USE OF LOGGING IN URANIUM PROSPECTING

By
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INTRODUCTION

The nation's ever increasing need for vast amounts of power capacity has vaulted uranium logging into a vigorous industry. As prospecting has become intensified, companies are using more complex and technical ways of finding uranium ore.

The areas known to be favorable for the deposit of uranium ore are often surveyed first by using airborne electronic sensing devices. Highly sensitive magnetometers and gamma ray detectors are being used in measuring surface deposits, but since most outcrops of uranium have been found, and a few feet of soil will effectively mask the ore from even the most sensitive gamma detectors, any indication of radioactive areas calls for exploratory drilling.

EXPLORATION AND PRODUCTION DRILLING

Much of the world's uranium ore is produced by either open pit or strip mining. Shaft mining is prevalent in the United States, but only to about 1500' in depth. Therefore, the major prospecting efforts generally are limited to this depth, although some companies are exploring deeper. In comparison to average oil well depths, the present uranium drill hole depths are shallow. The exploratory drill holes are laid out in a grid pattern that will cover the entire area. In practice, grid patterns may cover as much as thirty miles in length and width. The holes are usually drilled on a line with quarter mile spacing for the preliminary search. Smaller grids are then drilled in any area where ore is located. In order to define the ore bed, it may be necessary to drill some holes on a grid pattern with as close as 10' spacing between centers. After exploratory drilling has indicated the presence of uranium ore, "core" holes may be drilled to obtain samples that may be chemically assayed.

It is the usual practice to have the logging unit on the drill hole as soon as possible after completion. For example, some contracts require that drill hole only has to remain open for probing two hours after completion of the drilling. As the holes are shallow and closely spaced, one logging unit may log several wells in one day. This need for having logging units available as soon as the well is completed has resulted in many companies acquiring their own "probe" units. To the mining people, a "probe" unit is what the oil industry refers to as a logging unit.

Well logging tools familiar to the oil industry are being used for uranium exploration. They fit the "slim hole" classification since the uranium drill holes are normally from 3 inches to 4¾ inches in diameter. The basic and most useful logging tool is the gamma ray gross count probe. It is like a conventional oil well gamma ray gross count probe but has wider range of response. It provides the basic log because it directly detects the presence of uranium ore. With proper calibration, it will also provide quantitative evaluation of the ore body.

Resistivity logs are used in establishing lithology and/or underground mapping of new areas. Other logs useful are the S.P. for bed definition and water salinity determination, hole caliper for hole size correction factors, bulk density for calculating volume and weight of ore, sonic velocity measurements for cross checking the accuracy of seismic surveys, and temperature logs to assist in water migration studies.

GAMMA GROSS COUNT PROBE

After locating an ore body, the logs will be used for economic evaluation. The gross count gamma probe needs to be capable of producing the basic log for these calculations. Since the ore body may be expected to have any or all grades of ore, the gamma probe must have a wide range ratemeter with the cable connecting the downhole tool. Gross count simply means that the ratemeter is observing all gamma energy levels that are present at the detector. As the hardware and technique for accomplishing these objectives can be involved, the details are given under the following beginning with cable types.

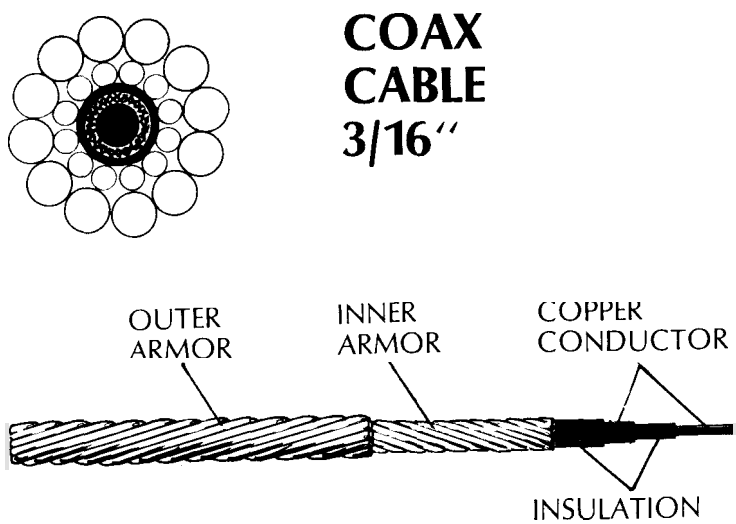

Fig. 1.

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CABLE TYPES

Multi-conductor cable will permit running multiple log types simultaneously. In areas where the S.P. and resistivity curves are both required along with the gamma log, a four conductor cable can be used to enable all logs to be recorded simultaneously. In general, uranium probe units use small diameter cable since use of this size cable permits using a small draw works and mobile vehicle for transportation. Core guns as small as 3 inches O.D. have been available only recently. In using core guns, it is recommended to have larger diameter cable for retrieving the core gun after taking samples. This is one of the most severe operating conditions for a probe cable and dictates using cable no smaller than 5/16 inch in diameter. Typical core barrel size for a 3 inch gun would be ⅞ x 1¼ inches. Job breakdowns may be caused by either cable failure or simple cable head leakage. Loss of insulation resistance will attenuate the signal.

Various types of cable are shown in Figures 1, 2, and 3. Currently the most commonly used cable for uranium logging is the 3/16 inch diameter. Both single and multi-conductor types are used, depending on the suite of logs to be run and whether or not the simultaneous recording of all logs is desired. The insulation resistance of single conductor cable is superior and often selected by users because of this factor. Since good operating practices dictate minimum number of runs, most companies use the multi-conductor types.

