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Performance Testing of Personnel Dosimetry Services

Final Report of a Two-Year Pilot Study
October 1977 - September 1979

Prepared by P. Plato, G. Hudson

University of Michigan

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Office of Standards Development
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

PERFORMANCE TESTING OF

PERSONNEL DOSIMETRY SERVICES:

FINAL REPORT

ABSTRACT

The University of Michigan conducted a two-year pilot study of the Health Physics Society Standards Committee (HPSSC) Standard titled, "Criteria for Testing Personnel Dosimetry Performance." The objectives of the pilot study were:

1. To give processors an opportunity to correct any problems that are uncovered.
2. To develop operational and administrative procedures to be used later by a permanent testing laboratory.
3. To determine whether the proposed HPSSC Standard provides an adequate and practical test of dosimetry performance.

Fifty-nine dosimetry processors volunteered to submit dosimeters for test irradiations according to the requirements of the HPSSC Standard. These tests satisfied the first objective of the pilot study.

The operational and administrative procedures developed during the pilot study are described in the Procedures Manual issued on August 14, 1979, NUREG/CR-1063. The Procedures Manual satisfies the second objective of the pilot study.

The Final Report discusses the feasibility of using the HPSSC Standard for a future mandatory testing program for personnel dosimetry processors, the third objective of the pilot study. This Report shows the results of the pilot study and contains recommendations for revisions in the Standard that will make a mandatory testing program useful to regulatory agencies, dosimetry processors, and radiation workers that use personnel dosimeters.

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INTRODUCTION

From September 28, 1977 to September 27, 1979, The University of Michigan conducted a pilot study, sponsored by the Nuclear Regulatory Commission, of the Health Physics Society Standards Committee (HPSSC) Standard, CRITERIA FOR TESTING PERSONNEL DOSIMETRY PERFORMANCE.[1*] The Standard has also been tentatively adopted by The American National Standards Institute as ANSI N13.11. The objectives of the pilot study were:

1. To give processors an opportunity to correct any problems that are uncovered.
2. To develop operational and administrative procedures to be used later by a permanent testing laboratory.
3. To determine whether the proposed HPSSC Standard provides an adequate and practical test of dosimetry performance.

During the two-year pilot study, 59 dosimetry processors volunteered to participate at no charge to them. These included 7 national laboratories, 9 prime Government contractors, 14 nuclear power generating stations, 3 universities, 6 industrial and medical facilities, 8 military and other Government agencies, and 12 commercial processors. The names of the participating processors are shown in Table 1.

Each processor was permitted to be tested twice during the pilot study. The processors sent us the appropriate number of dosimeters during each of the three months required to complete each test. We irradiated the dosimeters according to the requirements of the HPSSC Standard and returned the dosimeters to the processors for evaluation. The processors sent us their estimates of the delivered dose equivalents, and we deter-

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[*] The version of the HPSSC Standard used for the pilot study was dated November 30, 1977. Following the pilot study, the Standard was revised extensively.

mined if they passed or failed each test. In addition to the open tests, we blind-tested seven of the large commercial processors. The open and blind tests were conducted, in part, to satisfy the first objective of the pilot study.

The operational and administrative procedures developed during the pilot study are described in the Procedures Manual[2] issued on August 14, 1979. This Procedures Manual satisfies the second objective of the pilot study.

The purpose of this Final Report is to discuss the feasibility of using the HPSSC Standard for a future mandatory testing program for personnel dosimetry processors, the third objective of the pilot study. This Report contains our observations of the pilot study and our recommendations for revisions in the Standard that will make a mandatory testing program useful to regulatory agencies, dosimetry processors, and radiation workers that use personnel dosimeters.

METHODS AND MATERIALS

Table 2 is a one-page summary of the HPSSC Standard. The Standard defines eight radiation categories, each of which requires a particular type of radiation (gamma rays, beta particles, X rays, neutrons, and mixtures). Categories I through V require a single type of radiation, and Categories VI through VIII require specific mixtures of the first five categories. Each category is divided into several intervals, each of which covers a defined test range of absorbed doses or dose equivalents. Most of the intervals cover protection ranges with dose equivalents less than 10,000 mrem. Intervals 1 in Categories I and II cover accident ranges of 10 to 800 rad.

Ten dosimeters must be irradiated during a three-month period to complete a test for each interval. A processor can choose to be tested in any or all of the eight radiation categories, but the processor must participate in all the intervals of each category he chooses.

The HPSSC Standard requires a processor to report a shallow (7 mg/cm^2) and a deep (1,000 mg/cm^2) dose* for each dosimeter tested. A performance index, P, is calculated for each dosimeter as defined at the bottom of Table 2. For each depth in each interval, an average performance index, $\bar{P}$, and its standard deviation, S, are calculated for all 10 dosimeters in the interval (no outliers are permitted). A processor passes a category if, for each depth of each interval, $|\bar{P}| + 2S \leq L$ where the tolerance limit, L, is defined in Table 2. If a processor fails any of the statistical tests required for a category (e.g., Category II requires seven separate statistical tests as shown in Table 2), they fail the entire category.

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*For simplicity in this Report, the term dose will be used to refer to absorbed dose or dose equivalent.

