Energy Alinement of Gamma Spectrometers

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THE MULTICHANNEL gamma spectrometer is currently the most important piece of equipment for the assay of specific radionuclides in public health evaluations. Personnel in the radiological laboratories of a large number of State and local health agencies are taking advantage of the adaptability of these instruments to measure a wide spectrum of gamma-emitting radionuclides with minimum sample preparation. Although many screening measurements can be performed with simpler alpha or beta-gamma detection equipment, no valid estimate of the public health implications of radioactive contaminants can be made without the measurement of specific radionuclides. For such analyses, the gamma spectrometer is proving to be the backbone of current methodology. Because such an instrument is fairly complex, however, the quality of the data it provides depends strongly on its proper operation. Correct energy alinement is essential, and our paper offers guidance in this aspect of the operation of gamma spectrometers.

With a gamma spectrometer, maintenance of the relationship of energy to the channel number is of great importance, especially with mixtures of two or more nuclides in which the complex spectrum must be divided into its component parts. If the spectrum is treated by computer, rather than by desk calculation, the need for maintenance of calibration is stringent, permissible shifts being limited to a few thousand electron volts (kev) (1, 2).

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The spectrometer calibrations of four sodium iodide (thallium-activated) crystals connected to two multichannel analyzers have been investigated by the staff of the Analytical Quality Control Service at the Northeastern Radiological Health Laboratory of the Public Health Service, in Winchester, Mass. The detectors were 4- by 4-inch solid crystals, fitted with matched-window 3-inch multiplier phototubes. Each detector system was connected to one of the dual inputs of a 400-channel transistorized analyzer. Experimental results and techniques have been freely taken from the referenced literature. The parameters investigated included the energy calibration curve, channel alinement, linearity, source geometry, gain and baseline shifts, and drift characteristics. As a result of the study, we recommend specific procedures for channel alinement and quality control.

Calibration Curve

The calibration curve of a multichannel analyzer is the relation between photon energy and the number of the memory channel. The ideal relationship would be perfectly linear (that is, channel number proportional to energy). Figure 1, based on data from Devare and Tandon (3), shows, however, that the well-established nonlinear response of NaI(Tl) to photons makes it impossible for such an exact relationship to be attained. Nevertheless, the nonlinearity is small at energies above 0.3 million electron volts (Mev) and can readily be compensated for in the data analysis.

A linear calibration curve is best fixed by two points near its ends, as curve-fitting theory clearly shows (4). A quasi-linear curve, such as the one under discussion, is also best fixed by
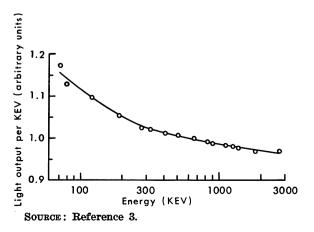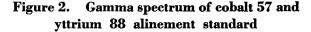
a point near each end. An additional point near the center is useful in measuring the extent of nonlinearity. To meet these requirements, calibrating nuclides should be chosen with low, intermediate, and high energies. This choice is especially useful since multichannel analyzers are normally fitted with two controls—zero and gain—and these are most readily adjusted by setting the low-energy and high-energy reference peaks in their appropriate channels.
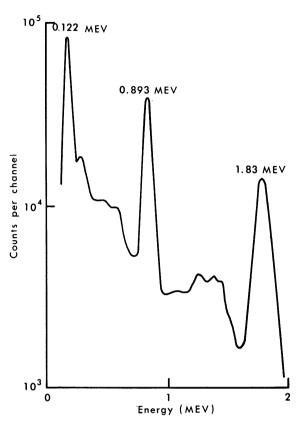
It is not essential to place the reference peaks precisely at the channel location which would correspond to their energy if the response of the instrument were completely linear. In fact, it is not even necessary that the energy of the reference gamma lines be known with great accuracy. What this paper presents is essentially a system for reproducibly locating the calibration curve.