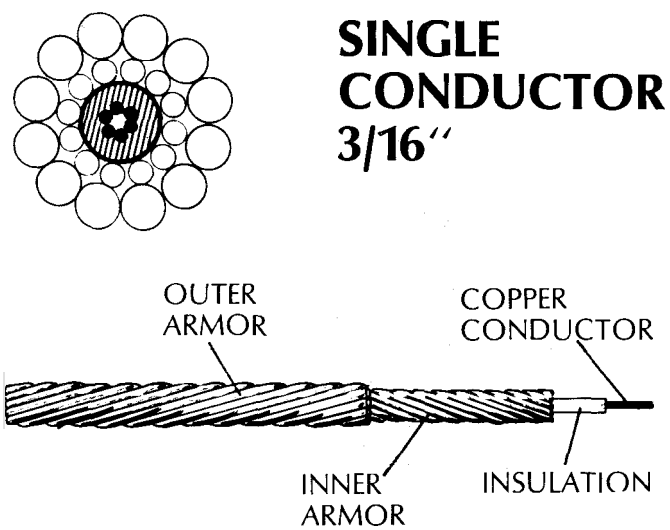

Fig. 2.

The most recent trend in cables has been to the coaxial type. These cables have the advantage of being able to transmit high frequency logging signals with lower line losses than the conventional types of well logging cable. The concentric conductors and copper jacket serve as a more efficient conductor, and have improved greatly the high frequency response, which would be associated with radiation spectral logging probes.

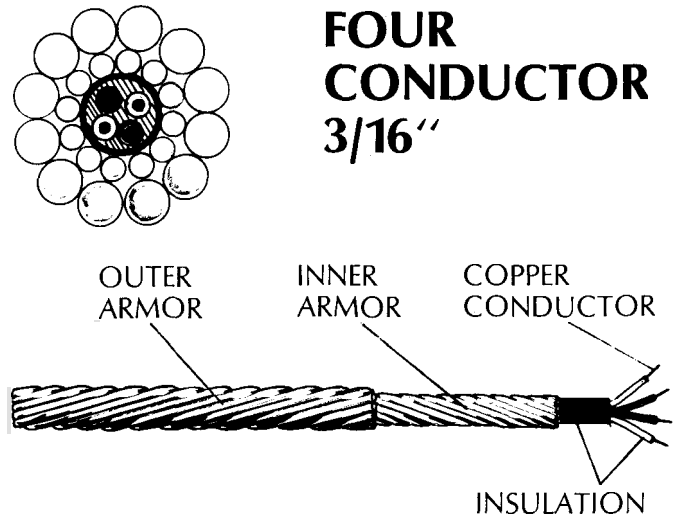

Fig. 3.

DETECTOR TYPES

Both scintillation and geiger counters are presently used as detectors of uranium ore with the scintillation unit being the most widely accepted. A scintillation detector assembly consists of a crystal, usually sodium iodide thallium activated and a photomultiplier coupled to the crystal. Experience has shown that where the grade of ore may be predicted, optimum results are obtained by matching the crystal size to a range of ore grades to be logged.

Table 1 shows the detector crystal size recommended for various ranges of ore grade and the yield of uranium oxide for various grades.

TABLE 1

DETECTOR CRYSTAL SIZE

Detector Crystal Size	*Relative Ore Grade*	*U_3O_8 Percentage*	*Yield*
½" x ½"	Extra High Grade Ore	2% or over	40# per ton & up
¾" x 1"	High Grade Ore	5% to 2%	10# to 40# per ton
¾" x 2"	Medium Grade Ore	10% to .5%	2# to 40# per ton
¾" x 4"	Low Grade Ore or Conventional Well Logging	05% to .10%	1# to 2# per ton

The reason for selecting smaller crystals when logging higher grade ore bodies is to reduce the count rate correction factors and prevent pulse pile-up. A more favored standard crystal size for most grades of uranium ore and one that has good lithology sensitivity is ¾ inch x 1 inch.

For the gross count gamma log, it is essential that all energies in the range of 100 KEV to 3 MEV are observed by the detector and are counted. This is done by electrical regeneration circuit in the probe to preshape and maintain constant pulse height regardless of energy levels. It may be noted in spectral pulse height analysis that the pulse shown represents various energies detected.

The upper graph in Figure 4 shows the probe signal data from a scintillation detector and linear amplifier connected directly to the oscilloscope input. The lower graph shows the linear signal photographed after transmission through a 1500 foot length of 4 conductor 3/16 inch diameter logging cable. The effect of the line loss on the pulse height and shape is apparent. Scope sensitivity was doubled after line transmission and the pulse height was still 50% lower than that shown by the photo of the input signal.

The rise time of the leading edge of the pulse must remain good for spectral work. Likewise, the fall of the trailing edge must not be too broad or the total resolving time of the system will limit the maximum counting rate.