During the two-year pilot study, we administered a total of 700 category tests among all the processors that particiated in the open tests. This required the irradiation of approximately 21,000 dosimeters. The blind testing program involved a total of 70 category tests and 1,680 dosimeters.

The dosimeters were irradiated on water-filled Plexig' phantoms, 30 cm by 30 cm by 15 cm thick. An attempt was made to irradiate six dosimeters simultaneously from six different processors. We recorded the time of day and the date for each set of six dosimeters irradiated. Occasionally, a processor's reported dose was considerably different from the delivered dose w imed for a particular dosimeter, and the processor insisted that they were correct and we were wrong. It was a relatively easy task to locate the results of the other five dosimeters irradiated simultaneously with the dosimeter in question. It was usually obvious from examining the results for the six dosimeters whether the dosimeter in question had the wrong reported dose or whether all six dosimeters had been irradiated improperly. If the latter were the case, all six dosimeters were voided.

All of the radiation sources used for the pilot study were calibrated directly or indirectly by the National Bureau of Standards (NBS). Exposure rates and absorbed dose rates were known to within about ±3%. The Standard requires that these rates be known to within ±5%. Throughout the pilot study, NBS advised us on methods of calibration and quality control.

Complete descriptions of the radiation sources, radiation geometries, phantoms, and administrative procedures are given in the Procedures Manual.[2]

RESULTS

Table 3 shows the results for Test #1 and Test #2 received to date for one type of dosimeter submitted by each processor, and Table 4 shows the results for additional types of dosimeters submitted by some of the processors. Table 5 shows the results of blind testing of seven processors. Tables 6 and 7 summarize the overall results for all the intervals and categories for both Test #1 and Test #2.

Table 6 shows that the passing rate among all the categories tested increased from 23% for Test #1 to 35% for Test #2. The X-ray categories, II and III, showed the greatest improvement, but the gamma-ray, beta-particle, and neutron categories also showed substantial improvement. The mixed-source categories, VI, VII, and VIII, showed little or no improvement. Improvement was also observed in the accident intervals in Categories I and II.

In Test #1, 5 processors passed every radiation category in which they chose to participate, although all 5 processors participated in only one category each. In Test #2, 8 processors passed every category in which they participated. These included one processor that passed all 8 categories and one processor that passed 6 categories.

In general, there was not a lot of change in the performance of the processors in Test #2 compared to Test #1. The bottom of Table 11 (referred to later in this Report) shows that among all the intervals tested, 76% of the processors passed both tests or failed both tests.

Table 7 shows that the results of the blind tests were almost constant for Test #1 and Test #2. The blind tests are discussed at length below.

DISCUSSION

Page 5 of the contract between the Nuclear Regulatory Commission and The University of Michigan to conduct the pilot study contains an outline of items to be considered in the Final Report. The sections below follow that outline and discuss information required for the CONCLUSIONS AND RECOMMENDATIONS section of this Report.

A. An evaluation of the Standard with respect to the feasibility of testing and for meeting the criteria.

We experienced some initial problems during the pilot study, especially with small processors that were not accustomed to shipping dosimeters to their users. These problems included the use of poor shipping containers (e.g., shoeboxes), lack of shipping controls, problems with establishing a monthly shipping schedule, etc. However, by the end of Test #2, most of the processors had become familiar with the administrative requirements of the Standard.

The results for Test #1 were poor, due in part to the fact that few processors were using the radiation sources or calibration procedures that are required by the HPSSC Standard. We sent a questionnaire to each participating processor before the beginning of Test #1 to determine how and why the processors were calibrating their dosimeters. The questionnaires showed that the great majority used cesium-137 for a gamma-ray source, natural uranium for a beta-particle source, and plutonium-beryllium for a neutron source. No processor used the standard NBS X-ray calibration techniques (specific combinations of kilovoltage and filtration) required by the Standard. Therefore, it was not surprising that only 23% of the category tests were passed.

We anticipated that processors would use their results from Test #1 to generate the necessary correction factors to enable them to pass Test #2. In fact, some processors expended a great effort to adjust for the requirements for the Standard and, as a result, showed considerable improvement in their results for Test #2. Other processors did not make an effort to adjust their procedures to match those of the Standard, because of a lack of funds, time, manpower, or interest. Some processors simply wanted to see how a dosimeter would perform in a radiation category for which it had never been calibrated.

We observed a number of clerical errors that negated an otherwise competent performance by a processor. For example, in preparing a report of their estimated doses, a processor would place a decimal point incorrectly. This would cause one dosimeter out of ten in an interval to be in error by a factor of 10, which usually meant the interval failed and, consequently, the entire category failed. Some clerical errors were due to the fact that some processors could not use their regular computerized reporting method for the pilot study. But the majority of clerical errors that were brought to our attention would have occurred even if the dosimeters were not part of a test.