The ideal nuclide source for routine energy alinements would have a photopeak at very low energy to measure the zero intercept, a peak at the high-energy end to check the gain, and one or more peaks in the midrange to measure the deviation of the calibration curve from true linearity. The intensity at the high-energy photopeak must be sufficient to allow an accurate determination of the mean channel number. Sum peaks, which are observed when coincident gamma rays are absorbed by the detector, are usually of such low intensity as to limit their use. For operation at 0–2 Mev, a low-

Figure 2. Gamma spectrum of cobalt 57 and yttrium 88 alinement standard

Figure 1. Comparison of light output with the energy of gamma ray per kilo electron volt

SOURCE: Reference 3.

energy peak could be in the range of 0.1–0.2 Mev and a high-energy peak in the vicinity of 1.8 Mev. (It is not practical to go much above 1.9 Mev because some of the counts necessary to determine peak location and resolution, as described in the section, "Peak center and resolution determination," will be lost in the excess over 2 Mev.)

After considerable search of the nuclear data, we recommend two sources. The first consists of bismuth 207 in equilibrium with its daughter lead 207m. These nuclides emit gamma photons with energies of 0.57, 1.06, and 1.77 Mev, in addition to X-radiation at 0.07 Mev. The other consists of a mixture of cobalt 57 and yttrium 88. The observed gamma spectrum (fig. 2) has peaks at 0.122, 0.893, and 1.83 Mev (5). For operation in the energy range 0–3 Mev, the sum peak at 2.72 Mev can be used after correction for sum excess as described in the next section. The wide separation of the peaks reduces their mutual interferences. While the

Table 1.   Nonproportionality excess for sum peaks in thousand electron volts

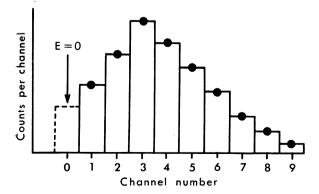| Nuclide	Photon energies	Calculated sum	Observed sum peak	Excess
Lutetium 177	113–208. 3	321. 3	330. 3	9. 0
Sodium 22	511–511	1,022	1,046	24
Indium 114	556–722	1, 278	1,308	30
Promethium 144	610–690	1,300	1,343	43
Bismuth 207	569. 6–1,063. 7	1,633	1,677	44
Sodium 22	511–1,274	1,785	1,820	35
Scandium 48	986–1,040	2,026	2,054	28
Cobalt 60	1,172. 8–1,332. 5	2,505	2,549	44
Yttrium 88	893–1,829	2,722	2,767	45
Sodium 24	1,368. 7–2,754. 7	4,123	4,170	47

For example, the practice of using the 1.78 Mev sum peak of sodium 22 introduces an error of 3.5 channels when operating at 10 kev per channel.

Source: The table is based on data from references 3 and 6.

energy spectrum of the cobalt-yttrium source is slightly better than that of the bismuth, the half-life of yttrium 88 is only 104 days. This short half-life necessitates replacement of the source, perhaps on a yearly basis.

Sum peak. Sum peaks can be used for calibration curve points. The sum peak, however, will not appear in the same channel as a single peak of the same energy because of the nonlinear response of sodium iodide. A hypothetical nuclide emitting two 0.66 Mev photons in cascade can be compared with another emitting a single 1.32 Mev photon. According to figure 1, fewer light quanta are produced by the crystal following absorption of the 1.32 Mev photon than after absorption of two 0.66 Mev photons—0.975 compared with 1.00. The higher quantum yield for the two 0.66 Mev photons would cause the observed sum peak to be 2.5 percent, or 0.03 Mev higher than the peak from a single 1.32 Mev emitter. Table 1

gives values of sum excess as taken from Devare and Tandon (*3*) and from Peele and Love (*6*).

Zero location. Since a channel represents a band of pulse heights from V to V plus dV, a plot of counts in relation to pulse height should be a histogram in which each bar represents the width of one channel. If a point plot is to be used, consideration should be given as to where the point representing a channel belongs. If the characteristic curve of the analyzer system intersects the pulse-height axis at zero and

Figure 3.   Zero-corrected histogram

Figure 4.   The 1.83 million electron volt peak of yttrium 88

NOTE: FWHM—full width at half maximum.

a Gaussian distribution of pulse heights within a channel is assumed, a point representing channel counts should properly appear as a point in the middle of the channel. For example, a point representing counts in channel 50 should be plotted at 50.5. If, however, the characteristic curve intersects the pulse-height axis at minus 0.5 channel, as suggested by Crouch and Heath (7), a relative pulse height of 50 would fall in the middle of channel 50 and could legitimately be plotted as a point at the 50 division line (fig. 3).