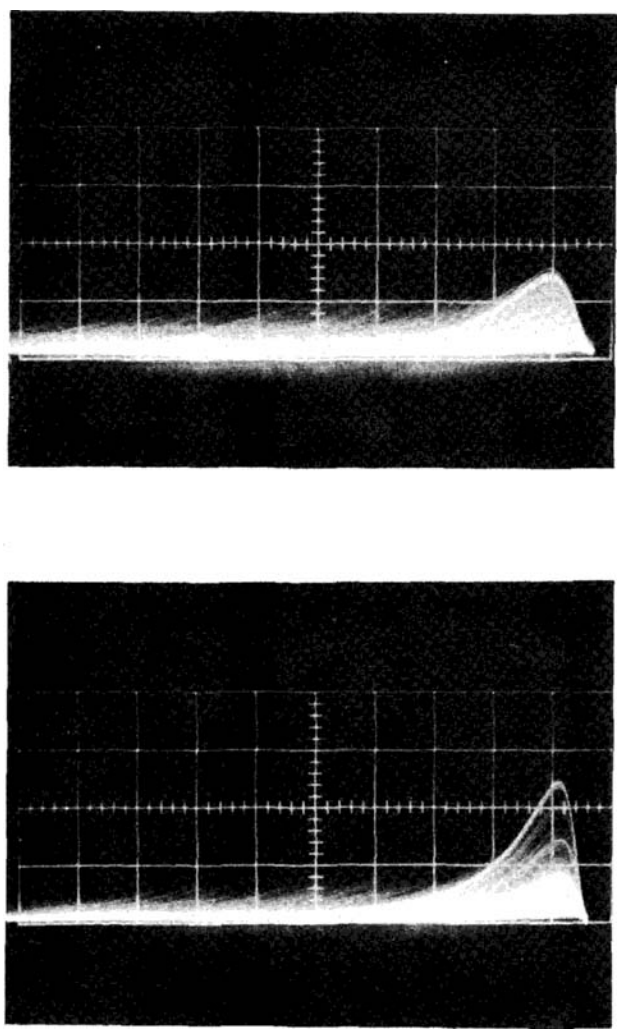

Fig. 4.

These photographs demonstrate how the line losses broaden the pulse and tend to destroy the identity of the pulse. The longer the cable, the greater the losses and the signal distortion rises accordingly. For gross count probe signals, a regeneration circuit causes all intermediate pulses to not appear. This is in complete contrast with the spectral pulse shown. The gross count will look uniform in height. This length of cable permits gross counting rates to 50,000 counts per second and allows a good quality spectral log to be made, as shown later.

DETECTORS AND SYSTEM RESOLUTION TIME

Other detectors such as Geiger-Mueller type do not make good gross count detectors since their resolving time is usually 100 microseconds or longer. Proportional counters have short resolving times but due to a lack of sensitivity they are poor for lithology logging. One of the prime requirements for an acceptable gamma gross count detector is a short resolving time. Since uranium ore emits gamma rays at a random rate, the detector will also have random pulse distribution. If two or more particles are spaced closer together in time than the resolving time of the detector, only one output pulse will be obtained from the detector. This nonlinearity or resolving time of the instrument must be corrected for in order to obtain valid quantitative results. Figure 5 shows dead time correction factors for various observed gross counting rates on the vertical scale and corrected true rates on the horizontal scale.

These curves are based on the following formula:

$$N = \frac{n}{1 - nt}$$

(True Gross Counts)
(Reading on ratemeter)
(Total Deadtime of the system in microseconds)

In actual practice, this correction for system deadtime is accomplished by use of a transparent overlay of the graph, to avoid repeated solution of the formula. Individual instruments that have the same resolving time loss would use the same graph. From zero to 10,000 counts the correction factor is negligible for systems employing a resolving time of microseconds or less.

FORMATION OF URANIUM

Figure 6 illustrates the "roll front" type deposition, which is how the mineralization is formed. In the beginning, minerals from remote areas were brought together by paleo-steam water movement. The early stages of the "roll front" is commonly referred to as the protore. This is a genetic process, depending upon oxidation and solution of selected mineral elements which have migrated towards a zone of reduction. From the protore or beginning of solution these elements guided by permeability move down, drip leaching into place and form a re-deposition of the dissolved elements, which is the ore area. This also sometimes referred to as a geo chemical cell. "Roll fronts" of