B. Recommendations for revision of the Standard to produce a more successful test program.

Throughout the pilot study we solicited suggestions from each processor concerning possible revisions of the Standard. Many processors feel that the complex statistical method used to determine pass/fail and the large number of dosimeters required make the Standard unnecessarily complicated. The diversity of suggestions received from the processors include:

1. Change the statistical method from $|\bar{P}| + 2S \leq L$ for each interval to:
   a. $|\bar{P}| + 1S \leq L$ for each interval.
   b. $|\bar{P}| + 1.5S \leq L$ for each interval.
   c. $|\bar{P}| + 2S \leq L$ using all the dosimeters in a category.
   d. a single tolerance limit placed on each dosimeter in a category with no outliers.
   e. a single tolerance limit placed on each dosimeter in a category with one or more outliers permitted.
   f. a single tolerance limit placed on each dosimeter in a category with one or more outliers permitted but with some limit placed on how far out of control the outliers can be.

2. Change the method in which L is calculated so that it will not be so large for low-dose intervals.

3. Change the statistical method so that a processor will not be penalized if a dosimeter reports more than the delivered dose.

4. Reduce the number of intervals within each category.

5. Reduce the number of dosimeters required.

6. Eliminate the accident intervals in Categories I and II.

7. Lower the maximum delivered dose limit in the accident intervals.

8. Make the accident intervals into a separate category so a processor could choose to be tested in either an accident or a protection category.

9. Inform a processor as to the type of radiation delivered to each dosimeter.

10. Change the Standard so that if a reported dose is in error due to a clerical mistake made by the processor, the dosimeter will be voided.

11. Do not change the Standard in any way that would make it more lenient than it already is.

12. Increase the front surface area of phantoms used for neutron irradiations.

13. Change the neutron source from unmoderated californium-252 to:
    a. moderated californium-252
    b. moderated plutonium-beryllium
    c. moderated americium-beryllium
    d. unmoderated sources of b and c above.

14. Change the beta-particle source from yttrium-90 (the beta particles from strontium-90 are essentially eliminated by the encapsulation of 100 mg/cm^2) to a lower energy source such as natural uranium or thallium-204.

15. Change the gamma-ray source from cobalt-60 to cesium-137 since many problems can be created by the production of scattered electrons by cobalt-60.

16. The Standard should permit several sources for each category, so a processor could choose the source that best represents the irradiation conditions of the workers they serve.

17. Change the depth at which deep doses are measured from 1000 mg/cm^2 as specified in the HPSSC Standard to 300 mg/cm^2 as specified on the Nuclear Regulatory Commission's Form 5, used as the permanent record for radiation workers.

18. Change the depth at which shallow doses are measured from 7 mg/cm^2 to a value closer to the average depth of the live layer of skin.

We have considered the advantages and disadvantages of these suggestions and, based on the experience of the pilot study, have recommended several changes in the Standard in the CONCLUSIONS AND RECOMMENDATIONS section of this Report.

C. Recommendations on the usefulness and desirability of blind testing.

Seven commercial processors were blind-tested during the pilot study. A utility company was asked to subscribe to each of the seven processors ostensibly to use the dosimeters in and around their nuclear power plants. The utility company then shipped the dosimeters they received to us to be irradiated with the same procedures applied to the open tests. At the end of each month, the dosimeters were returned to the utility company which mailed them to the seven commercial processors. All questions, answers, and problems regarding dosimetry, results, and radiation sources were relayed through the utility company to preserve the blind tests. The utility company was not informed of the pass/fail results. The seven processors were blind tested during the same months in which they were tested openly.

The results of the blind tests, shown in Tables 5 and 7, should not be viewed as the true ability of the processors involved. As with the open tests, the blind tests required sources and procedures not commonly used by the processors. The use of a middle-man, which necessitated outright lies to the processors, undoubtedly added to the increased failure rate of the blind tests compared to the open tests.

The blind tests did illuminate some problems that could be expected in a future mandatory testing program. First, blind testing may only be possible for large commercial processors that would not notice the additional dosimeters each month. It will be exceedingly difficult to blind test any processor that is familiar with the people who subscribe to their service (e.g., nuclear power stations, medical facilities, universities, and perhaps many of the National Laboratories and prime Government contractors). We observed nothing to indicate that the large commercial processors deserve to be blind tested any more than the other processors.

Second, many of the doses required by the Standard are very different from the doses normally observed by any processor. When a processor realizes that some of their dosimeters have been irradiated to more than about 200 mrem (many dosimeters received from 1,000 to 10,000 mrem and some received from 10 to 800 rad during the pilot study), the processor becomes suspicious. It is difficult for the middle-man to maintain cover stories.

Third, it is expecting a lot from a middle-man to transmit dosimeters between the testing laboratory and several processors without wanting to know the results of the blind tests.

D. Recommendations on radiation sources, especially neutron and beta sources.

Four types of radiation sources are required for the HPSSC Standard. Each is discussed separately below.

X-Ray Sources. We used several standard NBS X-ray calibration techniques (combinations of kilovoltage and filtration) for the pilot study as required by the Standard. These techniques are shown in Table 8. Before the pilot study began, those processors that calibrated for X rays (many processors simply use a gamma-ray source to simulate X rays) used their own combinations of kilovoltage and filtration. By the end of Test #2, most of these processors seemed to appreciate the need for a few common, standardized techniques.

During the pilot study, the Gesellschaft für Strahlen-und Umweltforschung mbH, München, Germany (GSF) published a catalogue[3] of X-ray spectra that are used internationally by many standards laboratories such as the National Bureau of Standards. Some of the spectra cover a relatively narrow range of energies and have no appreciable characteristic X rays.