Peak center and resolution determination. For proper adjustment of the instrument controls, the location of the peaks of a reference spectrum needs to be determined accurately. Accurate peak location gives th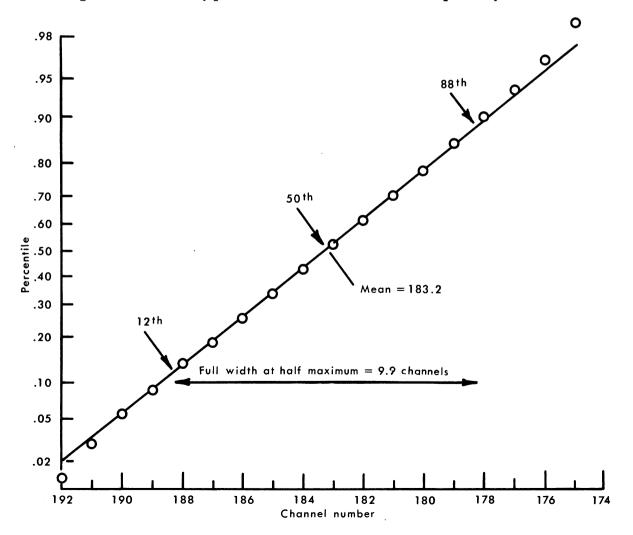e operator assurance that reproducible instrument parameters are used. An accurate and rapid determination of peak location within 0.1 channel (1 kev) can be made by using a probability plot, as discussed by Boekelheide (8). Visual estimation of the location of a peak center, on the other hand, will usually be accurate to only one channel (10 kev).

Working down from the high-energy side of a peak in the reference spectrum, the counts are summed; the cumulative percentiles are calculated as the ratio of accumulated to total photopeak counts. The 50th percentile is the center of the peak, and the resolution (full width at half maximum) can be expressed as the channel width between the 12th and the 88th percentiles. Including the background in the sum-

Figure 5. Probability plot of the 1.83 million electron volt peak of yttrium 88

Figure 6. Relationship of energy to channel number

A Normal linear operation
B Effect of zero shift
C Effect of gain shift

Figure 7. Integral linearity

Table 2. Position dependence of point source of cesium 137

Position	Mean channel $\overline{X}$	Resolution (percent) [1]
a	76. 00	8. 70
b	75. 48	8. 72
c	74. 55	9. 19
d	73. 33	9. 80
e	74. 20	9. 30

[1] Full width at half maximum.
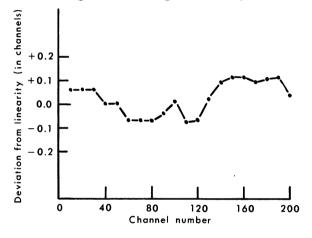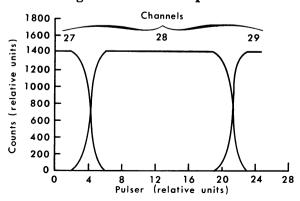
mation does not seriously affect the results for active reference standards. This technique uses all the data points to give a much better value for both resolution and mean channel than visual estimation; a mathematical least-squares fit can be calculated if desired.

As an example of the method, consider the

Figure 8. Channel profile

1.83 Mev peak of yttrium 88 shown in figure 4. It is difficult to determine the mean $\overline{X}$ or the resolution to better than one channel. The mean seems to be located at about channel 182.5. Yet, when the probability plot of the same data in figure 5 is examined, the values are easily determined to 0.1 channel, the mean being at channel 183.2. The non-Gaussian nature of the low-energy side of the peak is revealed by the deviation from a straight line.

Nonideal Conditions

To this point we have largely restricted the discussion to theoretical limitations, such as the nonlinear response of activated sodium iodide crystals, tacitly assuming that conditions were otherwise perfect. In practice, of course, such ideal conditions are never encountered, and we now need to consider practical difficulties.

The most immediate problem in quality control of gamma spectrometers is to maintain the relationship of energy to the channel number. Undesirable instrument behavior is composed of two types of shift—zero and gain—which may occur separately or in combination. As figure 6 shows, the zero shift is a lateral displacement of the characteristic curve. This displacement can be caused by the source geometry, by pulse pileup in the input circuit, or by any direct cur-

rent bias shift in the analyzer. The gain shift is a rotation of the characteristic curve around the origin, that is, a change in slope. It is caused by a change in the gain of the system as a result of high counting rates, component malfunction, or changes in voltage or temperature. At least two energy points, preferably well separated, are necessary to measure both shifts.

