HEDL-SA--2867-FP

DE84 003950

CONF - 831175--1

DISCLAIMER

FUEL DEBRIS ASSESSMENT FOR THREE MILE ISLAND UNIT 2 (TMI-2) REACTOR RECOVERY BY GAMMA-RAY AND NEUTRON DOSIMETRY

Raymond Gold, James H. Roberts, James P. McNeece, Bruce J. Kaiser, Frank H. Ruddy, Christopher C. Preston, James A. Ulseth, and William N. McElroy

August 22, 1983

6th International Conference on Nondestructive Evaluation in the Nuclear Industry

November 27 - December 2, 1983

Zurich, Switzerland

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company, a subsidiary of Westinghouse Electric Corporation, under the Department of Energy Contract No. DE-AC06-76FF02170
P.O. Box 1970, Richland, Washington 99352

DISCLAIMER

FUEL DEBRIS ASSESSMENT FOR THREE MILE ISLAND UNIT 2 (TMI-2) REACTOR RECOVERY BY GAMMA-RAY AND NEUTRON DOSIMETRY

Raymond Gold, James H. Roberts, James P. McNeece, Bruce J. Kaiser, Frank H. Ruddy, Christopher C. Preston, James A. Ulseth, and William N. McElroy

Westinghouse Hanford Company
Hanford Engineering Development Laboratory
Richland, Washington U.S.A.

INTRODUCTION

As a result of the accident on March 28, 1979, fuel debris was dispersed into the primary coolant system of the Three Mile Island Unit 2 (TMI-2) reactor. Location and quantification of fuel debris is essential for TMI-2 recovery. TMI-2 fuel debris assessments can be carried out nondestructively by neutron and gamma-ray dosimetry. In gamma-ray dosimetry, gamma-rays associated with specific fission products are measured. In neutron dosimetry, one measures neutrons generated from a combination of spontaneous fission and (α,n) reactions in the fuel. Efforts to date have been directed toward fuel debris characterization of the makeup and purification demineralizers, A and B, which maintain reactor coolant water purity. Since both A and B demineralizers were on-line during the accident and high gamma ray intensities have been observed in the location of these demineralizers, it was conjectured that significant amounts of fuel could have been trapped in the resin beds. An overall isometric view of these TMI-2 demineralizers is shown in Figure 1.

Existing constraints precluded the application of many routine dosimetry methods in the demineralizer cubicles. These constraints arise from many origins, ranging from sensitivity and background considerations to practical day-to-day restrictions of TMI-2 recovery operations. Two highly specialized methods have been applied to overcome these constraints, namely solid state track recorder (SSTR) neutron dosimetry and continuous gamma-ray spectrometry. The general applicability of SSTR neutron dosimetry for TMI-2 debris assess-

ments has already been established[1] and specific results for demineralizer A have been reported.[2] Results of continuous gamma-ray spectrometry with a unique Si(Li) Compton spectrometer have also been issued.[3] The ability of the Si(Li) Compton spectrometer to measure gamma-ray continua in reactor environments has been well established.[4-6] The Si(Li) gamma-ray spectrometry and SSTR neutron dosimetry efforts are described separately below.

Si(Li) CONTINUOUS GAMMA-RAY SPECTROMETRY

Access to the demineralizer A cubicle was limited to a 6" x 9" opening, penetration #891 in Figure 1, which is located at the 321'9" elevation approximately 8 feet above the demineralizer tank. A special boom and winch assembly was fabricated to remotely position the spectrometer/shield package inside the cell. The boom provided for horizontal movement of the detector over the complete width of the cell. A swing arm and winch provided for lowering the detector down both the north and south sides of the tank. Tape measures attached to the boom allowed for accurate positioning of the detector.

To reduce the intense background radiation from ^{137}Cs, the Si(Li) detector was surrounded by a 5.5" diameter lead shield 8" in length. Two shields were used to provide different levels of background attenuation. Small diameter collimator holes in the shields' sides permitted accurate mapping of the geometrical source distribution within the demineralizer tanks. The shield weighed 78 pounds and permitted operation in gamma fields up to 2000 R/hr. Horizontal traverses were made across the top of the tank at the 321'9" elevation and vertical traverses were made down both the north and south sides of the tank.

Two sets of data were taken, one set with the collimator opening plugged (background) and the other set with the collimator opening toward the tank (foreground). Geometrical source distributions are obtained by subtracting the background data from the foreground data. This difference is the response due only to the uncollided gamma rays that enter through the collimator opening. The collimator limits the field of view of the detector to small diameter regions, thereby allowing the relative source intensity distribution to be

geometrically mapped. On the other hand, flux distributions are obtained from the background data only. The flux at any location is obviously a function of the total source within the cell, not just the emission from a small region.

A typical Compton recoil electron spectrum obtained in the background mode is shown in Figure 2. The Compton edges corresponding to the most significant gamma rays are labeled. The gamma ray spectrum is obtained from the observed electron spectrum by an iterative unfolding technique.[4-6] The unfolding method requires the use of a response matrix whose column elements are the responses of the detector for a given gamma ray energy. The response matrix is derived by measuring the response of the Si(Li) spectrometer with a set of monoenergetic gamma ray calibration sources. Figure 3 displays the unfolded gamma ray spectrum from the observed electron spectrum shown in Figure 2.

Figures 4 and 5 display the relative intensity distributions of ^{137}Cs and ^{144}Ce from the horizontal and vertical traverses carried out in the demineralizer A cubicle. These data reveal non-uniform ^{137}Cs and ^{144}Ce source distributions. These horizontal source distributions are dramatically skewed with the higher intensity toward the north side of the tank. The vertical distributions show both the ^{137}Cs and ^{144}Ce to be limited to a region below the 309' elevation. Above 309' there is virtually no ^{144}Ce source. Some ^{137}Cs source is present above the 309' elevation. The ^{137}Cs source above 309' may be due to residual contamination left on the tank wall as the resin bed subsided due to radiation damage and thermal degradation.