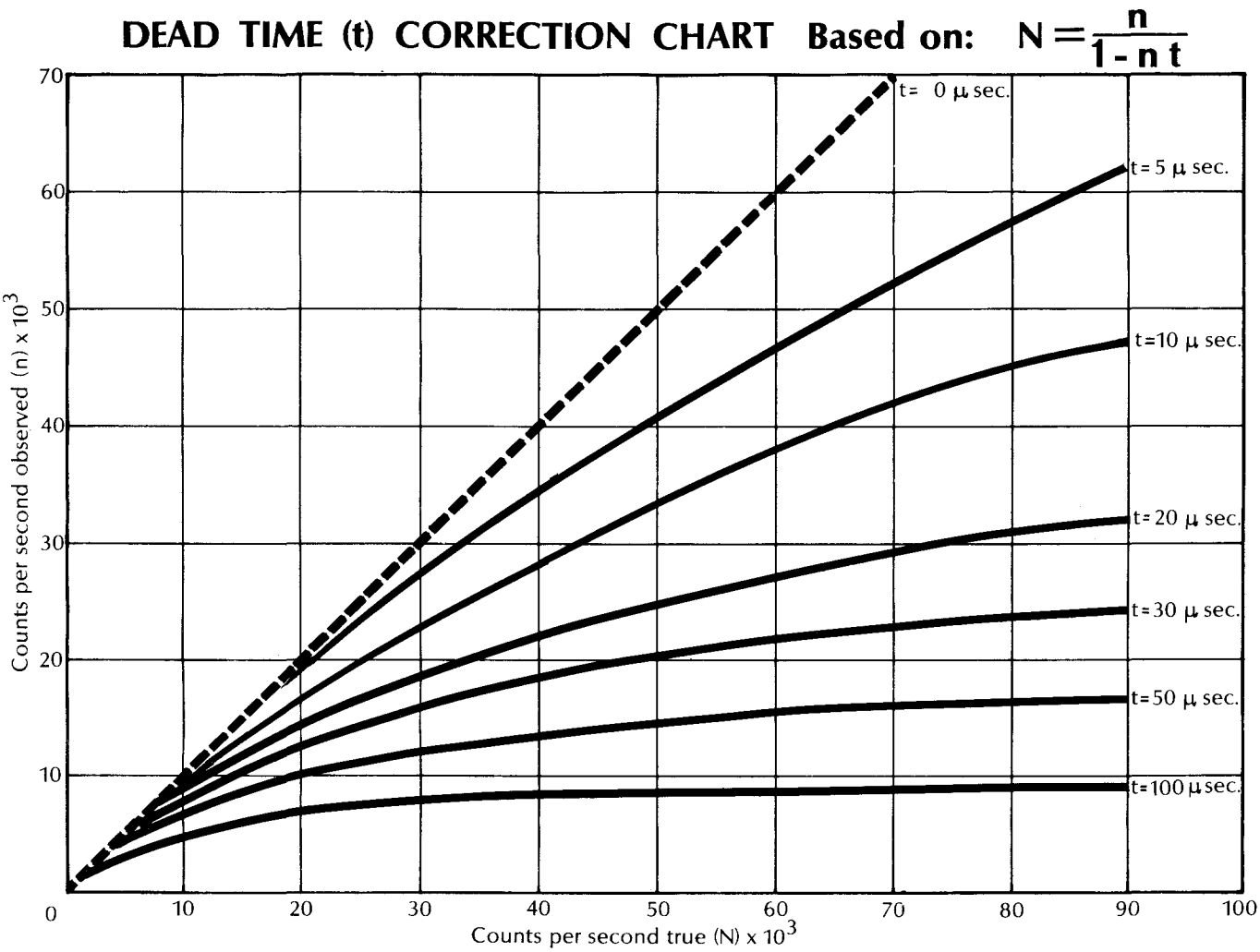

Fig. 5.

this type have been several yards to 5 to 10 miles in width and several hundred feet thickness. Analogy of this type of cell is known to closely follow other metalliferous sandstone deposits. In Figure 6, the vertical lines represent the log as it is recorded at each hole throughout a section of the "roll front".

If amounts of U-238 remain undisturbed for long periods of time, the daughter isotope formation will be equal to the rate of decay, and when this condition exists it is said to be in equilibrium. When a uranium ore is completely in equilibrium, the count rate on the gross count log will be directly proportional to the amount of uranium in the ore. Unfortunately, some companies have mined carloads of what was thought to be uranium, later to discover that it contained only the radioactive decay daughters of the uranium group, with complete absence of the uranium ore itself. Separation by leaching and other physical processes of nature are thought to be responsible. The disequilibrium requires a correction factor and is expressed as the ratio of the chemical assay to the radiometric assay of ore samples representing an area in question.

INTERPRETATION OF LOGS

Logs are surface recorded in the form of a strip chart on a 3 to 4 channel recorder. The recommended logging procedure is to simultaneously record two gamma logs and a resistance log. (Figure 7.) The gamma logs are on the left; one defined as the gross count low sensitivity curve, scaled in counts/second, the other a lithology curve. The lithology log, as shown, is off-scale when probing through mineralized ore sections. The gross count curve then takes its place in highly radioactive zones to give us a quantitative count value that is measured along the axis of the bore hole. This log is generally scaled in counts per second. The lithology curve is highly useful when mapping unknown areas and where unusual lower order Gamma peaks would be present but not be detectable from the gross count.

The Gamma Ray gross count log (Figure 8) gives a quantitative interpretation of the uranium ore body.

The basic area under the curve is determined by summing count rates per ½ foot of hole throughout the mineralized ore section. Counting rate of El, the first end value is taken ½ amplitude of the top excursion. Successive intermediate count rate values I_1 and I_2, etc. are read on ½ foot depth intervals. The last end value E_2 is read ½ foot below the lowest intermediate value which is considered the lower boundary of the mineralized ore section. E_1 and E_2 end point readings are multiplied by a tail factor of 1.4 to obtain tail area. Value of the area is determined by summing all the intermediate counting rate values of I_1 and I_2 etc., plus tail factor products. This total area is then multiplied by the borehole correction factor and the probe calibration "K" factor to obtain the Gy T product. This grade thickness product must be then corrected for disequilibrium and divided by the ore zone total thickness to give true grade. True grade is used for economic evaluation of the ore body.

Corroboration of this equation has been obtained in field results from natural uranium deposits. Core data has been compared to the Gamma Ray log data and relatively good correlation has been obtained. Because the probe samples are a larger volume in the hole than the core samples, the log data is thought to be more representative. However, the validity of the interpretation is dependent on the accuracy of calibration.

If a logging probe loses its sensitivity or for any reason the system shows a different counting rate than usually observed by the radioactive sleeve standard, a chart may be used to determine a new "k" factor (figure 9). Continuing to use the corrected "k" factor is not recommended but instead the tool or system should be repaired to restore the original calibrated sensitivity. However, within the limits shown, the corrected "k" factor may be used to fairly accurately determine the ore grade.

Spectral Analysis is based on the fact that pulse height from a proportional detector such as scintillation (or solid state) is related to the energy of the incident of radiation.

