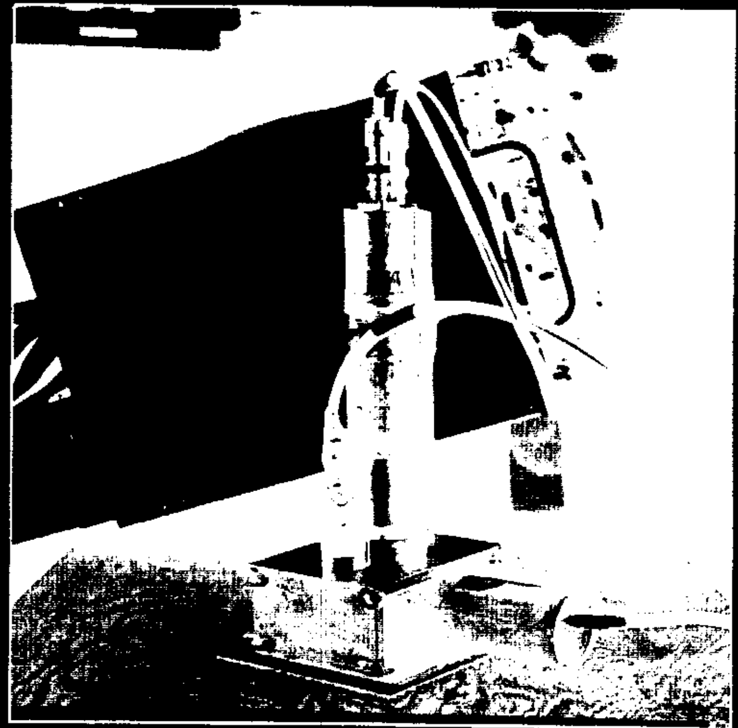


Figure 4-3. The detector configuration and electronics used in the tests. The NIM bin contains a high voltage power supply, spectroscopic amplifiers, scalars, and a printer. The preamplifiers are just visible under the table.

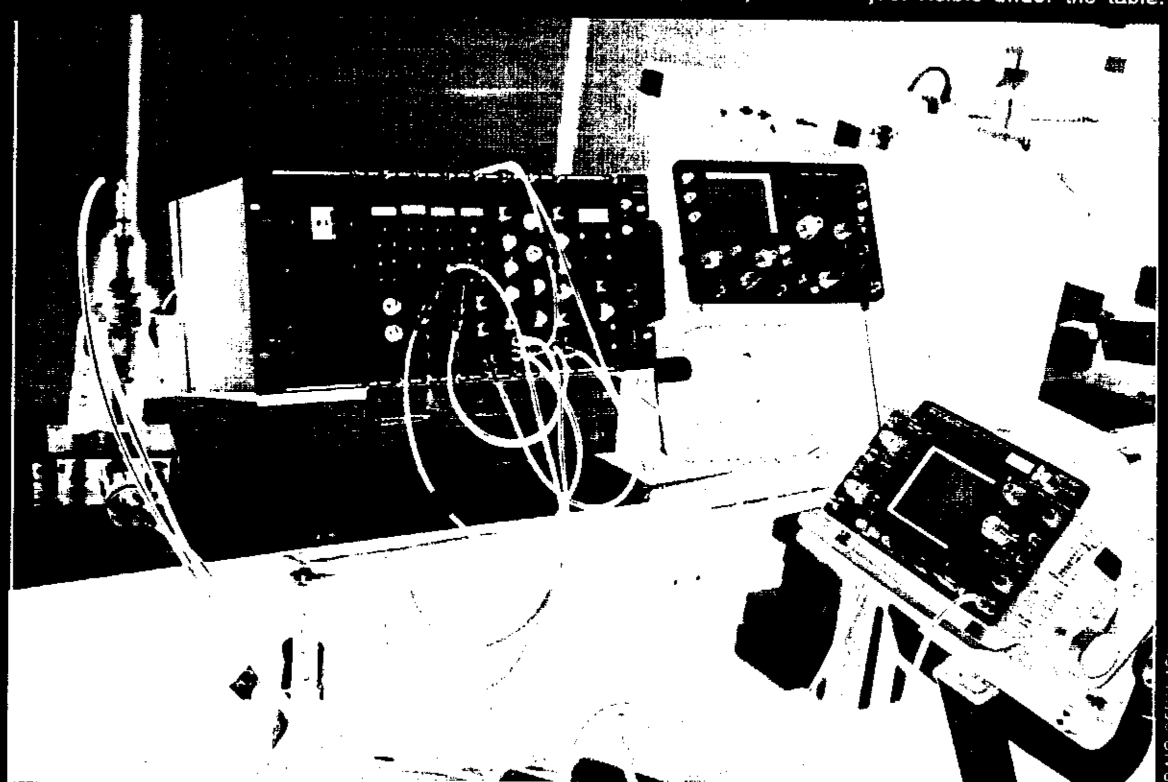


Figure 4-4. The detector configuration shown during a typical measurement.

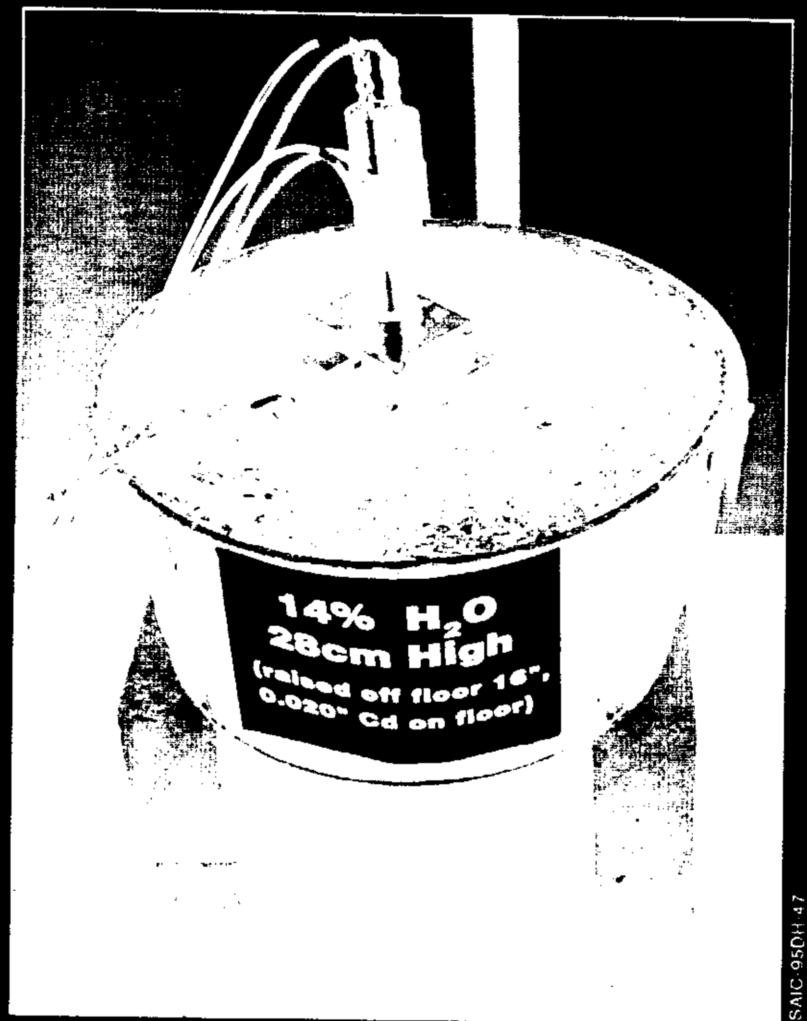
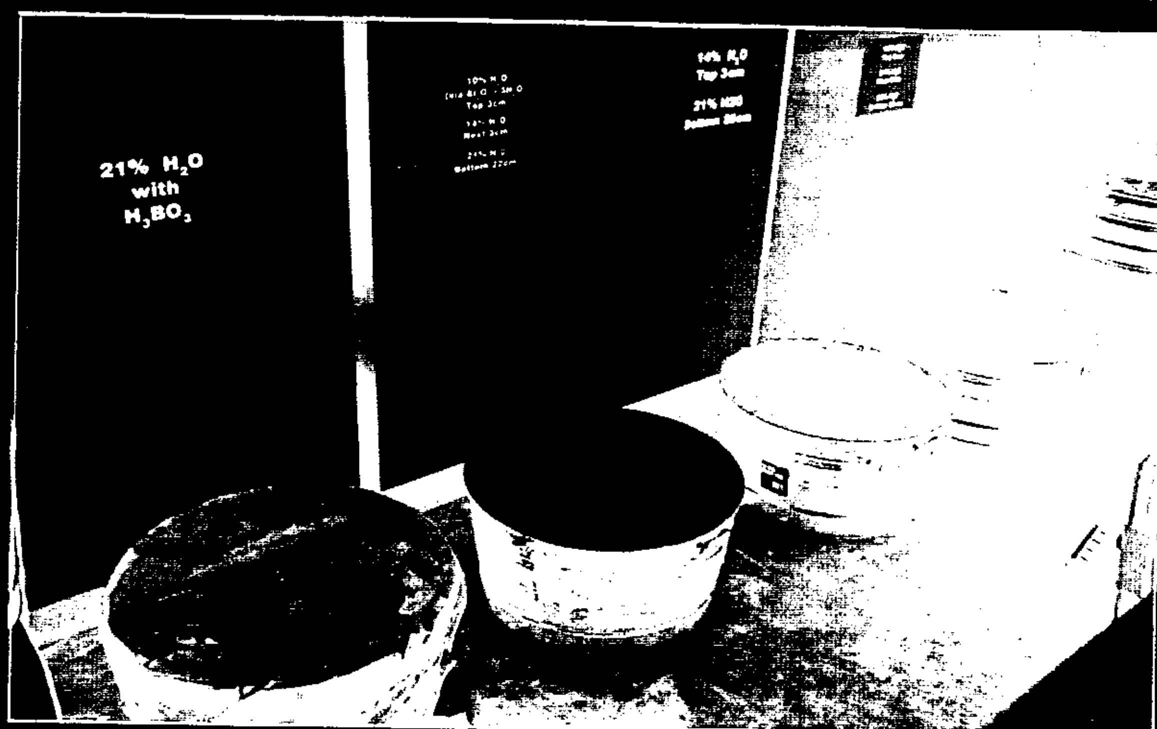