Background data obtained from the horizontal traverse were used to determine the absolute content of ^{144}Ce in the tank. Before the ^{144}Ce flux data could be used to determine the amount of fuel in the demineralizer tank, it was necessary to establish the amount of attenuating medium inside the tank. The difference between a tank full of water and a dry tank results in a significant difference, in fact up to two orders of magnitude, in the calculation of the fuel content.

The shape of the Compton recoil electron spectrum from the 0.662 MeV

^{137}Cs gamma-ray was used to determine the water equivalent attenuator in the tank. The foreground minus background spectrum at the 321'9" elevation was used. This spectrum was compared to spectra obtained from laboratory calibration experiments in which foreground minus background spectra from a ^{137}Cs source were measured for various thicknesses of water attenuator. In this way it was demonstrated that the ^{144}Ce source could be defined simply as a distributed source in a water equivalent medium in the two foot region below 309' elevation. The vertical intensity distribution of the source has already been shown in Figure 5. There is no additional attenuating medium above the 309' elevation.

Assuming the ^{144}Ce fission product does not migrate out of the fuel, the absolute activity of ^{144}Ce is directly related to the quantity of fuel present. Based on the observed source geometry and the measured absolute flux of the ^{144}Ce 2.18 MeV gamma-rays, the fuel content of the A demineralizer was calculated to be 1.3 ± 0.6 kg. The principal factors contributing to the experimental error of this result are uncertainties in the attenuation coefficient of the ^{144}Ce 2.18 MeV gamma-ray in both lead and water as well as the uncertainty in the ^{144}Ce fission product yield, which is based on fission product inventory calculations for TMI-2 fuel.

SSTR NEUTRON DOSIMETRY

SSTR neutron dosimeters were constructed as shown in Figure 6. Two 3" x 1" sheets of 0.004" thick 93% enriched ^{235}U were sandwiched between two pieces of mica and pressed in firm contact against an aluminum support plate between two 0.25" thick pieces of lucite. The lucite was used to enhance the neutron signal through an albedo effect, which has been reported previously.(1) The total SSTR area of this neutron dosimeter is approximately 85 cm^2. These dosimeters were assembled at TMI-2 immediately prior to the exposure to reduce background due to cosmic ray neutron induced fission and from spontaneous fission of the ^{238}U in the uranium.

Due to the intense gamma ray fields present near the demineralizers, SSTR neutron dosimeters had to be placed remotely on stringers from outside

the cubicle. Only the demineralizer A cubicle was accessible. After a 29 day exposure, the SSTRs were transported to the National Reactor Dosimetry Center at the Hanford Engineering Development Laboratory (HEDL), where they were processed by etching with 49% HF at room temperature for 90 minutes. The developed tracks from selected dosimeters were then manually counted with the aid of a microscope. Figure 7 shows the location of the SSTR dosimeters as well as the track density results that were obtained.

Background measurements gave a track density of about 5 tracks/cm^2, whereas baseline measurements in the demineralizer A cubicle was about 10 tracks/cm^2. This difference, ~5 tracks/cm^2, is due to room return neutrons. Whenever neutron metrology is conducted in a laboratory bounded by walls containing moderator materials (hydrogeneous concrete in the present case), the source neutrons will be transported, scattered, and absorbed throughout the environment and particularly in the walls if the dimensions of the laboratory are small. Room return neutrons are the last vestiges of neutrons originally emitted by the source, and, indeed, these neutrons have been scattered so often that they have attained thermal equilibrium with their environment. They prevade the entire laboratory space like a uniform homogeneous mist or fog. They retain no knowledge of their origin with the exception of their intensity, which is proportional to the total emission rate of the source. Consequently, proper calibration of room return neutron intensity will provide a determination of absolute neutron source strength that can then be used to quantify the amount of fuel that is present.

Room return response of the SSTR dosimeters was evaluated by calibration experiments in a concrete cubicle mockup at Hanford, using a ^{252}Cf spontaneous fission source. Based on this room return response, the SSTR neutron dosimetry result was 1.7 ± 0.6 kg of fuel in demineralizer A. The dominant contributing factors to experimental error are the statistical uncertainties of the track density data, the uncertainty in the room return calibration constant, and the uncertainty in the neutron emission rate, which is based on actinide inventory calculations for the TMI-2 fuel.

CONCLUSIONS

The fuel debris content of the TMI-2 demineralizer A has been determined nondestructively by Si(Li) continuous gamma-ray spectrometry and SSTR neutron dosimetry. To our knowledge, gamma-ray spectrometry has never before been carried out under such adverse conditions, where the general radiation field intensity exceeded 2000 R/hr. The track densities observed in the SSTR neutron dosimeters correspond to extremely low neutron flux intensities. In fact, the total neutron emission rate in the demineralizer A cubicle, about 500 neutrons per second, corresponds to an observed flux intensity of the order of 10^{-3} neutrons/(cm^2·sec), which is generally comparable with the intensity level of the cosmic-ray neutron flux at sea level. As a consequence, SSTR dosimetry is the only known method of neutron metrology possessing the combined attributes of passive applicability, extreme sensitivity, and low background response required for such fuel debris quantification experiments.

Si(Li) gamma-ray spectrometry and SSTR neutron dosimetry results, namely 1.3 ± 0.6 kg and 1.7 ± 0.6 kg, are in excellent agreement for the fuel debris content in TMI-2 demineralizer A. Background corrected SSTR data are compared with ^{144}Ce gamma-ray data as a function of elevation in Figure 8. These data reveal the complementary nature of these two independent methods. Indeed, source spatial distribution data obtained with the collimated Si(Li) spectrometer were used to guide the SSTR calibration experiments. On the other hand, SSTR evidence from the vertical stringer data implied that the demineralizer A tank was dry above the 309' level. This information, in turn, provided useful guidance for the analysis of the Si(Li) spectrometer data. Hence, these two independent nondestructive dosimetry methods provided concordant and complementary results. Some six months later, samples taken from the demineralizer A tank substantiated our conclusion that this tank was dry.