Gamma -Ray Source. We used high- and low-activity cobalt-60 sources for the pilot study, although the HPSSC Standard permits the use of either cobalt-60 or cesium-137. Cobalt-60 was convenient for us since The University of Michigan Hospital has two high-activity cobalt-60 teletherapy units located in large rooms with door interlocks. A 2700-curie teletherapy unit permitted us to deliver the maximum absorbed dose of 800 rad in approximately 13 minutes at 100 cm. However, the gamma-rays from cobalt-60 have sufficiently high energies to produce secondary electrons that can cause problems with many types of personnel dosimeters. This is especially a problem in the beta-plus-gamma category. In addition, the high-energy gamma rays from cobalt-60 are probably not representative of the gamma-ray spectra to which most radiation workers are exposed.

Beta-Particle Source. We used a strontium/yttrium-90 source encapsulated in 100 mg/cm^2 of low-atomic number material for the pilot study as required by the HPSSC Standard. The encapsulation essentially eliminates all the beta particles from strontium-90.

The source was mounted in a beam irradiator which emitted beta particles in a nearly 2π solid angle. However, the encapsulation had the effect of collimating the beta-particles and produced a usable beam only 6 cm in diameter at a distance 35 cm from the source. This meant that only one dosimeter at a time could be irradiated with this source. If strontium/yttrium-90 is used in a future testing program, the irradiator should be designed to permit several dosimeters to be irradiated simultaneously.

We considered several alternative beta-particle sources, but most had half lives that were too short or maximum energies that were too low. Thallium-204 was considered for several reasons. Its maximum energy, 0.765 MeV, probably represents beta spectra to which radiation workers are exposed better than does yttrium-90 with a maximum energy of 2.27 MeV. Since most thermoluminescent phosphors are approximately 100 mg/cm^2 thick, thallium-204 produces a more conservative calibration factor (response per mrem) than does a high-energy beta-particle source. The half life of thallium-204, 3.8 years, is acceptably long. The main disadvantage is that the National Bureau of Standards does not calibrate thallium-204 sources at this time. Thus, the testing laboratory and the processors would have to obtain calibrated sources from other countries. This is not an insurmountable disadvantage, but it would add unnecessarily to the expense and effort of a testing program.

We also considered metallic natural uranium which has several advantages over strontium/yttrium-90 as a calibration source:

1. It is already used by most processors that calibrate for beta particles.
2. It is uniform from source to source.
3. It is relatively inexpensive to purchase and maintain.
4. It presents few safety problems for the testing laboratory.
5. Many dosimeters can be irradiated simultaneously.

Natural uranium metal also has some possible disadvantages compared to strontium/yttrium-90:

1. It has a low absorbed dose rate (less than 4 mrad/min compared to about 150 mrad/min for the strontium/yttrium-90 source used for the pilot study). This problem can be overcome if a testing laboratory uses several uranium sources simultaneously.
2. The energy spectrum is not well known.
3. All the other sources used by the testing laboratory are point sources. There is some question as to whether a point source or a slab best represents irradiation geometries encountered by radiation workers.

Neutron Source. Several processors expressed dissatisfaction with the use of an unmoderated californium-252 source as required by the HPSSC Standard. Many radiation workers are exposed to fission neutrons, but the neutrons are moderated considerably.

Major disadvantages of californium-252 are its high cost, its relatively short half life, and its low dose equivalent rate. The testing laboratory will need to replace this source about every two years and will have to use long irradiation times to deliver some of the large dose equivalents required. Both problems will add considerably to the cost of testing.

If a californium-252 source is moderated, irradiation times will increase significantly. In addition, processors that use NTA film will have a difficult time calibrating for a moderated californium-252 source since NTA film is essentially insensitive to neutrons with energies less than about 0.7 MeV.

E. Recommendations on test geometries, including the use of phantoms for irradiations.

We followed the irradiation geometries required by the HPSSC Standard, and had few serious problems. Most irradiations were done at a distance of 100 cm or 200 cm from the source. However, it was necessary to do some neutron irradiations at a distance of 50 cm from the source to minimize room-scatter problems. Also, since the required encapsulation of the strontium/yttrium-90 source produced a narrow beam of beta particles (6 cm in diameter at 35 cm from the source), only one dosimeter at a time could be irradiated with this source. Therefore, all beta-particle irradiations were done at 35 cm from the source. This was the smallest distance allowed by the Standard, and was used to provide the highest dose rate possible.

The HPSSC Standard does not specify how the distance from the source to a particular dosimeter shall be determined. We wanted to irradiate six dosimeters from six different processors simultaneously as part of our quality control program. Since dosimeters come in a variety of shapes and sizes, we needed a method to define the irradiation distance in a way that would be satisfactory to everyone, including the testing laboratory. Therefore, we defined irradiation distance as the distance from the source to the face of the phantom. All processors were informed of this definition before the start of Test #1. It was the responsibility of each processor to apply a correction factor to account for the distance from the face of the phantom to the sensitive element of their dosimeters. These correction factors varied from about 1% for an irradiation distance of 200 cm to about 6% for an irradiation distance of 35 cm. From our discussions with the processors, few, if any, applied any distance correction factors.