Figure 4-5. Wide angle view of the entire test bed matrix. From the right, the tubs contain the following mixtures: 1) 26% moisture in filled tub, 2) 21% moisture in filled tub, 3) 14% moisture in filled tub, 4) 14% top 3 cm, 21% next 3 cm, 26% remainder, 5) 14% top 3 cm, 21% remainder, 6) 10% top 3 cm, 14% next 3 cm, 21% remainder, 7) 21% with boric acid, 8) 14%, 4 cm thick layer, 9) 14%, 6 cm thick layer, and 10) 14%, 9 cm thick layer.

Figure 4-6. Close-up view of tubs with, from the left, 1) 21% moisture and boric acid, 2) 10% top 3 cm, 14% next 3 cm, 21% remainder, 3) 14% top 3 cm, 20% remainder, and 4) 14% top 3 cm, 21% next 3 cm, 26% remainder.



SAIC-95DH-48

Figure 4-7. Close-up view of tubs with thin layers of water/sand/gravel mixtures for 14% moisture content. The tubs are raised 41 cm off the ground and a thin sheet of Cd is placed under the tubs to absorb any thermal neutrons passing back to the detectors from the cement.

SAIC-95DH-68

Figure 4-8. SMMS test results, July 1995. Thin layer mixtures. 0.013 cm of Cd on detector 2.

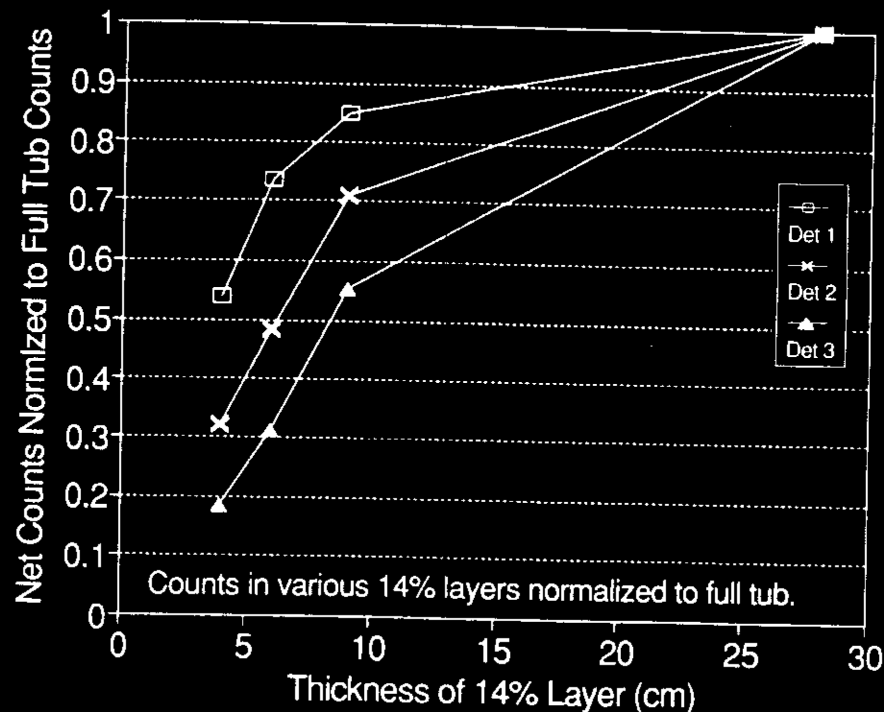


Figure 4-9. SMMS test results, July 1995. Stratified and full tubs. No Cd on detector 2.

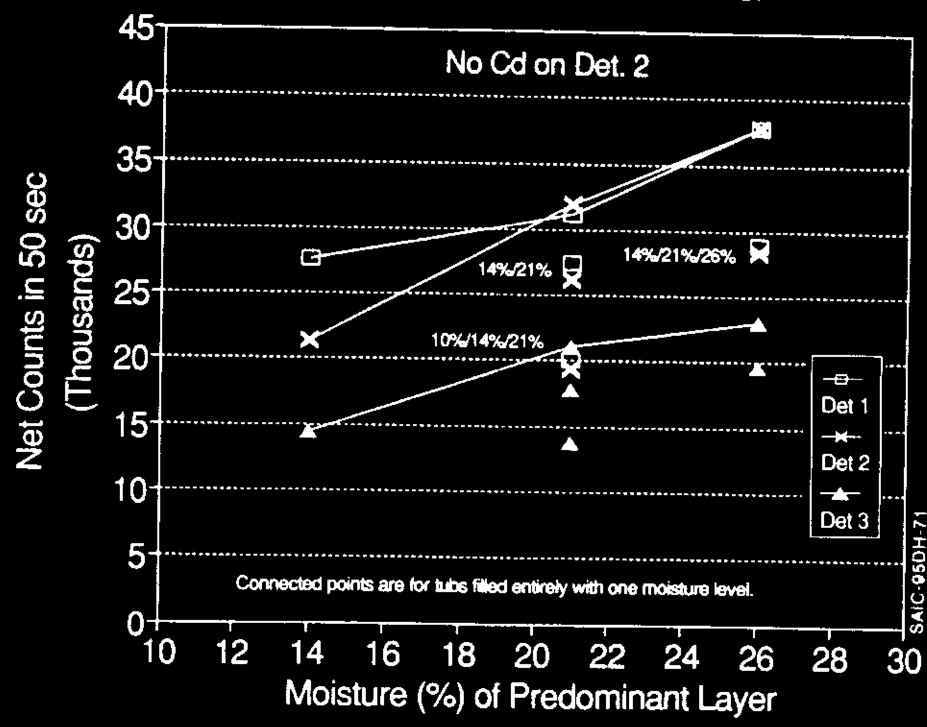


Figure 4-10. SMMS test results, July 1995. Stratified and single moisture content tubs. 0.005 cm of Cd on detector 2.

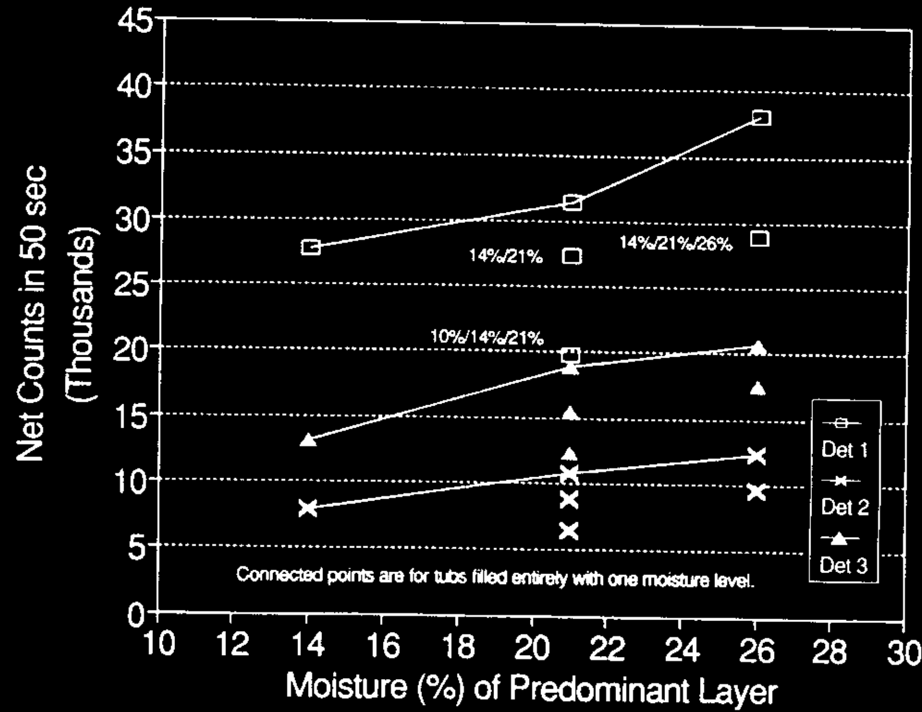


Figure 4-11. SMMS test results, July 1995. Stratified and single moisture content tubs. 0.013 cm of Cd on detector 2.