Finally, it is amusing to note that the experimentalist working in neutron metrology invariably regards "room return" neutrons as an undesirable background that compromises the accuracy of his work. To our knowledge, this is the very first productive application of this "room return" phenomenon for the benefit of society.

REFERENCES

1. R. Gold, F. H. Ruddy, J. H. Roberts, C. C. Preston, J. A. Ulseth, W. N. McElroy, F. J. Leitz, B. R. Hayward, and F. A. Schmittroth, "Application of Solid State Track Recorder Neutron Dosimetry for Three Mile Island Unit 2 Reactor Recovery," Proceedings of the Fifth Pacific Northwest Working Group on Nuclear Track Registration, July 28-29, 1982, Richland, Washington, Nucl. Tracks 7, pp. 13-30 (1983).

2. F. H. Ruddy, J. H. Roberts, R. Gold, and C. C. Preston, "Applications of Solid State Track Recorder Neutron Dosimetry for Fuel Debris Location in the Three Mile Island Unit 2 Reactor Coolant System," Proceedings of the 12th International Conference on Solid State Nuclear Track Detectors, September 4-10, 1983, Acapulco.

3. J. P. McNeece, B. J. Kaiser, R. Gold, and W. W. Jenkins, "Fuel Assessment of the Three Mile Island Unit 2 Makeup Demineralizers by Continuous Gamma-Ray Spectrometry," HEDL 7285 (1983).

4. R. Gold and B. J. Kaiser, "Status of Compton Recoil Gamma-Ray Spectroscopy," Trans. Am. Nucl. Soc. 33, p. 692 (1979).

5. R. Gold and B. J. Kaiser, "Reactor Gamma Spectrometry: Status," Proc. of the Third International ASTM-EURATOM Symposium on Reactor Dosimetry, Ispra, Italy, October 1-5, 1979, EUR 6813, Vol. 11, pp. 1160-1171 (1980).

6. R. Gold, B. J. Kaiser and J. P. McNeece, "Gamma-Ray Spectrometry in Light Water Reactor Environments," Proc. of the Fourth International ASTM-EURATOM Symposium on Reactor Dosimetry, Gaithersburg, MD, March 22-26, 1982, NUREG/CP-0029, Nuclear Regulatory Commission, Washington, D.C., Vol. 1, pp. 267-279 (1982).

FIGURES

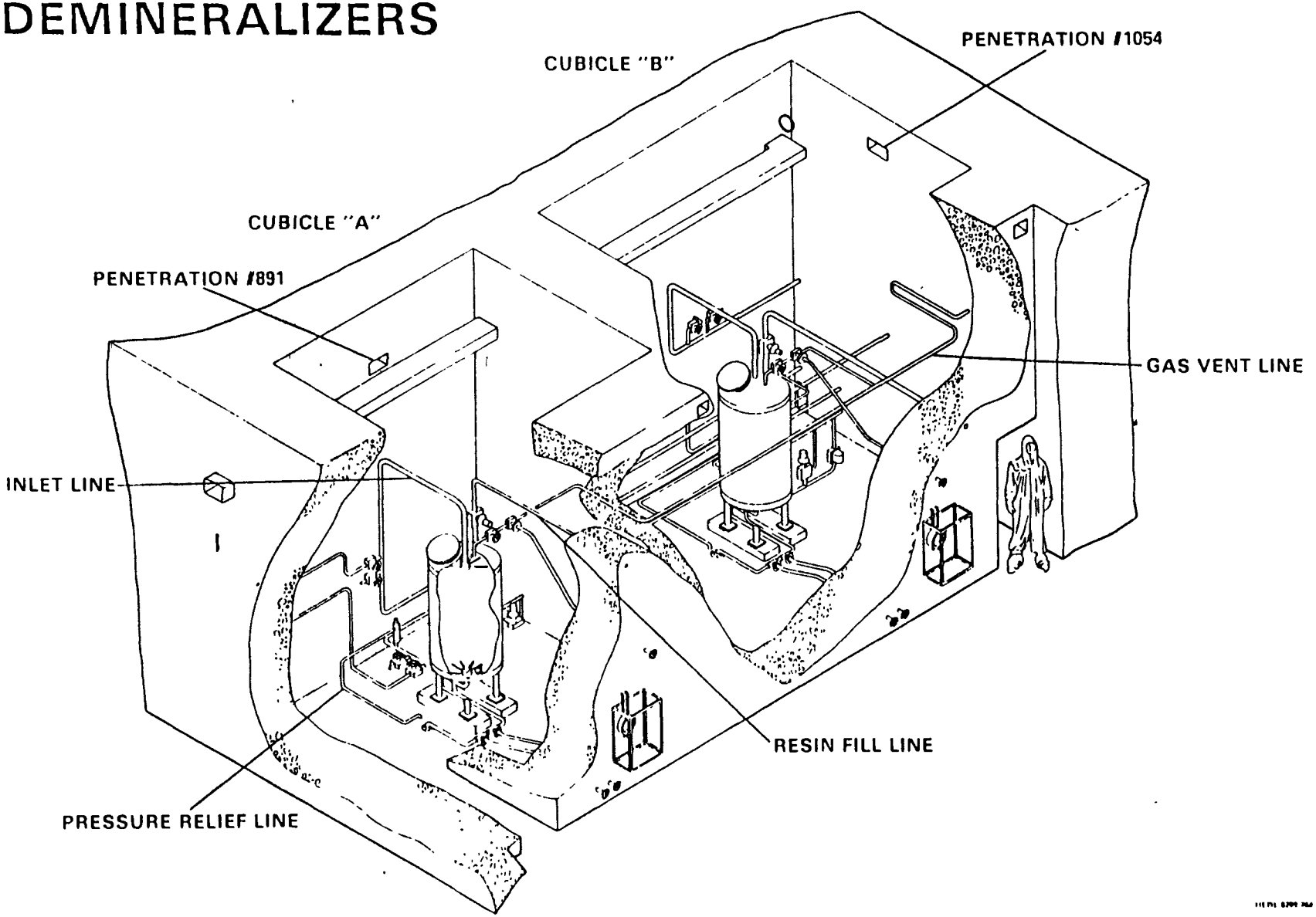

FIGURE 1. Isometric view of the TMI-2 make-up and purification demineralizer cubicles.