Instrumental nonlinearity. Nonlinearity may occur in any component, not only in the detector and phototube. Linearity, which can be measured with a sliding pulser, is specified as integral and differential. Integral linearity is defined as the ratio of the maximum deviation at any point to the pulse amplitude corresponding to full scale. Differential linearity is a term used to describe uniformity in channel width over the analyzer range. Linearity and alinement are discussed in detail by Crouch and Heath (7, 9, 10). Figure 7 shows the integral linearity of one analyzer. These data and those of figure 8 were obtained with a high-resolution pulser of the type described by Covell and Euler (11). With such a pulser, which is capable of measuring integral linearity to better than 0.1 channel, the nonlinearity of the analyzer can be clearly demonstrated (fig. 7). It is also possible to measure the channel profile (fig. 8) by taking a sufficient number of points within a channel. Such a profile gives a sensitive check on the performance of the analog-to-digital converter in the analyzer.
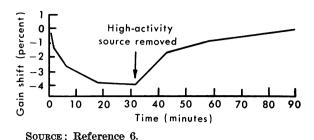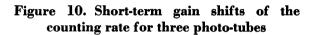
Geometry. The geometry—the size, shape,

Figure 9. Typical phototube gain shift at high counting rate and recovery after source is removed

SOURCE: Reference 6.

Figure 10. Short-term gain shifts of the counting rate for three photo-tubes

SOURCE: Reference 6.

and position of the source—affects the peak position, as tables 2 and 3 demonstrate.

When the source is moved off the axis, the peak position shifts to a lower channel and the resolution worsens. As a point source is moved from the axial position at a (table 2) to other positions, the peak moves from channel 76.00 to as low as 73.33 and the resolution increases from 8.70 percent to as much as 9.80. When an extended (or "volume") source is substituted for the point source (table 3), the peak position again shifts to a lower channel and resolution becomes worse. Table 3 shows this shift for two types of volume sources commonly used in this laboratory, a 400-ml. plastic cottage-cheese container and a 3.5-liter re-entrant (Marinelli) beaker. Observation that the two yttrium 88 peaks shift to the same extent indicates that the shift is independent of photon energy and is therefore a zero shift.

Thus, we see a significant change in peak posi-

Table 3. Peak shift for various containers

Containers and differences	Cesium 137		Yttrium 88	
	$\overline{X}$ channel	Resolution (percent) [1]	$\overline{X}_1$ channel	$\overline{X}_2$ channel
Point source_____	66. 69	8. 40	90. 61	182. 57
Cottage-cheese container_____	66. 20	8. 94	90. 21	182. 15
Marinelli beaker____	65. 96	9. 19	_____	_____
Difference between point source and—				
Cottage-cheese container_____	. 49	_____	. 40	. 42
Marinelli beaker__	. 73	_____	_____	_____

[1] Full width at half maximum.

tion and resolution from point to volume sources. When samples are in the volume form and the matrix equations are written for the volume configuration, volume sources must be used for energy alinements and for standard catalog spectra. Therefore the cobalt 57 and yttrium 88 used for instrument alinement were cast in a plastic resin material of approximately 400-ml. volume similar in shape to the cottage-cheese container. This configuration suffices for routine measurements, although not for the most precise work.

Counting rate. Multiplier phototubes used in scintillation counting show shifts in gain when subjected to high counting rates. The extent of these shifts varies significantly from tube to tube. For the Dumont 6393 type tube, which is used at the Northeastern Radiological Health Laboratory, Covell and Euler (*11*) observed gain shifts up to 14 percent. Figures 9 and 10 show that the shift is a function of time as well as of intensity. Counting rates extended over long periods should be kept below 50,000 counts per minute. If a standard is more active than this, it should be counted only a short time and quickly removed from the crystal.

Analyzer drift. The channel position of the 0.122 Mev and the 1.83 Mev photopeaks of cobalt 57 and yttrium 88 were measured each morning over a period of 43 days before any adjustments were made. Probability paper was used to locate the mean, as discussed in the section "Peak center and resolution determination." Figure 11 shows the day-to-day peak position of the 0.122 and the 1.83 Mev peaks. After the peak positions were determined each morning, the analyzers were alined by visual examination of the spectra of sodium 22 and cesium 137. Use of this technique accounts, in part, for the relatively poor alinement of the four analyzers (table 4). Figure 12 gives the integrated peak area for the 1.83 Mev peak of yttrium 88. The decay of this nuclide causes a general downward trend, on which the fluctuations caused by day-to-day drift are superimposed.