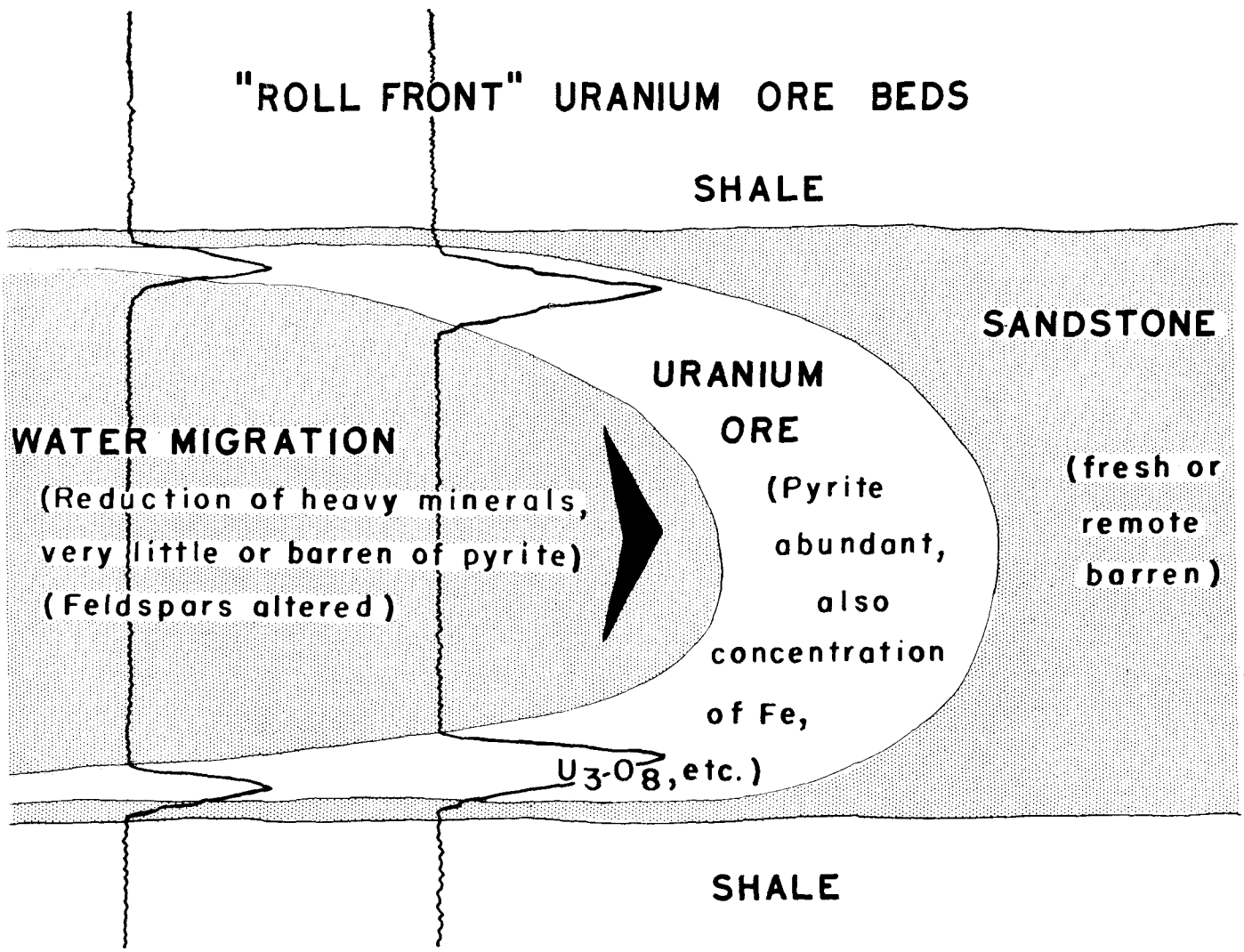

Fig. 6.

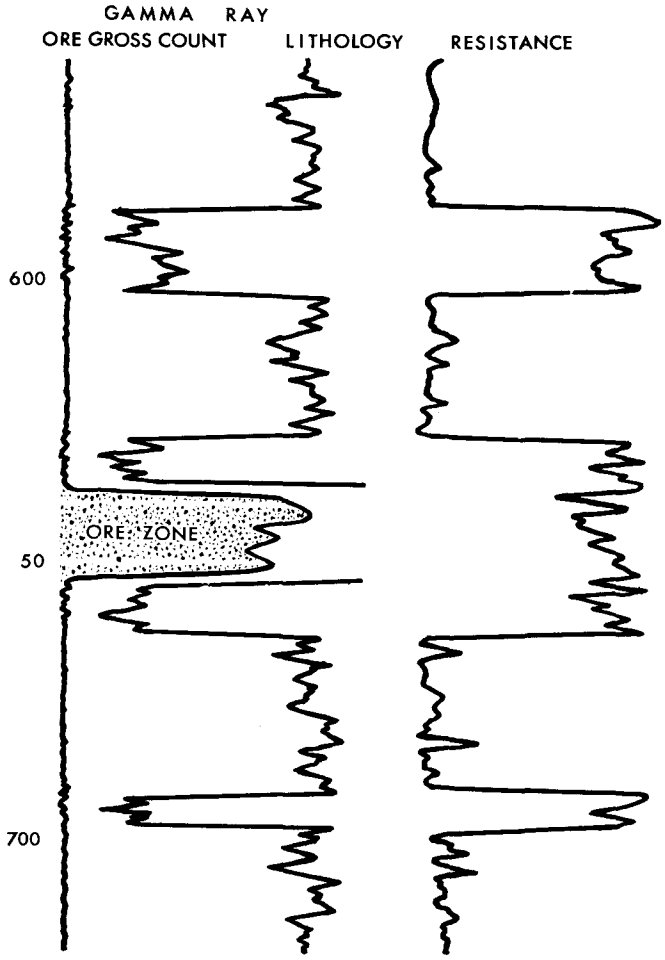

Fig. 7.