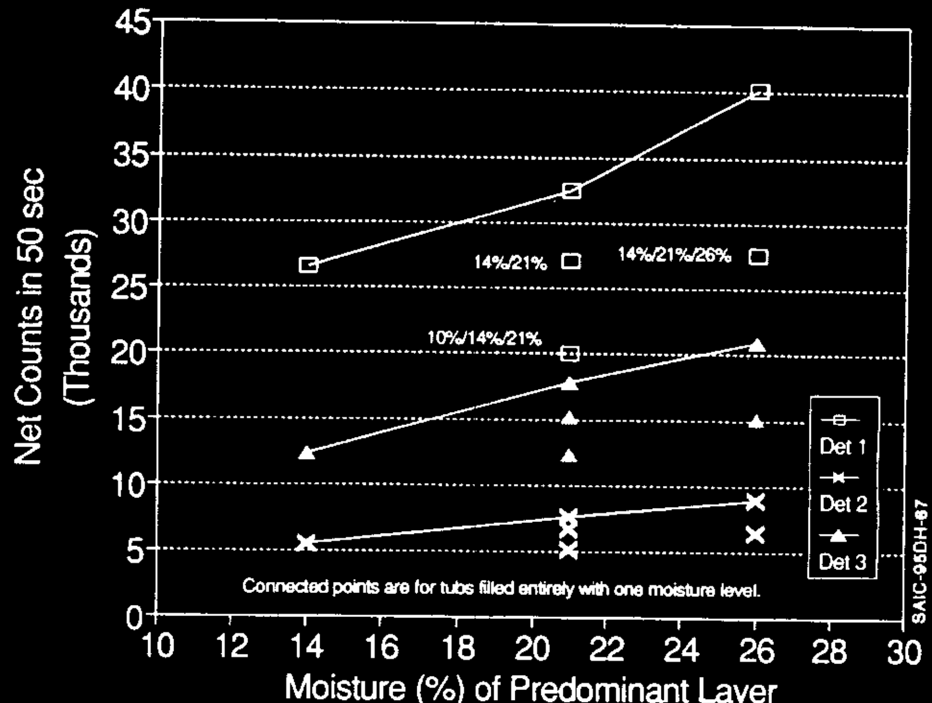


Figure 4-12. SMMS test results, July 1995. Boron contaminated tubs. No Cd on detector 2.

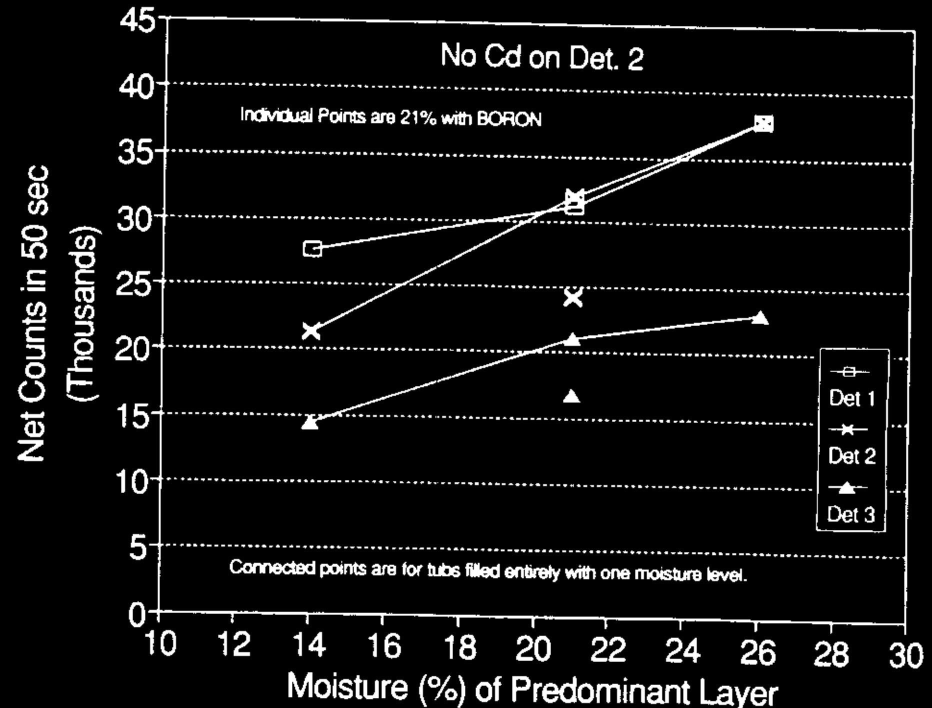


Figure 4-13. SMMS test results, July 1995. Boron contaminated tubs. 0.005 cm of Cd on detector 2.

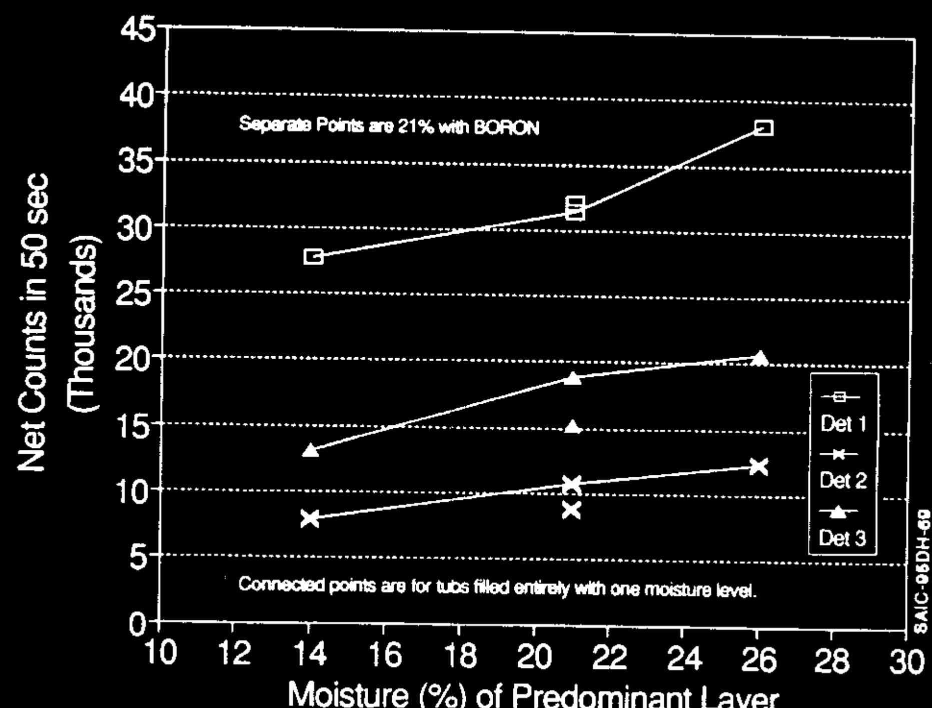


Figure 4-14. SMMS test results, July 1995. Boron contaminated tubs. 0.013 cm of Cd on detector 2.

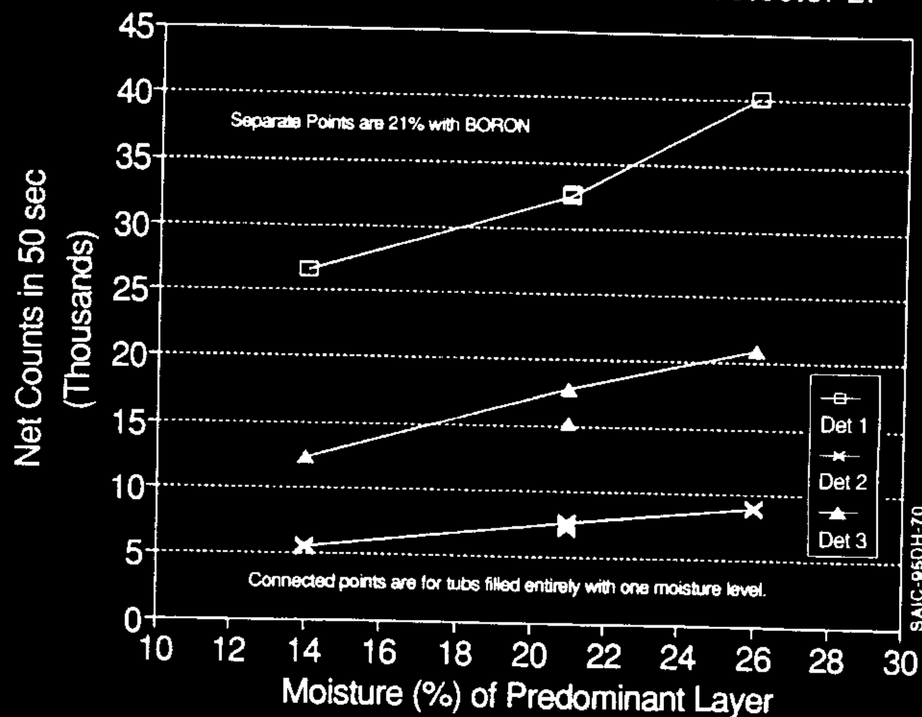


Figure 4-15. Comparison of Prototype Experimental and MCNP Modeling Results of Detector Response to Uniform Surface Moistures. (0.002 in. Cd around detector 2)