Conclusion

The drift characteristics of the analyzers of the Northeastern Radiological Health Laboratory show that a quantitative procedure is needed whereby both the zero intercept and the gain can be adjusted before counting. We suggest the method described by Covell (*1*). In brief, his procedure is to prepare a graph or nomogram of the low-energy and high-energy peak positions as a function of the gain and
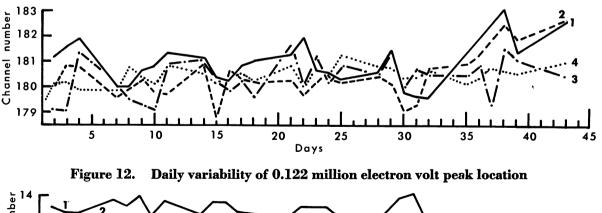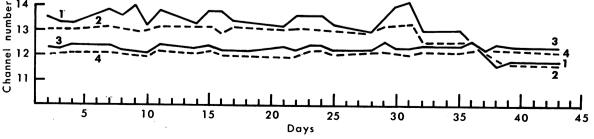
Figure 11. Daily variability of 1.829 million electron volt peak location

Figure 12. Daily variability of 0.122 million electron volt peak location
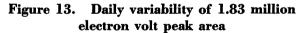
zero vernier readings. Thus, by counting the standard, one can discover directly from the nomogram the exact change in the verniers needed to aline the instrument. Using probability paper for the graphic calculation gives information on the resolution as well as on the peak position. For greater accuracy, the standard used should have energies at each end of the energy scale. Either bismuth 207, or cobalt 57 plus yttrium 88, seems to be a good working standard. The calibration standard should be in the same geometry as the sample and of low enough activity that it will not cause gain shifts.
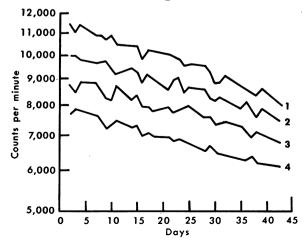
The analyzers should be periodically checked for electronic performance. Procedures for such a check, which are not discussed in this proposal, are given by Crouch and Heath (7, 9, 10). The daily quality control reports would consist of control charts providing the following information:

Table 4. Channel drift

Detector	0.122 Mev		1.83 Mev	
	Standard deviation	Range	Standard deviation	Range
1----------	0. 64	2. 55	0. 89	3. 56
2----------	.48	1. 68	.90	3.98
3----------	.13	.49	.83	2.93
4----------	.10	.35	.29	1.88

NOTE: All units are in channels.

Figure 13. Daily variability of 1.83 million electron volt peak area

1. The total counts of a long-lived standard such as cesium 137. (Such a chart will reflect changes in efficiency. An easy method of determining the total count is to use a scaler, which measures the total events stored in the analyzer.)

2. The daily gain and zero shift.

3. The resolution of a selected peak. (Malfunction of the detector or analyzer in many cases can first be detected as changes in the resolution or drift characteristics of the system.)

4. The instrument background.

Summary

One of the key requisites to proper operation of a gamma spectrometer is accurate energy alinement. Prominent among the characteristics of such systems which can affect energy alinement are the nonlinear response of scintillation crystals, the influence of the geometry of the source, and electronic performance—such as the variability in response to different counting rates and the shifts which occur in the zero and gain settings.

Regular checking of instruments, followed by any corrective adjustments indicated, is requisite to proper operation of a gamma spectrometer. In addition, control charts for documenting and monitoring instrument performance need to be set up. Regular application of such procedures will provide continual assurance that the data obtained from such a system are precise and accurate. Under normal conditions, information thus obtained will afford an accurate foundation on which to base public health evaluations of given radiological contaminations. In the event of elevated levels, the accuracy of such data will be indispensable to the application of sound procedures for corrective public health action.

The recommendations in the paper are directed particularly to public health personnel who have not had extensive experience in the detailed use and calibration of gamma spectrometers.