With this information transmitted to the surface, a conventional single or multi-channel analyzer may be used to analyze the downhole gamma spectrum. Figure 10 represents a spectrograph taken from a multi-channel Pulse Height Analyzer. Along the horizontal scale is the channel number which represents energy increasing to the right. The vertical scale is the count value in each channel. This spectrograph was obtained by placing the detector probe adjacent to a uranium enriched sand body and observing the natural decaying radionuclides. This was coupled through a 3/16 inch logging cable of approximately 1,500 feet long. Noted in the red, is a curve showing what an ideal detector crystal of 5 inch x 5 inch sodium iodide detector would be. The probe detector plotted alongside is 1¼ x 4 inches long.

After normalizing the sensitivities of the two detectors, there are very small differences. This data is in close agreement with the scintillation ore graphs obtained in the spectrum catalog.

Figure 11 shows a natural gamma spectra taken of a monazite thorium sand. Thorium ore is highly radioactive, but of no significant value to the uranium industry.

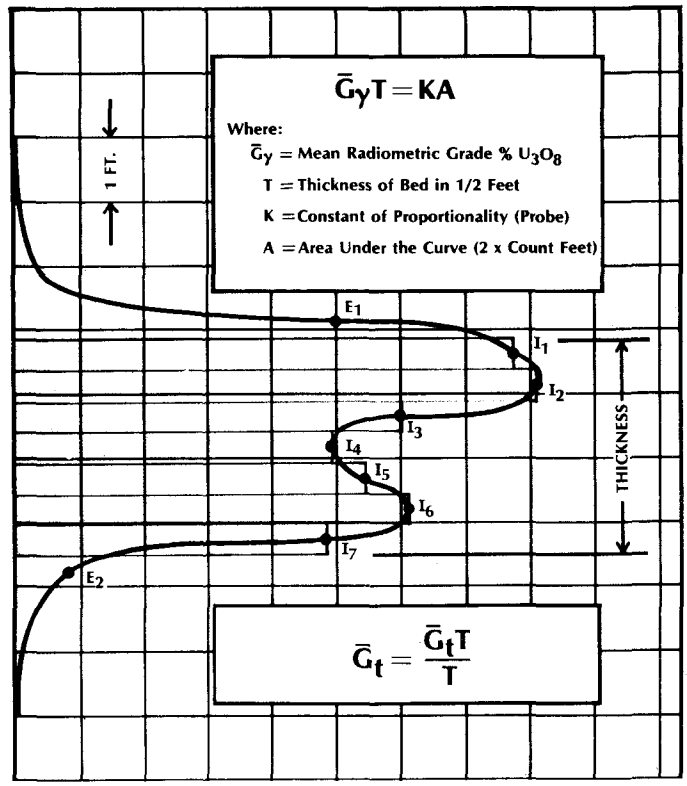

Fig. 8.

This is known as a type of "fools gold" to the uranium industry, and has not been considered as much of a problem in the United States. South America and other foreign countries have many areas high in thorium content. Note, one of the daughters, thallium 208, which gives rise to the 2.62 MEV Gamma, and compare it to the Bismuth 214 uranium peak of 1.76 MEV in the uranium decay. Effort has been made to observe the low end of this spectrum from .1 to .5 MEV, but due to back scattering and the Compton effect, it appears all washed out. This is where many low energy peaks associated with the uranium

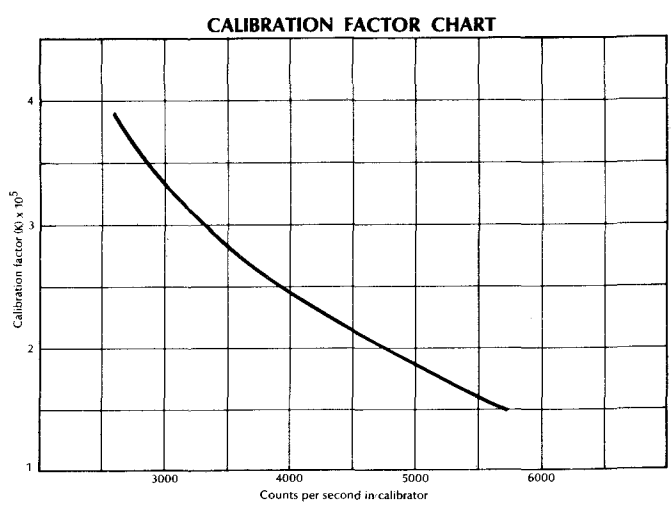

Fig. 9.