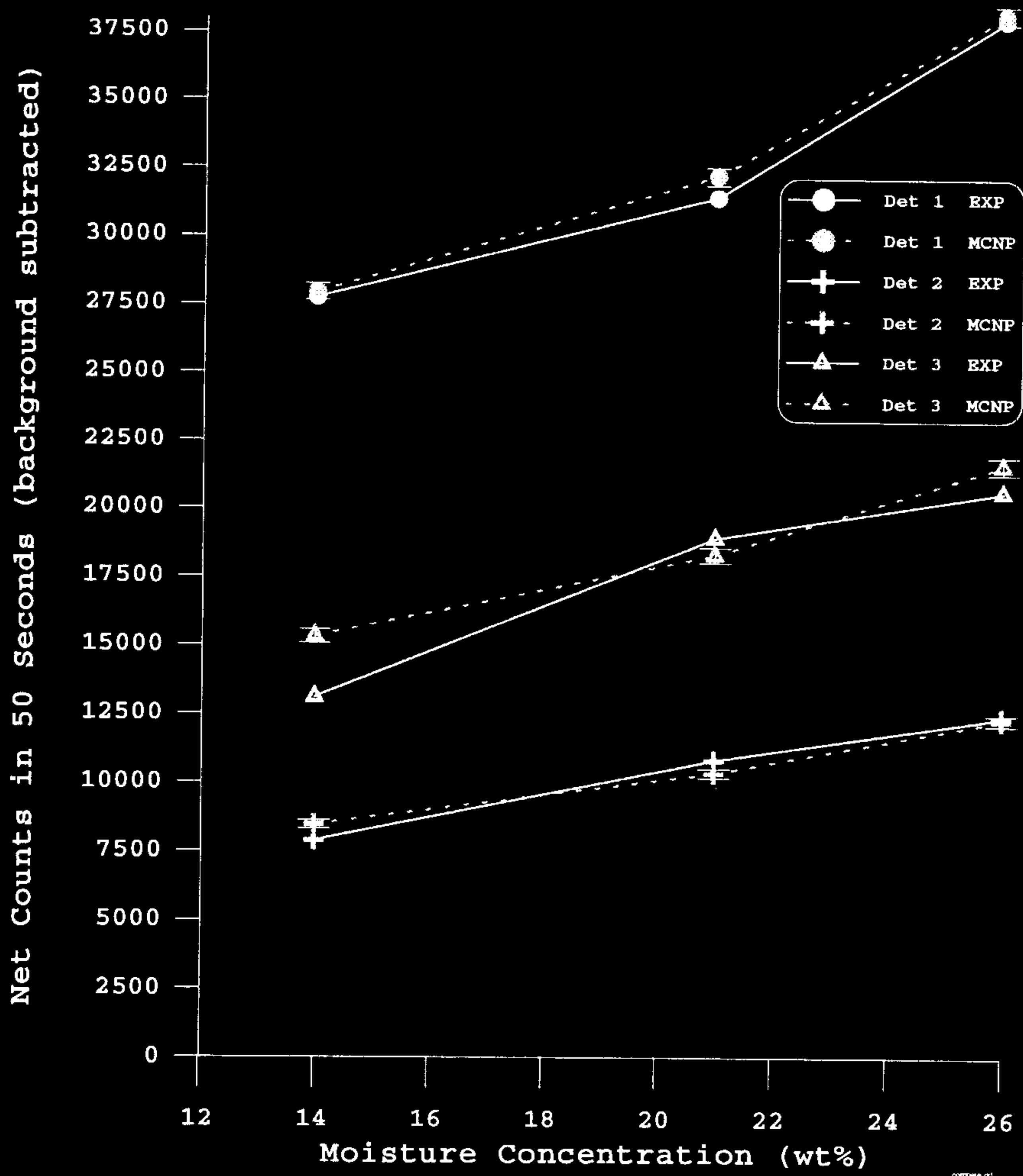


Figure 4-16. Comparison of Experimental and Modeled Detector Responses to Increasing Thickness of Moisture Material Beneath Surface Probe.

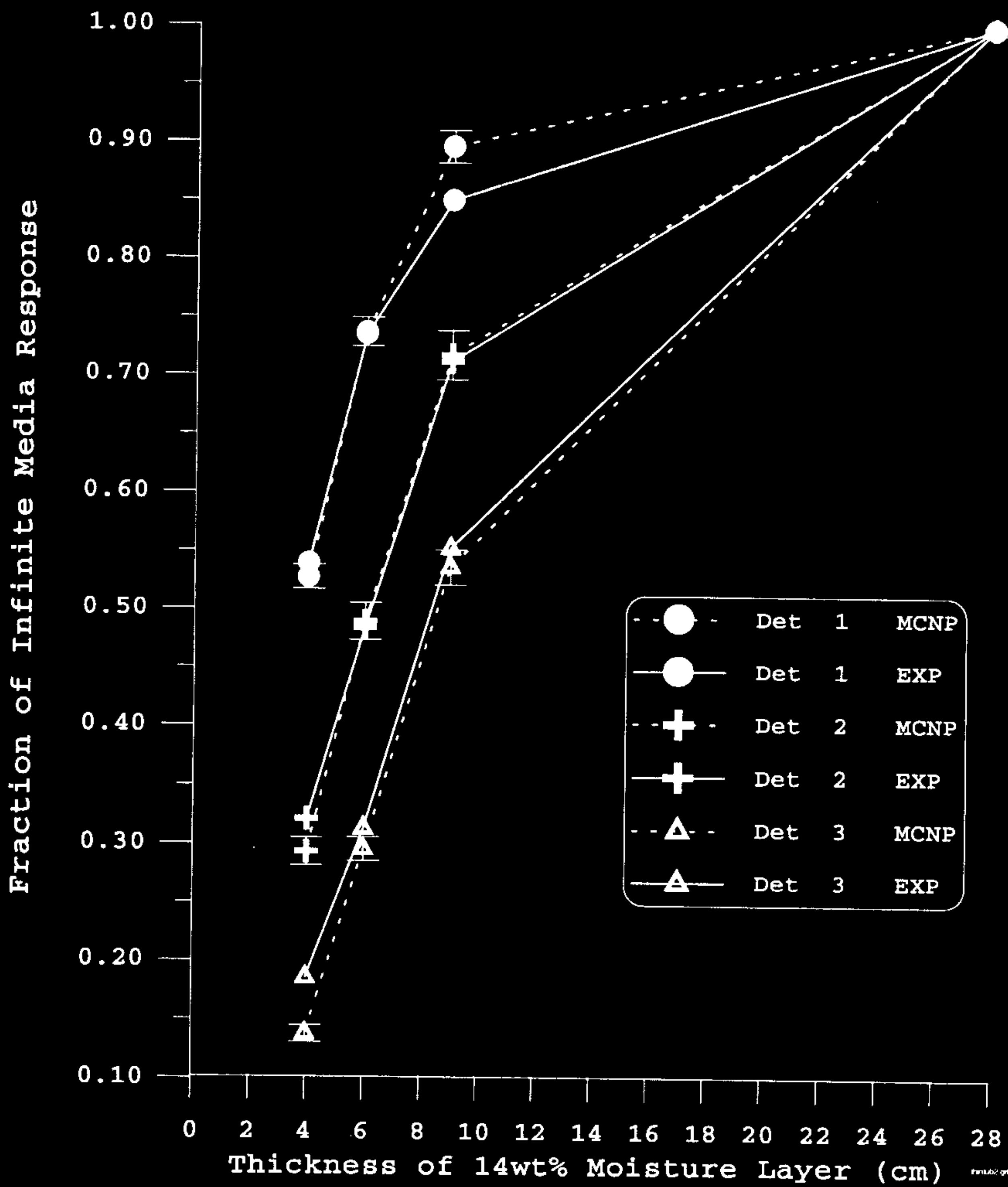
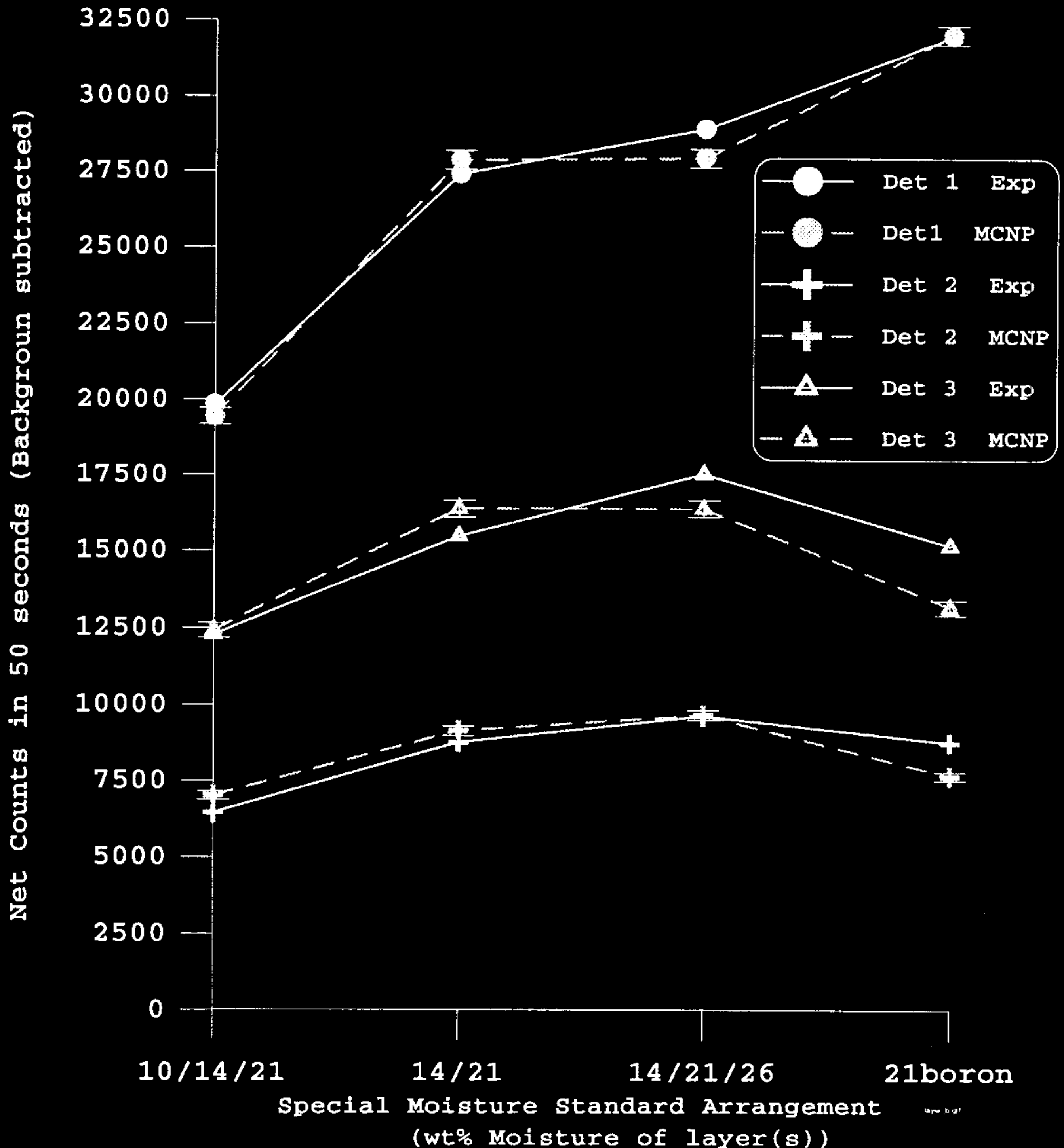