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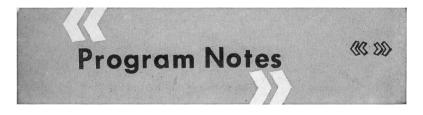
Planning Grants for Regional Medical Programs

Grants for planning Regional Medical Programs, authorized last year by Congress to bring advances in diagnosis and treatment of heart disease, cancer, and stroke to all Americans, have been awarded by the Public Health Service. These regional grants are centered in the University of Hawaii, Honolulu; University of Kansas Medical Center, Kansas City; University of Vermont, Burlington (for Northern New England); Yale University, New Haven, Conn.; and University of Missouri School of Medicine, Columbia.

The planning activities of the groups receiving the awards will be directed toward the needs of the region as a whole, and other medical institutions and organizations will participate in the planning process. Planning will include a detailed assessment of the health needs and present resources of the region for

carrying out the purposes of the program.

The grants will also support the development of plans for continuing education of physicians and other health personnel, demonstration of advanced techniques of diagnosis and treatment of heart disease, cancer, and stroke, more effective integration of research activities with improved patient care, better means of gathering and analyzing medical data, and introduction of modern electronic technology in the distribution of medical knowledge and diagnosis of disease.

The five grant requests total $1,630,392. However, the final amount of each award will be determined by the Division of Regional Medical Programs, National Institutes of Health, Public Health Service, which is administering the grant program.

Program Notes

Alcohol Education

A teacher's personal feelings about alcohol fall into the same category as his ideas on politics or religion. They are taboo in the classroom.

This observation is made in "Alcohol Education—An Annotated Bibliography for Educators," a publication issued by the Colorado State Department of Public Health.

Compulsory Measles Vaccination

An amendment to Michigan's State school code requires that all public, private, and parochial school children be vaccinated against common measles by January 1, 1967. An appropriation of $350,000 for measles vaccine was included in the measure.

Data Processor for Individuals

A recently developed Health Education Reference Card should enable health educators and behavioral scientists to conveniently file information for subsequent quick retrieval.

A 5- by 8-inch file card contains 125 holes punched around the edges. More than 125 items of information pertaining to health, health education, and social sciences are printed and coded to these holes. The information to be filed is coded on the card by notching out the appropriate hole.

To obtain information, a sorting rod is inserted in the appropriate hole of the deck of cards (see photo) and all notched cards drop out. The only equipment needed is a hand punch and sorting rod.

The developer of this data-processing tool, Dr. Wilbur I Hoff, 6049 Skyline Blvd., Oakland, Calif. 94611, points out that it eliminates cross-filing, cards can be replaced in any order, and classification systems may be changed at will.

Emergency Generators in Hospitals

All new hospitals built in New York State must have emergency electric generators for use in case of power failure. The requirement is included in the new State hospital code.

Condition of New York Hospitals

Forty-seven of New York City's 130 general care hospitals should be replaced, and virtually all of the remaining 83 facilities require costly modernization. That was the conclusion of the Hospital Review and Planning Council of Southern New York, Inc., after a study conducted at the request of the United Hospital Fund.

The total costs of overcoming deficiencies in New York City's 78 voluntary general care hospitals are estimated at $389 million; for the municipal hospitals, $267 million; and for the 35 proprietary hospitals, $49 million.

Removing Coal Acid From Water

Two Pennsylvania State Health Department scientists, Dr. Robert H. Emerich and Evan Goodwin, have developed a new method to help Pennsylvania's coal operators and the State sanitary water board in keeping the Commonwealth's streams free from coal acid pollution.

Crushed coal samples mixed with glass wool are placed in an extractor. Air is continuously bubbled through the coal sample, which is periodically washed with distilled water. The resulting mine-drainage products from the coal sample are analyzed for iron and acid concentrations.

Hansen's Disease in Texas

Hansen's disease is not only more prevalent in Texas than was known but is also on the increase, an intensive 6-year survey has shown.

A program to control the disease, however, got underway in the State on October 1, 1966, with a 3-year Public Health Service grant of $267,734. Administered through the Texas State Department of Health, the program is under the direction of Dr. M. S. Dickerson. Dickerson stated that he plans to expend much effort "in dispelling and debunking erroneous conceptions . . . charged with emotional and spiritual content."—*Texas Health Bulletin*, September 1966

Items for this page: Health departments, health agencies, and others are invited to share their program successes with others by contributing items for brief mention on this page. Flag them for "Program Notes" and address as indicated in masthead.