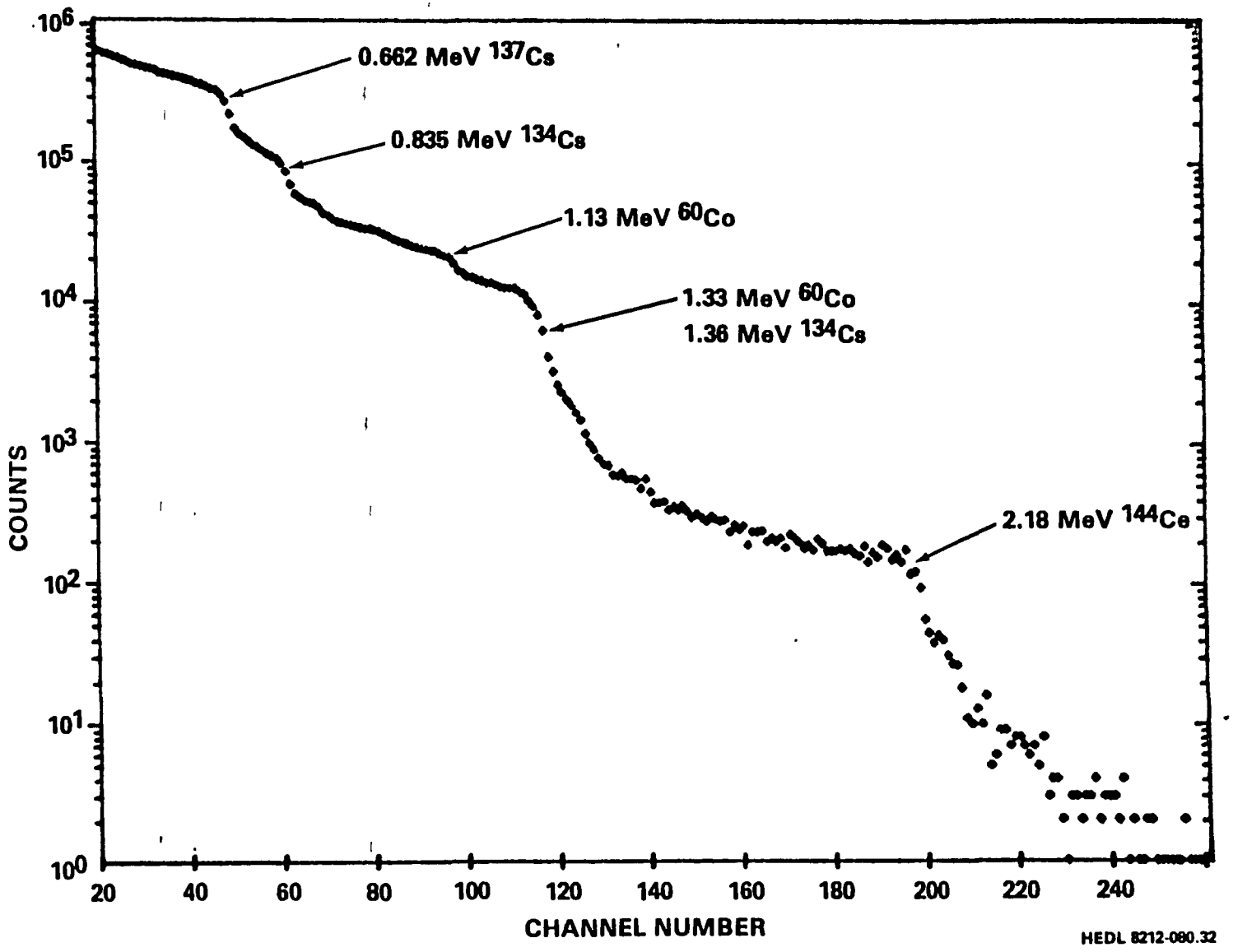

FIGURE 2. Background Compton recoil electron spectrum at 321'9" elevation approximately 8' over the center of demineralizer A.