Figure 4-17. Comparison of Experimental and Modeled Prototype Detector Responses to Layered Moisture and Neutron Absorber Containing Standards. (0.002 in.Cd around detector 2) Weight Percent Moisture of Each Layer (top to bottom) and Absorber, if any, is Specified.



7.0 REFERENCES

Carter, L. L., 1995, *Certification of MCNP Version 4A for WHC Computer Platforms*, WHC-SD-MP-SWD-30001, Rev. 7, Westinghouse Hanford Company, Richland, Washington.

Finfrock, S. H., 1995, *System Design Description for the TMAD Code*, WHC-SD-WM-CSRS-028, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hanlon, B. M., 1994, *Tank Farm Surveillance and Waste Status Summary Report for February 1994*, WHC-EP-0182-71, Westinghouse Hanford Company, Richland, Washington.

Hearst, J. R., and R. C. Carlson, 1994, *A Comparison of the Moisture Gauge and the Neutron Log in Air-filled Holes*, Nuclear Geophysics, Vol. 8, No. 2, pp. 165-172.

LANL, 1993, *MCNP - A General Monte Carlo N-Particle Transport Code, Version 4A*, LA-12625, (J. F. Briesmeister, Ed.), Los Alamos National Laboratory, Los Alamos, New Mexico.

Meacham, J. E., H. Babad, R. J. Cash, G. T. Dukelow, S. J. Eberlein, D. W. Hamilton, J. L. Huckaby, G. D. Johnson, J. W. Osborne, M. A. Payne, D. J. Sherwood, and D, A. Turner, 1995, *Approach for Tank Safety Characterization of Hanford Site Waste*, WHC-EP-0843, Westinghouse Hanford Company, Richland, Washington.

Meacham, J. E., H. Babad, and H. Toffer, 1993, *Moisture Monitoring of Ferrocyanide Tanks: An Evaluation of Methods and Tools*, WHC-EP-0658, Westinghouse Hanford Company, Richland, Washington.

Parra, S. A., and W. T. Watson, 1994, *Integrated Beta and Gamma Radiation Dose Calculations for the Ferrocyanide Waste Tanks*, WHC-SD-WM-TI-634, Westinghouse Hanford Company, Richland, Washington.

Postma, A. K., J. E. Meacham, G. S. Barney, G. L. Borsheim, R. J. Cash, M. D. Crippen, D. R. Dickenson, J. M. Grigsby, D. W. Jeppson, M. Kummerer, J. M. McLaren, C. S. Simmons, B. C. Simpson, 1994, *Ferrocyanide Safety Program: Safety Criteria for Ferrocyanide Watch List Tanks*, WHC-EP-0691, Westinghouse Hanford Company, Richland, Washington.

Science Applications International Corporation (SAIC), 1995, *Phase 1 of Cone Penetrometer Moisture Probe Study*, (Task MJB-SWV-370248-001), San Diego, California.

Stokes, T. I., 1995, *Surface Moisture Measurement of Tank Waste Engineering Work Plan*, WHC-SD-WM-WP-300, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

Stokes, T. I., W. T. Watson, M. Gimera, J. H. Bussell, A. Dabiri, D. T. Holslin, F. Johansen, 1995, *Design Requirements Document (DRD) for Surface Moisture Measurement System (SMMS)*, WHC-SD-WM-DRD-002, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

Watson, W. T., S. H. Finfrock, and H. Toffer, 1994, *Potential Tank Waste Material Anomalies Located Near the Liquid Observation Well: Model Predicted Responses of a Neutron Moisture Detection System*, WHC-EP-0809, Westinghouse Hanford Company, Richland, Washington.

Watson, W. T., 1993, *Proof of Principle Report for In-Tank Moisture Monitoring Using an Active Neutron Probe*, WHC-EP-0695, Westinghouse Hanford Company, Richland, Washington.

WHC, 1995a, *Neutron Moisture Probe Dual Epithermal Detector*, February 1995, drawing H-14-100154, Rev.1, Westinghouse Hanford Company, Richland Washington.

WHC, 1995b, *Neutron Moisture Probe Dual Thermal Detector*, February 1995, drawing H-14-100155, Rev.0, Westinghouse Hanford Company, Richland Washington.