F. Recommendations on whether one passed test per year is sufficient.

From May 1, 1978 to April 30, 1979, we administered two tests to each of the processors that chose to participate. The Standard requires each test to be conducted over a three-month period. Thus, once a month for three months, each participating processor sent us one-third of the total number of dosimeters required for a complete test. For Test #1, we staggered the starting time for the processors so that some participated during May-June-July, some during June-July-August, etc. Although this method of scheduling enabled us to increase our workload gradually, it was awkward to have some processors in their first month while others were in their second or third month of the test. For Test #2, half the processors participated during November-December-January, and the other half during February-March-April. This schedule was considerably easier to manage than the schedule used for Test #1.

We were able to visit eight of the processors during the pilot study, and we spent many hours on the telephone discussing the Standard with all the processors. From our visits and conversations, we doubt that requiring a processor to pass more than one test per year is possible or necessary. If the mandatory testing program provided four three-month tests on a schedule similar to the one developed for Test #2, a processor would be doing well to participate in one test and, if they failed some categories, take the necessary corrective action and be retested in those categories during a twelve-month period. Timing would permit few, if any, processors to pass more than one test per year. Even if time permitted, we saw nothing to indicate that a processor's procedures or performance varied enough to warrant more than one passed test per year.

G. Recommendations on the tolerance limits in the Standard.

The tolerance limits, L, for each category and the statistical method required by the HPSSC Standard are shown in Table 2. For the low-dose intervals, the average delivered dose, $\bar{H}$, was about 60 mrem which resulted in a value of L of about 2. For medium-dose intervals, L was about 1, and in the high-dose intervals, L was either 0.3 or 0.5. The dependence of L on $\bar{H}$ was based on the assumption that the accuracy of personnel dosimetry is not required to be as great at low doses as at high doses, and therefore the tolerance limit must be higher at low doses than at high doses.

Figures 1 through 12 show the performance index, P, for individual dosimeters in Test #2 plotted as a function of the delivered dose, H, for several representative categories. Figures 13 through 24 show the standard deviation, S, for each set of 10 dosimeters in an interval of Test #2 plotted as a function of the average delivered dose, $\bar{H}$, for several representative categories. Similar graphs generated for the other categories show the same results as these figures. Figures 1 through 24 show that flaring of performance from low to high doses does not occur. Therefore, although the dependence of L on $\bar{H}$ can be justified considering only health physics requirements, a flaring of L does not appear to be necessary considering the state-of-the-art of personnel dosimetry.

For any interval in which L is greater than 1.0, a processor can (and a few processors did) pass if all their reported doses are zero since $\bar{P} = -1.0$ and $S = 0.0$. Although it is not possible to pass an entire category by reporting all zeros, it seems inappropriate to permit a processor to pass any part of a test in this manner.

Table 2 shows that the low-dose intervals in the Standard have relatively small test ranges (e.g., 30 to 100 mrem). The small test ranges, together with the large values of L, make it relatively easy to pass these low-dose intervals. In fact, we participated in Test #2 ourselves, not by processing dosimeters, but by using a table of random numbers to generate reported doses. Although we were not able to pass a complete category, we did pass 52% of the intervals in this manner.

We examined eight possible statistical methods. The consequences of using each method, in terms of the number of processors that would pass each category, are shown in Tables 9 and 10 for Test #1 and Test #2, respectively. The first statistical method is the one used for the pilot study, $|\bar{P}| + 2S \leq L$ for each interval. The second method is the same as the first except that 1S is used instead of 2S. As expected, the passing rate is considerably higher if 1S is used.

There are two objections to basing the performance of a processor on combinations of $\bar{P}$ and S for each interval. First, only 10 values of P are used which is a relatively small number of data from which to calculate an S. Text books on statistics typically recommend a minimum of 30 data points.[5] The use of all dosimeters (20 to 40) in a category, instead of the 10 dosimeters in each interval, would provide a better number of data from which to calculate $\bar{P}$ and S. Second, the values of P cannot be normally distributed (a requirement for the use of standard deviations) since the minimum value of P is -1.0 whereas the maximum is infinity.

The third and fourth statistical methods we examined require that L be a constant for an entire category and that all dosimeters in a category be used to calculate $\bar{P}$ and S. This approach was also tried with the protection intervals separated from the accident intervals in Categories I and II. In addition to providing an improvement in the statistical base for $\bar{P}$ and S, we assumed that if only one dosimeter in a category had a large value of P, the effect of that dosimeter would be less if it were combined with all the dosimeters in the category instead of just with the dosimeters in one interval. This statistical method was tried with L = 0.3 and L = 0.5. Tables 9 and 10 show that with L = 0.3, the processors did considerably worse than with the current method of L as a function of $\bar{H}$. For L = 0.5, the processors did about the same as with the current method. The average value of L for each category in the current Standard is considerably larger than 0.5. Apparently, this fact balances the blending of one bad dosimeter with all the other dosimeters in a category. However, we prefer $|\bar{P}| + 2S \leq 0.5$ for an entire category, with the accident and protection intervals computed separately, to the current method of $|\bar{P}| + 2S \leq L$ for each interval since the former approach incorporates a larger number of dosimeters.