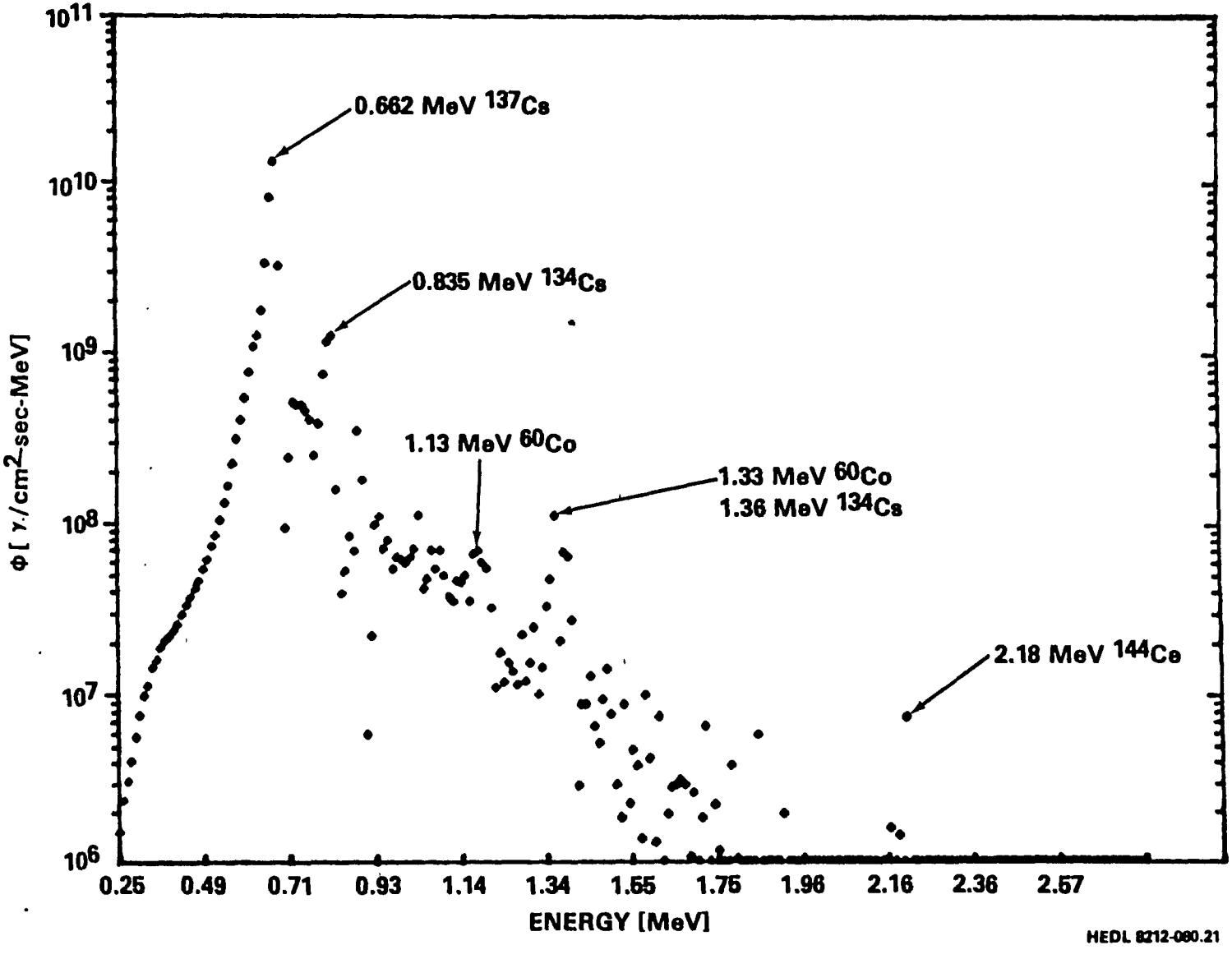

FIGURE 3. Unfolded background gamma-ray continuum from the electron spectrum observed at the 321'9" elevation approximately 8' over the center of demineralizer A (see Figure 2).