APPENDIX A

Example MCNP Input File

message:

```
 Vert Surface Neutron (t18 geom)
c        15% water saltcake
c
c
  1  1  -8.0          75 -72 -15  imp:n=100  $ Cf-252 source
  3  13 -1.138e-3     70 -68 -40  imp:n=150 $ det 2 air
  4  13 -1.138e-3     67 -71 -43  imp:n=250 $ det 2 air
  9  3  -.96  67 -70 -40 43  imp:n=290 $ det 2 poly
 10  6  -9.833e-4 92 -93 -42 imp:n=300 $ det 1
 11  6  -9.833e-4 71 -70 -43 imp:n=650 $ det 2
 12  6  -9.833e-4 91 -90 -44 imp:n=350 $ det 3
 13  8  -8.65  (62 -69 -41) (40:68:-67) imp:n=190 $ det 2 cad
 14  8  -8.65 (96 -97 -46 45):(-45 96 -99):(-45 98 -97) imp:n=110 $ det 1 cad
 15  3  -.96 99 -98 -45 42 50 imp:n=220 $ det 1 poly
 16  13 -1.138e-3 -93 92 -45 42 -50 imp:n=100 $ det 1 air
 17  13 -1.138e-3      -98 93 -45 #15 imp:n=120 $ det 1 air
 18  13 -1.138e-3     -92 99 -45 #15 imp:n=120 $ det 1 air
 21  19 -7.8       9 -8 1 -62 imp:n=100 $ steel housing
 22  19 -7.8    -9 1 -62 #1   imp:n=100 $ steel housing bottom
 23  19 -7.8      9 -8 62 -60 imp:n=100 $ steel housing
 50  15 -1.50          2 -1 -10 imp:n=100   $saltcake
 51  15 -1.50          3 -2 -10 imp:n=98
 52  15 -1.50          4 -3 -10 imp:n=90
 53  15 -1.50          5 -4 -10 imp:n=50
 54  15 -1.50          6 -5 -10 imp:n=15
 55  15 -1.50       -100 -6 -10 imp:n=5
 57  15 -1.50          2 -1 10 -11 imp:n=100   $saltcake
 58  15 -1.50          3 -2 10 -11 imp:n=95
 59  15 -1.50          4 -3 10 -11 imp:n=90
 60  15 -1.50          5 -4 10 -11 imp:n=25
 61  15 -1.50          6 -5 10 -11 imp:n=7
 62  15 -1.50       -100 -6 10 -11 imp:n=2
 64  15 -1.50          2 -1 11 -100 imp:n=95   $saltcake
 65  15 -1.50          3 -2 11 -100 imp:n=80
 66  15 -1.50          4 -3 11 -100 imp:n=25
 67  15 -1.50          5 -4 11 -100 imp:n=12
 68  15 -1.50          6 -5 11 -100 imp:n=3
 69  15 -1.50       -100 -6 11 -100 imp:n=1
 89  13 -1.138e-3 74  -77 -9 -60 #200 #12 imp:n=220
 90  13 -1.138e-3 1 -16 8 -10 imp:n=100  $ air
 91  13 -1.138e-3 1 -16 10 -11 imp:n=100  $ air
 92  13 -1.138e-3 1 -16 11 -12 imp:n=98  $ air
 93  13 -1.138e-3 62 -9 -77 -74 (-96:97:46) #1 #100 imp:n=100  $ air next to
source & det 1
 94  13 -1.138e-3 62 -60 -9 77 #11 #9 #13 #3 #4 #200  imp:n=140  $ air next to
det 2
 95  13 -1.138e-3 60 -16 -8 #12 imp:n=25 $ air above probe
100  19 -7.8 ((-80 -75 -9):(-83 75)) -81 -9 62 #1 imp:n=100 $ source enclosure
200  8  -8.65     -13 -82 74 43 #13 #3 #4 imp:n=95 $cadmium
500  0                16:12:(100 -1) imp:n=0

  1  pz    0.00       $ top of saltcake
  2  pz   -4.00       $ saltcake
```

```
  3  pz   -10.00        $ saltcake
  4  pz   -15.00        $ saltcake
  5  pz   -20.00        $ saltcake
  6  pz   -30.00        $ saltcake
  8  c/z  1.7 4.22 4.214  $ outer steel housing x y R .125 in thick wall
  9  c/z  1.7 4.22 3.896 $ outer steel housing x y R 3.068 in ID
 10  c/z  1 4.22 10 $ waste radius
 11  c/z  1 4.22 23 $ waste radius
 12  c/z  1.0 4.22 38.0 $ waste radius
 13  c/z  1.5 4.22 3.6  $ cadmium x y R
 15  c/y   -1.409 0.643 0.216  $ source radius  x z R
 16  pz    15.0     $ top of air
 40  c/z   4.38 4.22 1.2 $ cad inner/poly outer 2.05 mm thick poly
 41  c/z   4.38 4.22 1.205 $ detector 2 cad 0.005 cm thick
 42  c/y   1.65 1.837 0.79 $ detector 1 radius (.62"OD) x z R
 43  c/z   4.38 4.22 0.79 $ detector 2 radius (.62"OD) x y R
 44  c/z   1.75 4.22 1.27 $ detector 3 radius (.62"OD) x y R
 45  c/y   1.65 1.837 1.29 $ det 1 poly
 46  c/y   1.65 1.837 1.455 $ det cad
 50  p   1.1 4.22 1.05  1.1 5 1.05  1.2 4.22 1.9 $ det 1 poly
 60  pz    14.5  $ imp plane
 62  pz    0.381  $ top of housing bottom
 67  pz    0.386        $ top of det 2 Cd 0.005 cm thick
 68  pz    5.4818  $ top of det 2 Cd
 69  pz    5.4868       $ top of det 2 Cd 0.005 cm thick
 70  pz    4.5284  $ top of det 2
 71  pz    1.3484  $ bottom of det 2
 72  py   4.220001  $ top of source
 74  pz   4.8 $ bottom of cadmium disk
 75  py   4.219999  $ top of source
 77  px    3.12  $ left side of iron block
 79  px    4.0   $ right side of cadmium
 80  px  -.479 $ source enclosure (side)
 81  pz  1.65   $ source enclosure (top)
 82  pz  4.965  $ top of cadmium
 83  px  -.873   $ thin side of source enclosure
 90  pz  11.569 $ end of top det 3
 91  pz   6.489  $ end of top det 3
 92  py  2.93 $ end of det 1
 93  py  6.11  $ end of det 1
 96  py  1.5  $ cad/air
 97  py  7.6924  $ cad/air
 98  py  7.5324  $ cad/air
 99  py  1.66  $ cad/air
100  s    1.0 4.22 0.0 38.0

c       idum   4j -7
mode  n
phys:n  20 20
sdef  cel d1  pos fcel d2  axs 0 1 0  ext fcel d3
      rad fcel d4  wgt=2.3e7  erg d5
sc1   source cell is Cf-252 source in cell 1 : 10 micrograms
si1   l  1
sp1   d  1.0
sc2   source location is centered in cell 1
```

```
ds2   1   -1.409 4.22 0.643
sc3   source extent
ds3   s   6
sc4   source radius
ds4   s   7
sc5   energy distribution: Cf-252 Watt Spontaneous Fission Spectrum
sp5   -3  1.025  2.926
sc6   source extent is 2.0e-6 centimeter total length
si6    0.000001
sp6   -21  0
sc7   source radius is .216 centimeters
si7    0.0  0.216
sp7   -21  1
f4:n   10                          $ detector regions
fm4    8.489e-6   9   207             $ (n,alpha) interactions
f14:n   11                         $ detector regions
fm14    8.489e-6   9   207            $ (n,alpha) interactions
f24:n   12                         $ detector regions
fm24    8.489e-6   9   207            $ (n,alpha) interactions
m1      98252.35c   2                 $ Cf-252
         8016.50c   6
        16032.50c   1
m3     1001.50c 2.000000                  $ Polyethylene
       6000.50c 1.000000
m3t     poly.01t
m6       5010.50c   0.24              $ BF3 gas (2.99 g/l at 1 atm)
         5011.50c   0.01              $ Ref: HCP-62ed B-84
         9019.50c   0.75              $ 96% enriched in B-10
m8     48000.50c -1.00     $ cadmium
m9       5010.50c   1.00              $ B-10 used for tallying
m13      7014.50c   0.8000            $ LOW air (1.138e-3 g/cc)
         8016.50c   0.2000
m15      1001.50c   -0.017168          $ BY-104 Saltcake Simulant
         7014.50c   -0.1234            $ 15% H2O
         8016.50c   -0.5923
        11023.50c   -0.2466
        12000.50c   -0.0003
        13027.50c   -0.0126
        14000.50c   -0.0031
        15031.50c   -0.0012
        20000.50c   -0.0009
        25055.50c   -0.0005
        26000.55c   -0.0021
m15t    lwtr.01t                      $ hydrogen in water 300 K
m19      6000.50c   -0.003            $ 4130 carbon steel
        25055.50c   -0.005
        15031.50c   -0.00035
        16032.50c   -0.0004
        14000.50c   -0.002
        24000.50c   -0.01
        42000.50c   -0.002
        26000.55c   -0.97725
totnu
nps     15000000
print    60 120 126 140
```

APPENDIX B

Review Comment Record

REVIEW COMMENT RECORD (RCR)

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3. Project No.	4. Page
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5. Document Number(s)/Title(s)	6. Program/Project/ Building Number	7. Reviewer	8. Organization/Group	9. Location/Phone
WHC-SD-WM-DTR-044	UC-606	PR Deichelbohrer	Char. Eng. Imp.	S7-12, 373-2037

17. Comment Submittal Approval:

Organization Manager (Optional)

10. Agreement with indicated comment disposition(s)

11-27-95
Date

Reviewer/Point of Contact

Author/Originator

11. CLOSED

Date

Reviewer/Point of Contact

Author/Originator

12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/ resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
1	page i Include a Table of Contents and a List of Figures.		These tables will be added.	
2	page 1 First sentence. Include the words "Under Ground" to distinguish from waste lying on the surface. Middle of first para. Missing word in the sentence" "The design requirements for this probe may be found in ." Second para., last sentence. Here you imply that you are redesigning the SMMS probe. You are actually designing it from the LOW probe.		Word "underground" has been added to description. This sentence is deleted. Its meaning is covered in the following sentence. Reworded to read: "Differences in the waste geometry, relative to the probe, between the surface and the LOW or cone penetrometer applications require a unique design for the surface probe to function as desired."	