The fifth, sixth, seventh, and eighth statistical methods we examined require that a single tolerance limit be placed on each dosimeter within a category rather than on an average dosimeter as is required by the previous methods. This approach was tried by requiring that the values of P for every dosimeter in a category be within either ±0.3 or ±0.5. It was also tried allowing one dosimeter within a category to be outside the tolerance limit. The results are shown in Tables 9 and 10.

In examining the results of the eight statistical methods shown in Tables 9 and 10 to determine which is preferred, we struggled with two opposing philosophies. First, there is no passing rate that is considered acceptable. That is, we were not trying to devise a statistical method so that, for example, 50% of the processors could pass. Second, if a statistical method were chosen that resulted in a large number of processors failing, the initiation of a mandatory performance testing program would probably be delayed considerably or permanently. Thus, consideration must be given to the anticipated passing rate of the statistical method selected.

H. Recommendations on the feasibility and desirability of testing in the 15 to 30 keV photon range (Category III in the HPSSC Standard), and whether the upper energy of the range in Category III and the lower energy of the range in Category II should be increased.

Many processors have expressed their support for a radiation category that includes low-energy photons. In fact, 26 of the 59 processors chose to participate in Category III during the pilot study. Since participation in any category is the choice of the processors, there is an obvious demand for a low-energy photon category.

There are four intervals in Category II of the HPSSC Standard. During the pilot study, we selected a different NBS X-ray calibration technique for each of the four intervals.* The four techniques were used in the same

*All intervals within a category require the same type of radiation. For the intervals in Categories II and III, the type of radiation is the same (X rays), but different spectra were used for each interval.

intervals in Test #1 and in Test #2. Processors generally had more difficulty passing interval 4 ($\bar{E}$ = 53.9 keV) than the other three intervals ($\bar{E}$ = 91.1, 204.2, and 117.5 keV for intervals 1, 2, and 3, respectively). Although processors had about the same trouble with interval 1 as with interval 4, we believe their problems with interval 1 were due more to the high doses involved than to the average energy of the spectrum used. Their performance in Category II, interval 4 was similar to their performance in both intervals of Category III ($\bar{E}$ = 19.7 keV). Therefore, it is likely that processors would have fewer problems with the high-energy X-ray category if the energy division between the low- and high-energy X-ray categories were greater than the present 30 keV but less than about 100 keV.

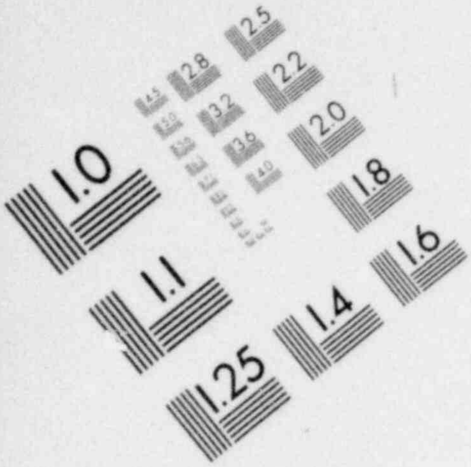
I. Recommendations on whether there should be two separate categories that include neutron irradiations.

Of the 59 processors that participated in the pilot study, 27 chose to participate in the neutron category, and 26 chose to participate in the neutron-plus-gamma ray category. Thus, the demand seems to exist to have two neutron categories. From our discussions with the processors, it is apparent that gamma rays can seriously interfere with the ability of most neutron dosimeters to detect neutrons accurately.

J. Recommendations on the appropriateness of varying the X-ray energies in the 15 to 30 keV and 30 to 300 keV categories when the processor does not know the X-ray energy.

Before the start of Test #1, we chose the standard NBS X-ray calibration techniques that would be used for each interval of the X-ray categories, and we informed the participating processors of these techniques. The release of this information is forbidden by the HPSSC Standard, a restraint which we overlooked. The performance of the processors in the categories requiring X rays was undoubtedly improved because of this error.

It was our intent at the beginning of the pilot study to use different NBS techniques in Test #2 than in Test #1. However, when it became apparent that few processors could pass the X-ray categories in Test #1, even though they were told which technique was being used for each interval, we felt that by using the same techniques in Test #2, we could best gauge the ability of the processors to adjust to the X-ray spectra required by the Standard. If different techniques had been used in Test #2, and if the performance of the processors had not improved in Test #2, we would not have known whether the lack of improvement was due to their permanent inability to estimate X-ray exposures correctly or to their inability to adjust to changes in X-ray energies. Table 6 shows that the passing rate for Category II went from 4% in Test #1 to 17% in Test #2, and the passing rate for Category III went from 3% to 42%. These results indicate that processors can adjust to the NBS techniques provided that they know which techniques are being used in each interval.