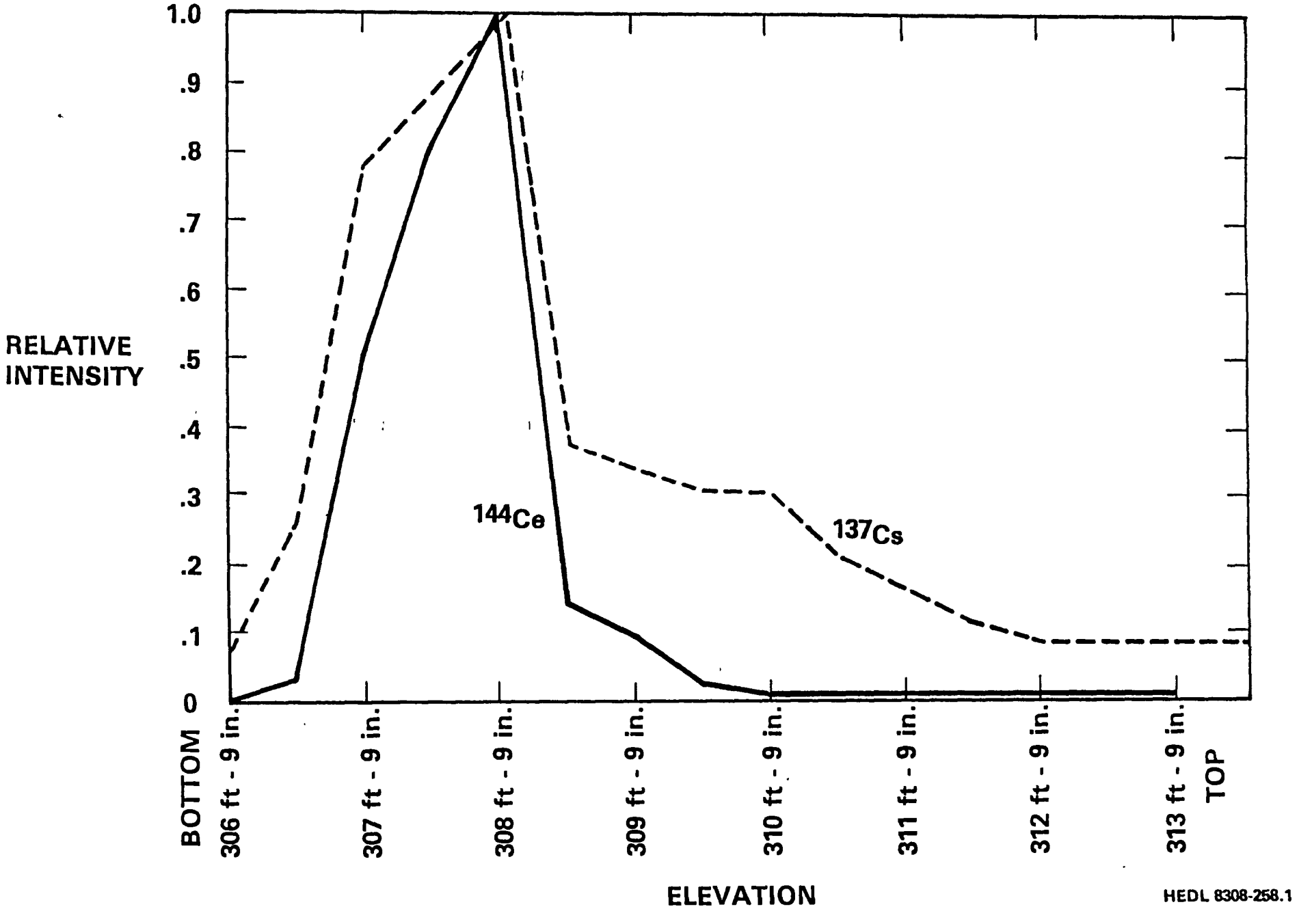

FIGURE 4. Relative ^{144}Ce and ^{137}Cs source intensities from the vertical scan on the south side of demineralizer A.

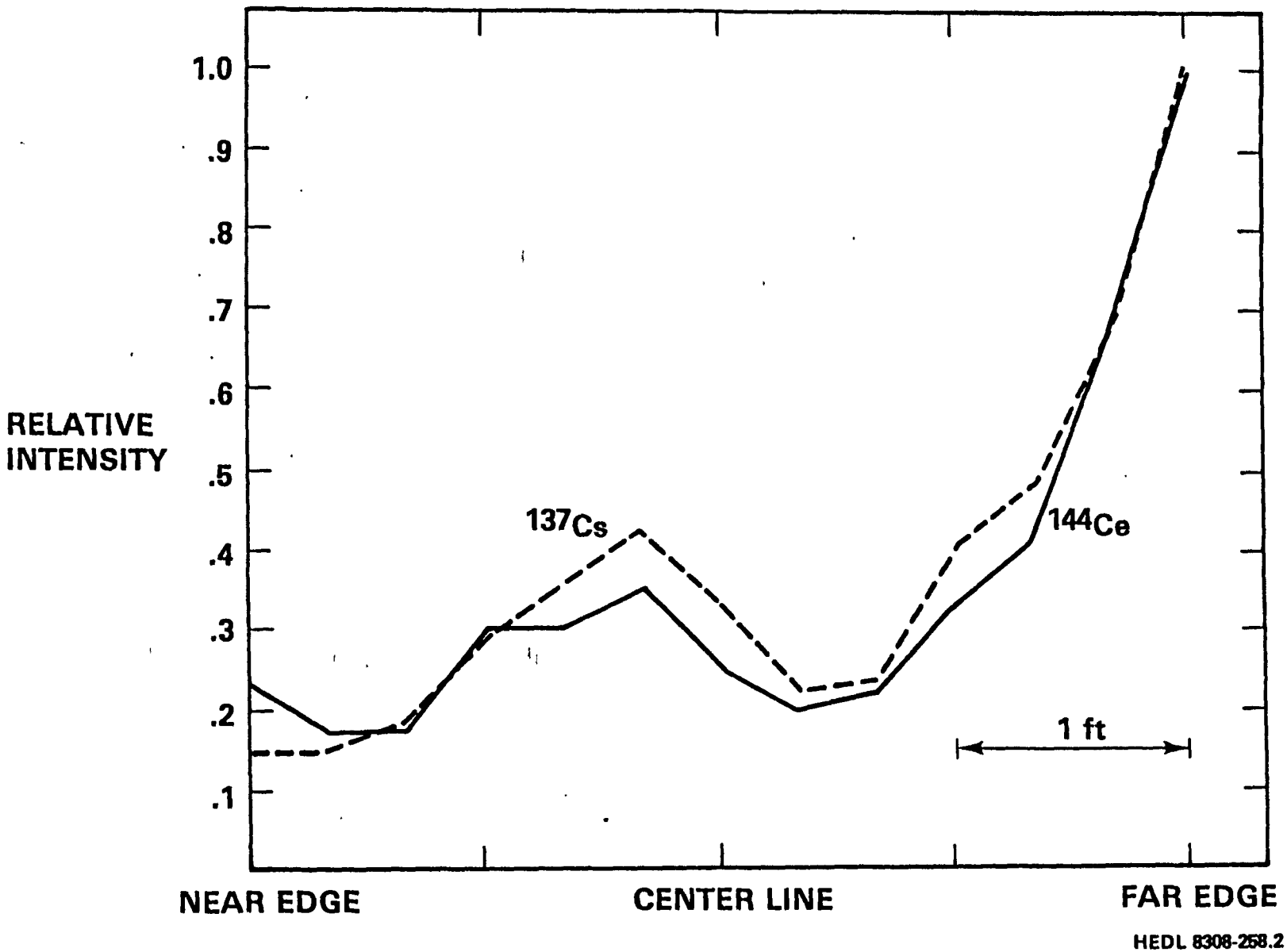

FIGURE 5. Relative ^{144}Ce and ^{137}Cs intensities from the horizontal scan approximately 8' over demineralizer A at 321'9" elevation.