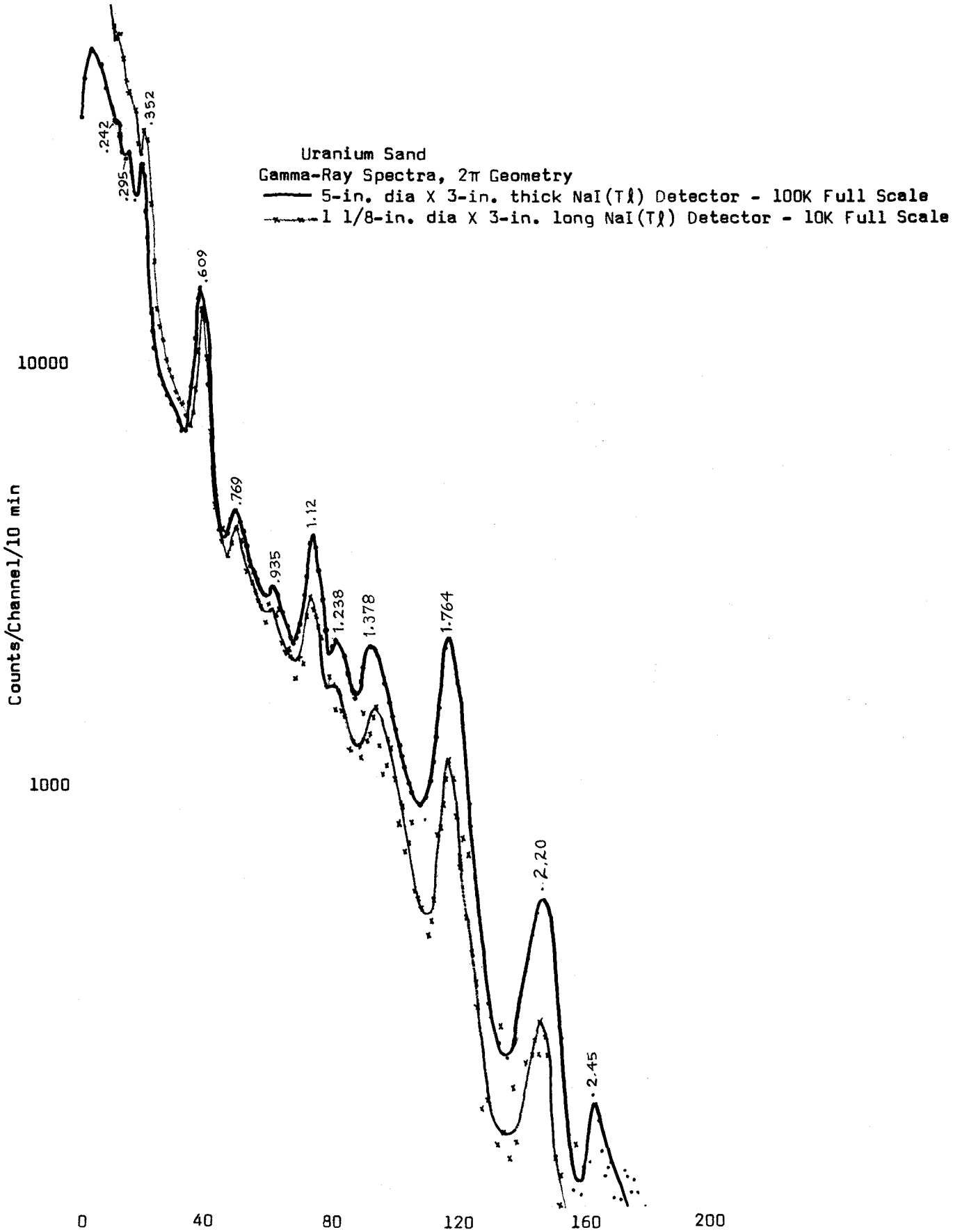
Uranium Sand
Gamma-Ray Spectra, 2π Geometry
5-in. dia X 3-in. thick NaI(Tℓ) Detector - 100K Full Scale
1 1/8-in. dia X 3-in. long NaI(Tℓ) Detector - 10K Full Scale
Counts/Channel/10 min
10000
1000
0
40
80
120
160
200
.242
.295
.352
.609
.769
.935
1.12
1.238
1.378
1.764
2.20
2.45

Fig. 10.