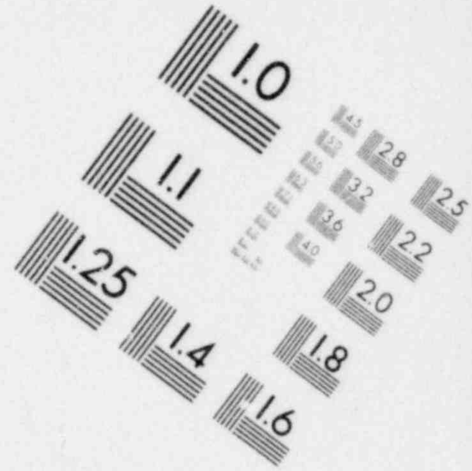
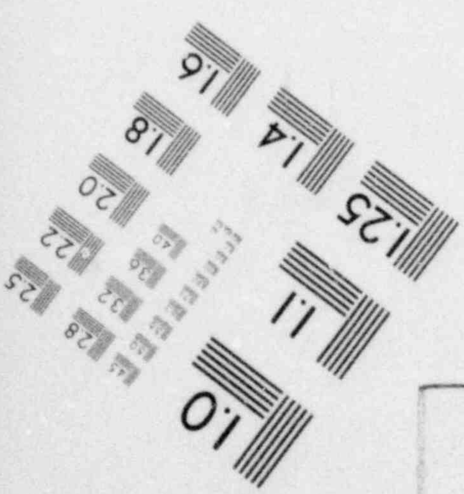
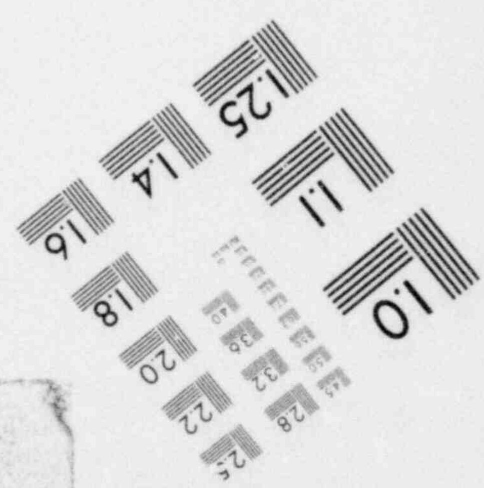


IMAGE EVALUATION TEST TARGET (MT-3)

MICROCOPY RESOLUTION TEST CHART





Unfortunately, we did not generate data that would indicate the consequences of varying the techniques from test to test without advanced notification of the techniques to be used in a particular test. Based on our discussions with several processors, we believe the passing rates will decrease appreciably if the techniques are varied, unless the processors calibrate for all the techniques that could be used by the testing laboratory. If the energy division between the high- and low-energy categories is raised from 30 keV to about 80 keV, the processors will probably have fewer problems with variations in X-ray energies within each category.

K. The economic feasibility of a self supported testing laboratory to conduct this testing in the future.

It is difficult to do a detailed cost estimate at this time since this Final Report will recommend several changes in the Standard and others will undoubtedly recommend changes also. However, based on two years of experience with the pilot study, we can estimate an approximate cost to a processor for a future mandatory testing program.

We assume a testing program will require the labor of one director, two technicians, and a half-time secretary. These labor costs, including fringe benefits and overhead, are estimated at $130,000 year. Routine operating costs will include mailing charges, long distance telephone calls, maintenance of equipment, computer services, and calibrations with NBS. We estimate these operating costs to be about $20,000 per year.

It will be necessary to set aside funds to replace the X-ray machines, radionuclide sources, ionization chambers, etc., periodically. We estimate these replacement costs to be about $10,000 per year. Thus, our estimate of the total operating cost is about $160,000 per year, estimated in August, 1979, dollars. This est ioes not include the costs required to construct and maintain the buildings necessary to house the sources.

L. Updating the procedures developed in the preliminary phase.

The Preliminary Phase of the pilot study extended from September 27, 1977, to April 30, 1978. During that time, we obtained the necessary radiation sources, and established calibration, quality control, irradiation, and administrative procedures. Calibration data and the proposed procedures were given in the Preliminary Phase Report,[4] submitted to the Nuclear Regulatory Commission on March 31, 1978.

On August 14, 1979, we submitted the Procedures Manual[2] developed for the pilot study to the Nuclear Regulatory Commission. The Procedures Manual contains a description of the radiation sources and the calibration, quality control, and administrative procedures developed and used for the pilot study, and reflects changes made since the Preliminary Phase Report was prepared.

M. Other observations.

Several miscellaneous problems and observations are discussed below. Specific recommendations for these subjects are given in the CONCLUSIONS AND RECOMMENDATIONS section of this Report.

Voided Dosimeters and Reporting Errors. During the pilot study, we occasionally misirradiated a dosimeter. When such an error was brought to our attention, we voided the dosimeter in question. The statistical analyses required for each interval were then based on 9 instead of 10 dosimeters. Approximately 1% of the nearly 23,000 dosimeters irradiated for the open and blind tests of the pilot study were misirradiated and subsequently voided.

Several times during the pilot study, a processor would recognize an error they made after they received their computerized report of a complete test showing delivered and reported doses to each dosimeter. These errors by the processors included clerical errors, calibration errors, and reporting errors (e.g., doses reported in units of mR without being converted to mrem). We adopted a policy that once a processor was informed of the delivered doses, it was too late to change the reported doses or to void dosimeters if the error were the processor's.