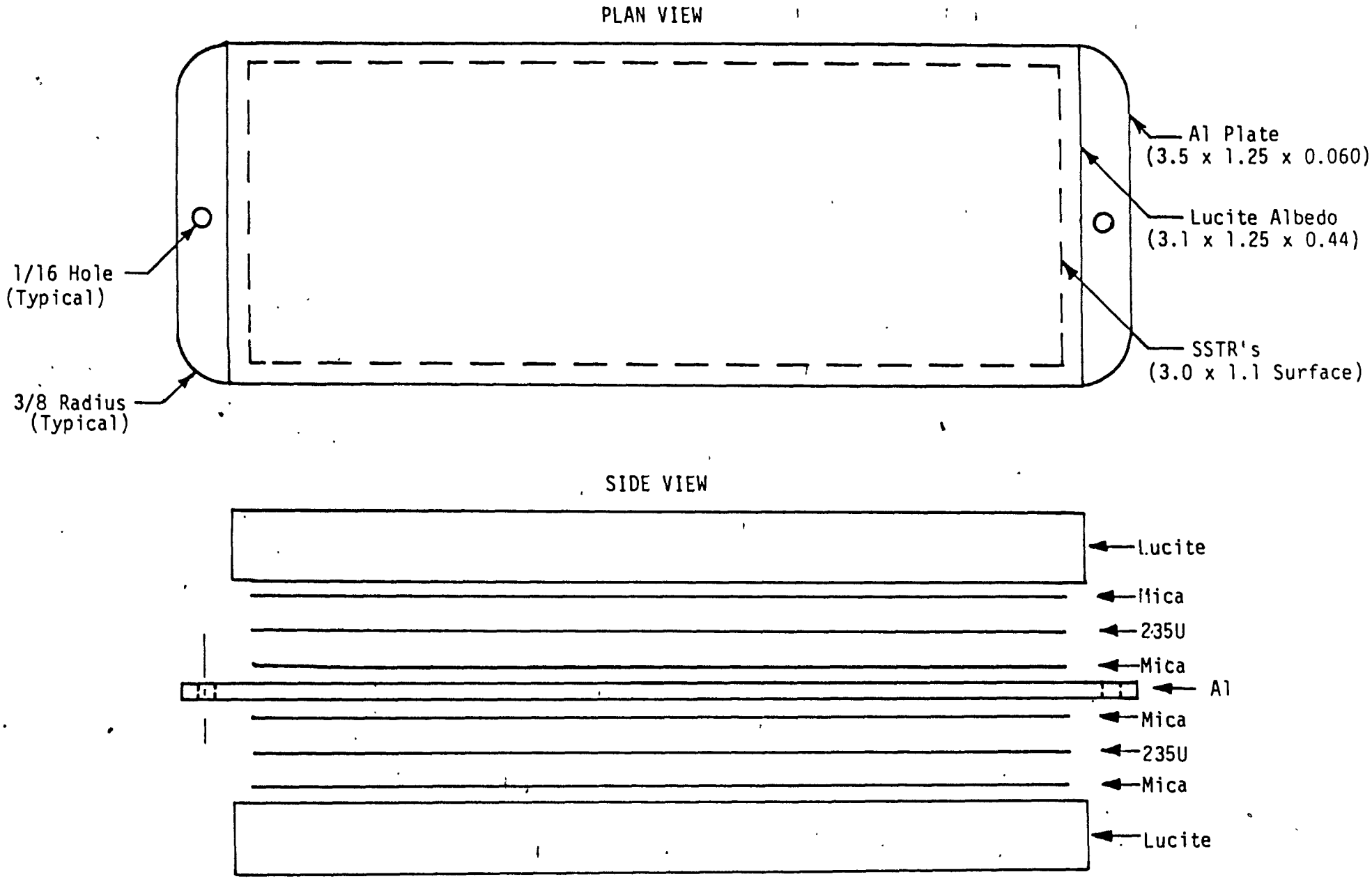

FIGURE 6. SSTR neutron dosimeter used for the TMI-2 demineralizer A experiment.