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12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
3	page 2 last sentence. "Comparisons of the computer modeling predictions and the experimental prototype measurements confirm that the design should be able to meet the requirements for the SMMS." I am reading that you have some confidence that the SMMS probe will work. Logically, then, I have some confidence that it will not work. And, when it doesn't work, you'll just say, "I told you so." Section 2.0 rad/hr is not metric Is Parra and Watson also the source of the tank-bottom dose rate?		We are stating that, based upon currently available testing and modeling information, the baseline surface neutron probe design should be able to meet design requirements. It is certainly true that there could be circumstances, as of yet uninvestigated, that could raise the uncertainty of some measurements beyond design requirement limits. We simply do not want to make unsubstantiated claims concerning probe performance. A developmental probe to be used in an uncontrolled environment will not, in general, come with absolute performance guarantees. Changed to grey/hr. Yes.	
4	page 3 The verification of the MCNP code certification has to be cited. last para two metric violations		Reference cited. Carter, L. L., 1995, *Certification of MCNP Version 4A for WHC Computer Platforms*, WHC-SD-MP-SWD-30001, Rev.7, Westinghouse Hanford Company, Richland, Washington. Metric equivalent added, except for "4-inch riser" which is considered an item name rather than a dimensional reference.	

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12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
5	page 4 The following sentence is too hard to understand: "While modelers did not allow this mechanical preference to constrain the models considered, model geometries that would allow the probe to be easily and repeatably placed on the waste surface so that all detectors would be in the same position relative to the plane of the waste surface were preferred." next-to-the-last para. "Figure 3-2 shows the model predicted responses to changing moisture of a 4 cm long detector placed at the 10 source to detector spacings shown in Figure 3-1." "...placed at the 10 source.." could be better written: "...placed at the location of source number ten..." Also, the nonlinearity of the #1 curve (Fig 3-2) has to be explained, or at least, discussed. The word "dampen" in: "...been contributing enough to the far-field response to dampen the moisture sensitivity." seems to be associated with moisture. Replace it with "reduce".		Replace with: "Modelers did not allow this mechanical preference to constrain the models considered. However, model geometries that would allow the probe to be easily and repeatably placed on the waste surface so that all detectors would be in the same position relative to the plane of the waste surface, were preferred. For instance, each time the probe is placed upon the surface a given detector should automatically be at the same height above the surface." Replace with: "Figure 3-2 shows the model predicted responses to changing moisture of a 4 cm long detector placed at each of the 10 positions corresponding to the source-to-detector spacings shown in Figure 3-1." Sentence added: "The detector responses, while related to moisture content of the waste, are not expected to have linear relationships with moisture concentration." Substitution made.	
6	page 5 second para. Where are the results illustrated that are talked about in: "The sensitivity to moisture was improved for these arrangements over that predicted for the horizontal source-to-detector spacing, but the depth of investigation did not increase as the detector was further spaced from the source and waste surface. "		Results are not illustrated, but are simply discussed. Because the results did not help to meet the design requirements we determined the results were not of sufficient interest to present graphically. I maintain that these results are not of interest to the design.	

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12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
7	page 6 second para. Provide reference to support the sentence: "This choice was made primarily because of the results of tests performed for the design of the penetrometer neutron probe. " last para. "Figure 3-5" should be "Figure 3-6"		Reference cited: Science Applications International Corporation (SAIC), 1995, *Phase 1 of Cone Penetrometer Moisture Probe Study*, (Task MJB-SWV-370248-001), San Diego, California. Typographical error has been corrected.	
8	page 7 second para. Specify dimension of "thin cadmium" in: "The model was refined by placing an ultra thin cadmium shield around detector 2 in order to reduce the average depth of investigation for that detector. " next-to-the-last para. Reword the sentence "The range of moisture concentrations of most interest are from 0 to about 30 wt% water." to "The range of moisture concentrations of greatest interest are from 0 to 30 wt% water." Change "investigation" to "interrogation" in: "Figure 3-7 shows computer model estimated depths of investigation for each of the three detectors as a function of waste moisture." In reference to Figure 3-8 explain why the closest detector has the weakest signal.		Cadmium dimension of 0.005 cm included. "greatest" is substituted for "most" I disagree with this change of word choice. Investigation is the standard term in neutron probe well logging literature to describe this parameter (see Ref. Hearst and Carlson) Explanation added: "Detector 3 is predicted to experience the highest count rates, both because it is not wrapped with thermal neutron absorbing material and because it has a larger active region than the other two detectors. Detector 1 is expected to exhibit the lowest counting rates because of the thick thermal neutron absorber, cadmium, completely surrounding the detector."	

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12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
9	page 8 The sentence: "For this estimate of signal contribution, all scattering events are not weighted equally. " should start a new paragraph.		New paragraph begins with: "For the calculated estimates of signal contributions in figures 3-9, 3-10, and 3-11, all scattering events are not weighted equally."	
	last para. Figure 4-22 should be Figure 4-2.		Typographical error corrected.	
	Explain why BF3 was use when earlier the preferred detector was B10.		Previous para. (Sec 4.0): "This prototype probe, utilizing available size and type detectors and a similar neutron source, enabled us to produce a configuration very similar to the detector arrangement modeled in the baseline design." Boron-lined detectors, close to the desired size, were not available in desired time frame. This detector substitution will not affect substance of test results.	
	Metric error. torr is not metric. In Hanford Info, I believe it is Pascal.		Conversion in Pascal has been cited.	

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12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
10	page 9 first para 5 metric errors What is the significance of CH2 following polyethylene? second para. mCi in not metric. last sentence. The word "tub" shows up with no previous reference or explanation. Furthermore, in the Figure it looks like a barrel. next-to-the-last para. one metric error.		Curies are converted to becquerel. Inches converted to centimeters. cc are renamed as cm^3. CH_2 is listed, as an appositive, to inform the reader of the chemical formula of the compound referred to as polyethylene.	

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11	page 10 Was the sand etc. autoclaved or heat-dried before? Does pea gravel have any hydrated moisture? Was it removed before the samples were prepared?		Neither the sand nor the pea gravel were heat dried before mixing and may have contained a small concentration of adsorbed moisture. It is unknown whether or not the pea gravel contains any hydrated moisture. Small unknowns in the makeup of these standards will not change the conclusions of this DTR. Text will be included to clarify that some error in the moisture concentration of these standards is possible because of possible adsorbed or hydrated water in the matrix. Final calibrations of the SMMS will be performed with standards whose composition and moisture content are well controlled and understood.	
	item 7. cc in not metric.		cc changed to cm^3	
	last para. Change the wording of "Approximately 30 tanks on a critical ..." to "Approximately 30 **Hanford Waste** tanks on a critical ...".		Wording change is accepted.	

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12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status
12	page 11 second para. "The amount of neutron absorbing material in the pea gravel is negligible and, therefore, would not affect the results of these tests." This conclusion does not seem to be logical. I'd suspect that the 4.2% was from hydrated water. Also, we are targeting for 3% accuracy. 4.2% is not negligible compared to 3%. third para. "The average systematic error in the count rates determined from measurements over the 4 different locations was 1.2% (rms), and the average statistical error in the count rates is about 0.6% (rms)." Explain how this was done. What do you mean by rms? How did you distinguish between systematic and statistical errors?		This was a simple test to determine if there were significant amounts of neutron absorbing materials in the pea gravel. Results show that either neutrons were attenuated less by the gravel than by the sand or the gravel contained a small amount of water in some form or that the larger void space in the gravel lead to some neutron streaming. Since the neutrons passing through the mixture were already thermalized by polyethylene surrounding the source, it is less likely that the change is because of hydrated material in the gravel. The 3% accuracy is actually ±3 wt% accuracy, which would still be satisfied by a 4.2% change in count rate. The total uncertainty in the measurements is a combination of systematic and statistical effects. The relative statistical error is given by (Number of Counts)$^{-1/2}$. The average statistcal error in the total counts is about 0.6% (one standard deviation). The systematic error is caused by things such as changes with time in the electronics and spatial variations in the test beds, the latter believed to be the most significant contributor to the error. To obtain a measure of the systematic error, four measurements in different positions on each tub were made. The total error was calculated by determining the standard deviation for the group of four measurements on a tub. To derive the systematic error, we assumed that the total error was the sum	

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12 cont			of the systematic and statistical errors added in quadriture. The systematic uncertainty was found to be about 1.2% (one standard deviation).	
13	page 12 second para. one metric error third para. one metric error		Metric equivalents provided.	
14	page 13 first para. one metric error second para one metric error third para. What is you justification for stating that the critical moisture concentration range is 20%?		Metric equivalents provided. Reference cited for 20wt% moisture safety criteria (Meacham et al 1995). The approach for safety characterization states that tanks may be declared "conditionally safe" if their moisture concentration is greater than 20 wt%.	