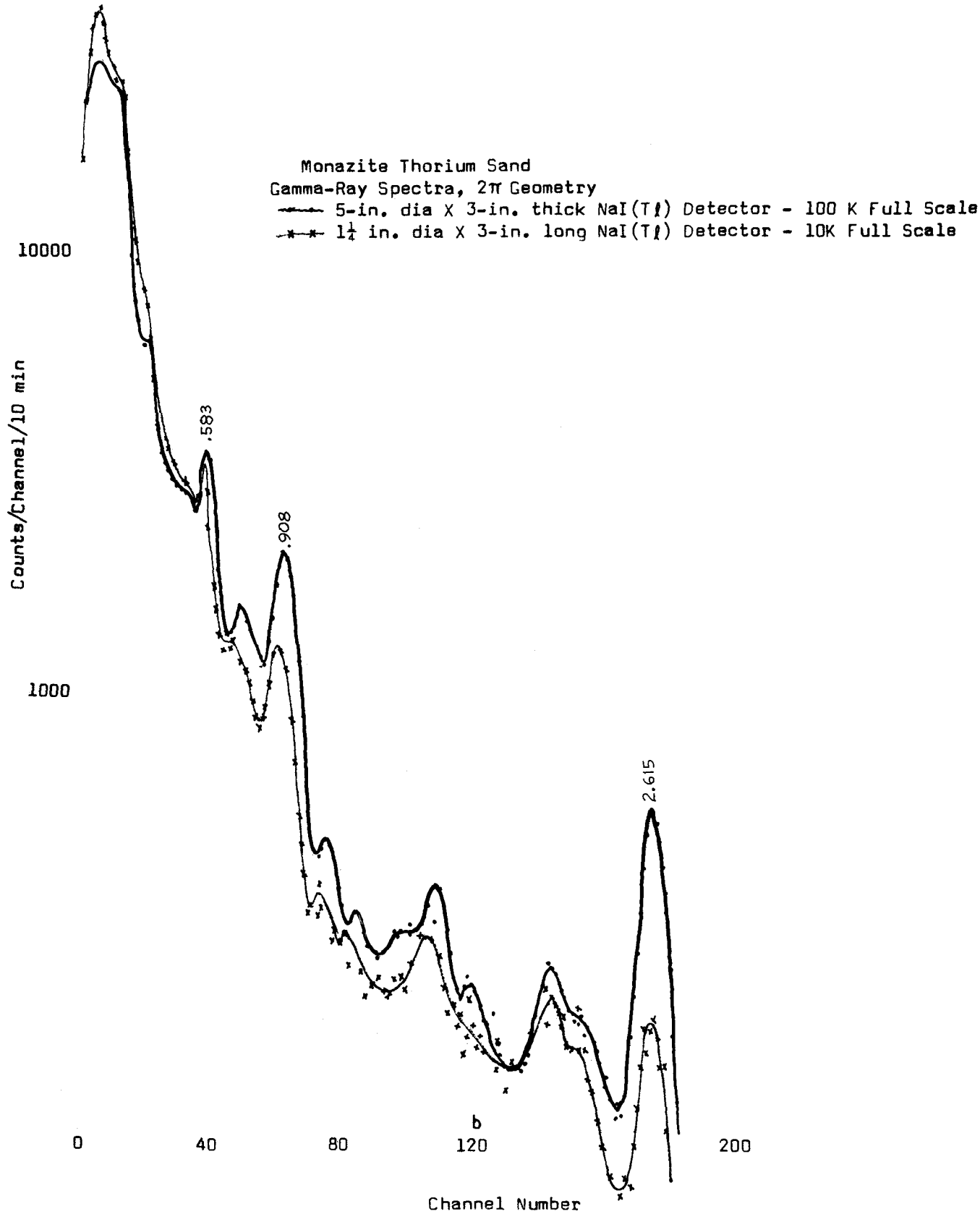
Monazite Thorium Sand
Gamma-Ray Spectra, 2π Geometry
5-in. dia X 3-in. thick NaI(Tl) Detector - 100 K Full Scale
1¼ in. dia X 3-in. long NaI(Tl) Detector - 10K Full Scale
10000
1000
Counts/Channel/10 min
.583
.908
2.615
b
0
40
80
120
200
Channel Number

Fig. 11.

elements are abundant; therefore, at this time, bore hole information for the low end of the spectrum has not been successful. A special absorber sleeve around the detector helps the resolution of higher energies by suppressing the rate effect of lower energies.

Close calibration with known energy sources are required to set up this type of survey. C137 and CO60 radioactive sources are an aid in establishing instrument resolution and desired energy ranges. A single channel analyzer with its window base line and recorder synchronized to time gives us the simplest approach to this type measurement. Although time consuming, it can be a useful tool.

OTHER LOGS

CALIPER

Caliper logs are useful for determining the "mechanical" borehole conditions. The borehole effect in smaller hole sizes is very significant and should be carefully corrected for gamma gross count logs. This correction factor must be established for each individual tool. A typical wide range gross count gamma tool with a ¾ inch x 1 inch detector crystal would have a hole size correction factor of 1 for a 2.25 inch diameter hole, 1.1 for a 4.5 inch diameter hole and 1.2 for a 6.5 inch hole size. This correction factor for larger hole sizes would not be much different than the 6.5 inch hole size.

TEMPERATURE

The use of highly sensitive temperature logs, and in particular the addition of the differential temperature curve, has enabled temperature anomalies to be detected that are related to water zones. Such anomalies do not appear on the gamma, S.P., resistivity or sonic log. Since uranium ore beds are often found in a "roll front" type deposition and such deposit is a result of water movement through the sand body, it should be valuable to detect the water zones and trace their movement. The data obtained to date is not sufficient to draw any conclusions on the use of this log for these purposes.

DENSITY

Conventional oil well logging density tools of the black scattered gamma ray type are not used. Because of the intensity of natural gamma radiation in uranium deposits, the scattered gamma rays of the density measurements are obscured. Methods have been devised to cancel the background radiation and measure the wet bulk density. It requires making two logs with a difference in source spacing of about four inches. Special tools have been built with means of varying the source spacing in the hole to accomplish both logging runs on one trip. This "difference" method of scattered gamma ray logging can be used to calculate bulk density, dry density, porosity and water content.

The AEC has constructed scale model test pits at Grand Junction, Colorado, Casper, Wyoming and recently Austin, Texas, that may be used at any time for prime calibration of tools and determination of the "k" factor. For secondary calibration of a tool, while at the logging site, it is important to use a radioactive source that closely simulates counting rates such as those in medium to high grade ore bodies. Sleeve calibrators are normally used since they surround the detector similar to the well bore and may consistently be positioned accurately.

In addition to strip chart logs, a teletype page print readout with punch tape is being used on some field trucks. With this system counting rates and depths are recorded numerically for the quantitative measurement. The keyboard also offers a convenient way to enter data such as well correlates, surface elevation, etc. This method of digital recording is compatible with any number of probe types such radioactive logging probes, caliper and temperature.

CONCLUSIONS

Wide range gross count gamma probes are now available for recording the count rate of wide grades of uranium ore with other logs being used for specialized study. Properly calibrated systems are being used for gross count quantitative evaluation of the ore bodies.

Experimental data available in field spectral logging has helped define the limitations of existing equipment. The use of coaxial type transmission logging cables and field use of new solid state detectors are expected to advance spectral well logging in the future. New and different probe designs are being developed that will help to establish areas that will be more favorable for deposits of uranium ore.