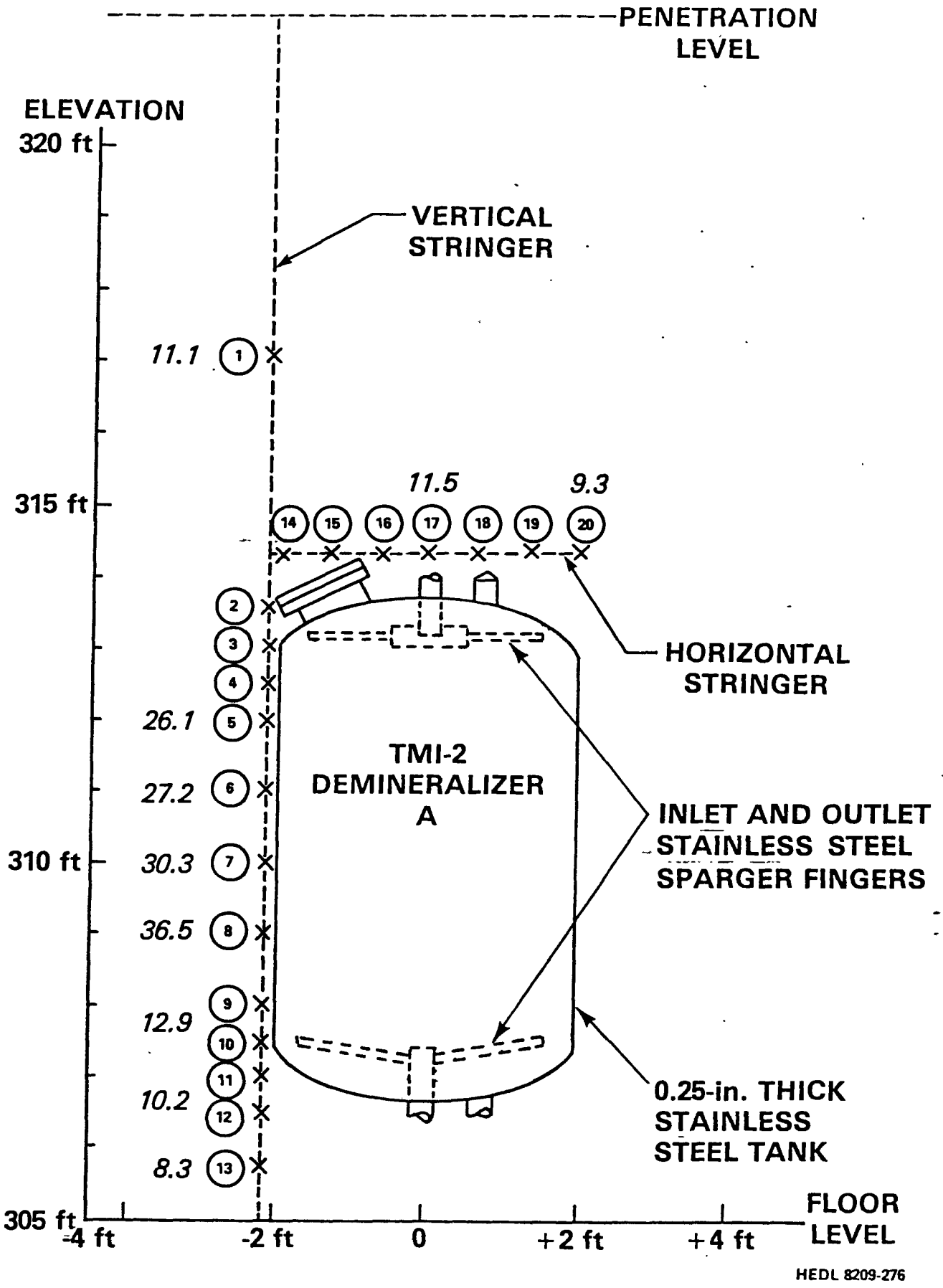

FIGURE 7. Location of the SSTR neutron dosimeters on the horizontal and vertical stringers which were remotely positioned in the demineralizer A cubicle. The underlined numbers in italics are the observed track densities in tracks/cm^2 at selected dosimeter locations.

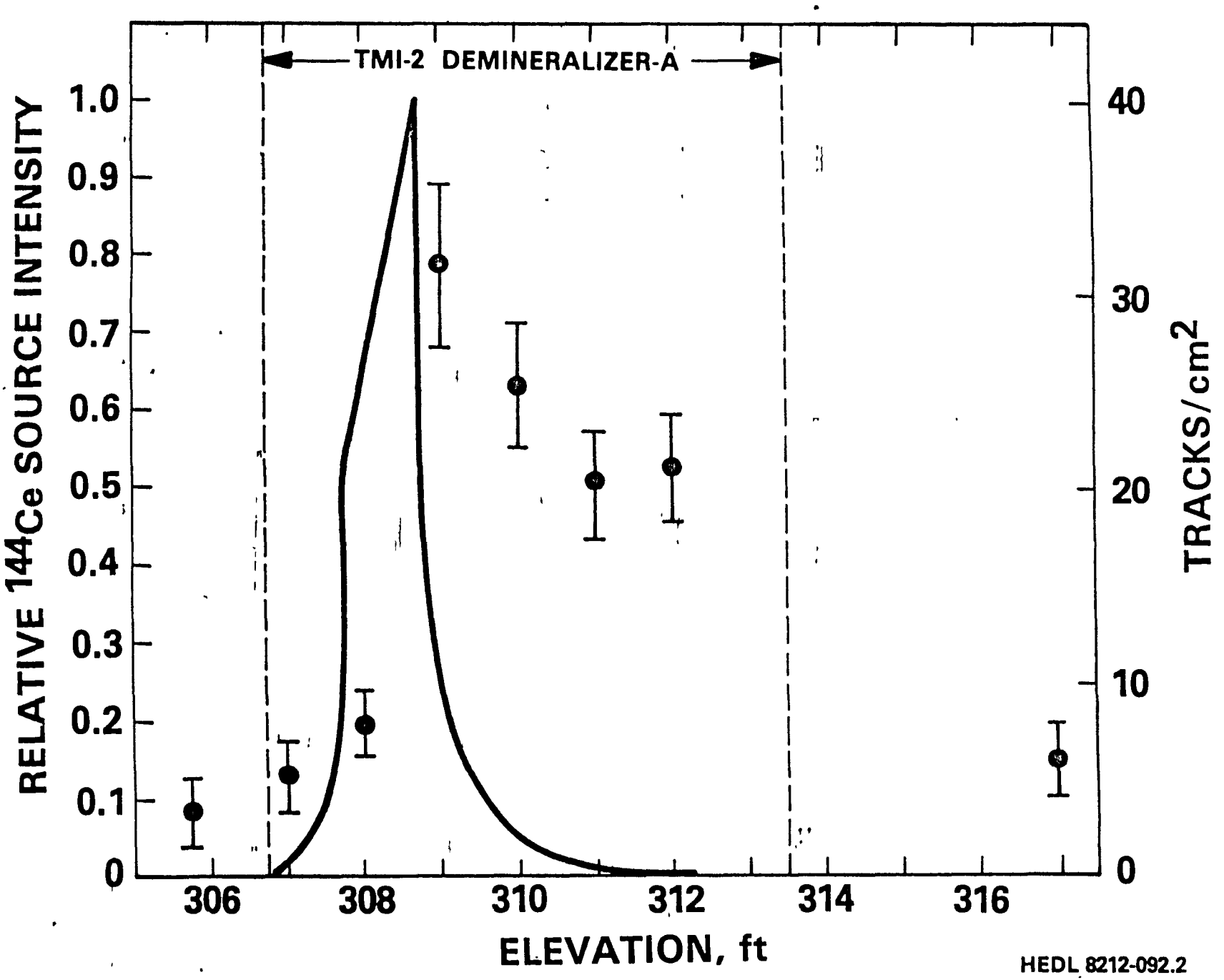

FIGURE 8. Observed track density as a function of elevation for SSTR neutron dosimeters exposed in the TMI-2 demineralizer A cubicle in comparison with ^{144}Ce activity obtained from Si(Li) continuous gamma-ray spectrometry.