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15	page 14 second para. one metric error third para. 3 metric errors. "To study how well the probe can determine the amount of neutron absorbing material within the waste, further testing with more tubs and/or additional calculations would need to be performed." Current funding and scheduling does not include "further testing". In this section you should indicate how the probe will be calibrated and how the count rates will be interpreted. you should have formulas similar to: [% moisture] = A + B*r1 + C*r2 + D*r3 moisture conc. [B conc.] = E + F*r1 + G*r2 + H*r3 neutron abs. conc. [% mois/cm] = J + K*r1 + L*r2 + M*r3 moisture grad. where: r1, r2, and r3 are the count rates from each of the detectors. A, B, ...M are constants that will be established during calibration. You should describe, a little, how A, B, ...M will be determined by the calibration procedure.		Metric provided. Current schedule refers to two activities: Calibrate Probe Assembly and Surface Irregularity Testing. The suggested tests/calibrations may be performed within the scope of these activities. A future activity, currently on the schedule, is the preparation of calibration procedures. They do not belong in a development test report. Interpretation of results will be achieved using an automated interpretation routine, TMAD, that has been developed. This routine will compare measured data from each of the detectors with benchmark responses produced using a calibrated computer model. These benchmark responses will not only be available for different moisture concentrations, but also for different moisture gradients as a function depth in the waste. The routine uses second order curve fits to the modeled data to produce solution curves, but, because two variables are assumed (moisture concentration and gradient), a simple equation, like you suggest, is not possible. Measurements are then compared with these curves to locate the best (lowest error) solution. Documentation for this routine will be referenced and a brief explanation of this method will be included in an added section to this test report.	

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16	page 15 first para. second sentence "level agreement" should be "level of agreement" last para. The sentence: "Using these same constants, nearly all of the model-predicted results are in excellent agreement with measured results. " seems optimistic. Most of the points are off by 10 to 20%. "Since these absorption properties, were changed in a know way,..." should be: "Since these absorption properties, were changed in a known way,..." The sentences: "More tests will be needed to determine how these differences may be reconciled. These tests could include multiple boron concentration standards and should utilize standards where the uniformity of the boron distribution is better controlled better." are requesting additional funding and time which do not show up in the schedule.		Missing word added. Given the lack of detail included in the computer model and the amount of systematic uncertainty present in the experimental measurements, the agreement is quite good. Substitute "good" for "excellent". Typographical error corrected. These tests/calibrations will be performed under currently scheduled activities. See response to Item 15.	

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17	page 16 first para. The "should" in the sentence: "Both the test results and the modeling predictions confirm that the baseline surface moisture probe design should be capable of meeting the data needs." was discussed in item 3. Also, the last sentence.		Sentence revised: "Both the test results and the modeling predictions, performed to date, confirm that the baseline surface moisture probe design is capable of meeting the sensor design criteria." Sentence revised: "Results suggest that data obtained from all three detectors will provide information that will lead to an interpretation of the surface waste moisture concentration and an estimate of the moisture concentration gradient as a function of depth within the top 10-15 cm of waste." We do not intend to misrepresent probe capabilities by stating that the probe will perform in ways not yet demonstrated.	

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18	page 16 last para. second sentence and the last two sentences. At each point on the waste you will get three count rates--one from each detector. And, at each point on the waste you will be looking for three numbers i.e.: surface moisture content, moisture gradient and neutron absorber concentration. Suppose you have more than one model. When you input the three count rates into the first model, it will produce the desired three numbers. If another model were used, and it produced a different result, how would you know which one is correct? In other words, all models would have to give the same results, if they were accurate. That result could be obtained from formulas similar to those I suggested in Item 15. I do not see the need for a big, model-handling computer in the van. A PLC could handle the formulas. I can imagine you could have several models based on different stratification schemes, or different neutron absorber distributions, etc. Each may yield different sets of the three desired numbers, but how would a person choose between them? You may be planning to submit your results to the Safety Program and let them choose. Are we supposing they would have means to choose between the models/results?		We plan to ignore effects of thermal neutron absorbers for initial interpretations for two reasons. 1) Elements that have large thermal neutron absorption cross sections and are expected to be present in some tank wastes, such as Cadmium, are not likely to be found in the salt cake. Most of these elements would form oxide compounds that are not very water soluble and would likely have precipitated out into the sludge rather than crystallized in the salt cake. The surface moisture probe will be deployed primarily upon salt cakes. 2) Two of the three detectors in the baseline probe design have cadmium thermal neutron shields that will nearly eliminate these effects. As in reply to Item 15, the interpretation program will choose the interpretation that provides the best fit to the data. Assumptions about waste properties such as bulk density will be made and stated in interpretation reports. In cases where multiple or no clear interpretation is made, a scientist will interpret the data using additional modeling, hand calculations, and any extra available data (such as tank specific sampling or waste history data). Provided interpretations will include estimated uncertainty or confidence levels. We will not rely upon the Safety Program to select from among a number of results.	

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19	page 16 last para. Also, funding and scheduling will be needed for all this modeling which is not in the current budget. Near the beginning of the last para. target accuracy of 5% is stated. I believe this deviates from the FDC which claims 3%.		The requirement for this modeling has been known to the WHC physicist since the beginning of this project and has been communicated to project management. This 5% accuracy refers to the accuracy of individual modeling predictions of count rates. The 3% accuracy, actually 3 weight percent accuracy in the FDC, refers to the target accuracy of the interpretations of the waste moisture. For the detector response predicted in Figure 3-8, a 5% error in count rate would translate to about a 1 wt% error in moisture prediction if the interpretation were based upon a single model calculation. A 5% error in all modeled count rates, if not systematically high or low compared with measurements, would result in a family of "calibration curves" fit more accurately than 5% to the measurements. The use of these curves would result in less than a 1 wt% contribution to the error in the interpretation from errors in the modeling.	

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20	Figure 4-15 These graphs show the expected sensitivity of the SMMS probes. Typically, I'd say you are getting about 500 counts per %. For a target accuracy of 3%, you'd need your count result to be accurate to 15. In the Figure you are indicating on the order of 20 000 counts during the counting period which would be repeatable within 141 counts (based on one standard deviation being the square root of 20000). Repeating the counting time, to increase accuracy, to 100 periods would (perhaps) provide sufficient accuracy (i.e., 14). One hundred counting periods would be 83 hours. Are we planning to count each probe location for 83 hours?		The target accuracy is ±3 weight percent not 3 percent absolute. Detector 2, for instance, detects about 14100 neutrons in 50 seconds at 15 wt% moisture and will detect about 16100 neutrons at 18 wt% moisture for a difference of about 2000 counts. As you point out, poisson counting statistics would give an error of about ±120 counts ($14000^{1/2}$) using a counting period of 50 seconds. This corresponds to an associated weight percent uncertainty of about 0.2 wt%. Anticipated counting periods of about 4-5 minutes will give an uncertainty, due to counting statistics alone, of less than 0.1 weight percent.	
21	Figure 3-1 Add a title. Add an eleventh segment so this figure will be consistent with Figure 2.		You reviewed draft figures, many of which did not yet have titles printed on the page. A title has been added and an 11th segment will be drawn.	
22	Figure 3-2 Change title from: "Predicted Responses of Horizontal Placed Surface Neutron Detectors to Changes in Moisture. Incremental Source-to-Detector Spacing Interval: 4 cm." to "Predicted Responses of the Horizontal-Placed Surface Neutron Detectors Shown in Figure 1 to Changes in Moisture"		Change accepted.	
23	Figure 3-3 Indicate horiz and vertical locations of source.		Source was maintained at the same location, relative to the waste surface, for all of these calculations.	
24	Figure 3-5 Include a Title		Title included.	

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25	Figure 3-6 Include a title. Include dimensions of detector/source or else reference a drawing with dimensions. I would really prefer it if this figure were reproducible in black and white.		Title included. I will include a copy of a sample MCNP input file in an appendix that includes all dimensions in the modeled geometry. This figure is drawn in black and white, not color.	
26	Figure 3-7 Add a title		Title included.	
27	Figures 3-9, -10 Add titles. Explain the fine printing under the figures. What are the abscissas and their units? I would really prefer it if these figures were reproducible in black and white.		Titles added that summarize information and fine printing deleted. Abscissas explained in title. Color represents neutron energy (legend added), black and white not possible to convey all information.	
28	Figure 4-1 one metric error in title		Metric conversion made.	
29	Figure 4-13 Metric error in title. Metric error on graph.		Metric conversion made.	
30	Figure 4-14 Metric error in title. Metric error on graph.		Metric conversion made.	
31	Figure 4-17 How can I tell what moisture/B-conc. the labels on the abscissa represent?		Extra explanations added to title and to axis label.	

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