Another problem arises when the processor reports no dose for a dosimeter. For example, some dosimeter results were shown as "data lost" instead of a reported dose. During the pilot study, we simply voided such dosimeters and performed the statistical analyses on the remaining dosimeters. This policy concerns us since a processor with severe problems could elect not to report doses for the dosimeters for which they have little confidence. They undoubtedly would not void such dosimeters that were worn by their customers.

Reporting Schedule. During the twelve months of the pilot study in which the two tests were being conducted, we attempted to complete all the irradiations scheduled for each month and mail the irradiated dosimeters to the processors before the last day of the month. This schedule is required by the HPSSC Standard. However, the Standard places no restrictions on the time given to a processor for reporting their doses. Some processors took more than six months to submit their reported doses to us.

Depth for Deep Dose. The HPSSC Standard specifies 1000 mg/cm^2 as the depth at which deep doses are to be determined. However, the Nuclear Regulatory Commission's Form 5, the permanent record of doses to radiation workers, specifies 300 mg/cm^2 as the deep depth when eye protection is not worn. If eye protection is worn, 1000 mg/cm^2 is to be used. Several processors were concerned about the differences between the Standard and Form 5, especially processors that are designing or selecting new dosimeters and must decide on the depth to specify for deep doses.

Consistency of Performance. The HPSSC Standard requires the testing laboratory to, "... provide in each report to the processor information on the consistency of his performance." The Standard then recommends a statistical method that could be used to determine if the precision and bias of a processor are consistent from one test to another. Table 11 contains a summary of the results of the two consistency tests calculated for the data obtained during the pilot study. For example, if a processor passed an interval in Test #1 and passed the same interval in Test #2, his precision and bias are expected to be consistent. Table 11 shows that this combination was, in fact, a common occurrence.

The consistency test appears to be an unnecessary requirement of the testing laboratory. If information on consistency is desired by a processor (we found no processor during the pilot study that was interested in consistency), then perhaps the processor should perform the necessary calculations.

Angular Dependence. The HPSSC Standard requires that, "For each dosimeter design submitted for test by a processor, a study of the angular dependence of the response ...," shall be conducted by the testing laboratory. Although there is a need for each processor to understand the angular response of his dosimeter, it is perhaps unnecessary to require such a study as part of a performance testing program. A processor should be encouraged to investigate such parameters as angular response, consistency, and effects of temperature, humidity, etc., but these studies should not be part of the requirements of the Standard.

Phantom Size. There is a suspicion that the simultaneous irradiation of six dosimeters on the 30 cm by 30 cm phantoms used for the neutron source caused some edge effects for some dosimeters.[6] If the sensitive element of a dosimeter were not in the geometric center of the dosimeter, then the sensitive element would be closer to the edge of the phantom at some of the six irradiation positions than at others. The problem could be corrected with the use of a slightly larger phantom, but extensive irradiations must first be done with several designs of dosimeters to determine the magnitude of the problem.

Choice of Radiation Sources. During the two-year pilot study, several processors suggested the use of radiation sources that would be directly applicable to the radiation workers they serve. For example, several processors recommended the use of a moderated neutron source to simulate the working conditions inside nuclear power plants, while other processors wanted an unmoderated neutron source to simulate working conditions inside nuclear fuel fabrication and weapons facilities. Two options are available for the design of a standard and the related operation of a testing laboratory. First, the testing laboratory can be required to maintain a large number of highly calibrated radiation sources. Each processor could then choose the gamma-ray source, the beta-particle source, and the neutron source that would best simulate the working conditions of the people who use their dosimeters. The second option is to select one source for each type of radiation for testing purposes, and to hope that if a processor can adjust their calibrations for the testing program, they can also make similar adjustments for the radiation workers they serve. Under the second option, the testing laboratory could, if they chose, maintain a variety of calibrated radiation sources. The testing laboratory could then assist each processor in determining the appropriate correction factor between a required test source and the source that the processor believes best satisfies the needs of the workers they serve.

CONCLUSIONS AND RECOMMENDATIONS

No testing program will guarantee that if a processor passes the test, the radiation workers they serve are being treated with the same care given to the test dosimeters. We believe, however, that a testing program can be designed with the following objectives:

1. It must be able to distinguish a competent processor from an incompetent or casual one.
2. It must use radiation sources and procedures that come reasonably close to simulating the working conditions of a significant fraction of all radiation workers.
3. It must not be so expensive to operate that many small processors, which presumably can meet the specific needs of their workers, will abandon their efforts in favor of a commercial processor that perhaps cannot provide the customized service of the small processor.

The conclusions and recommendations given below are based on these objectives.

Most of the conclusions and recommendations given in this Report relate to the specific subjects covered in the DISCUSSION section above. However, two general recommendations, if accepted, will influence these specific recommendations.

Recommendation for a Three-Year Review

Some aspects of the HPSSC Standard appeared to work well during the two-year pilot study. We are recommending changes in some aspects in this Report, and other changes will undoubtedly be made before the mandatory testing program begins. We strongly recommend that after the mandatory testing program has been in operation for three years, the Standard and the operation of the testing program be critically reviewed.

Recommendation for a Certification and Review Board

As part of the mandatory testing program, we recommend the creation of a Certification and Review Board. The responsibilities of the Board would include the following:

1. Situations will arise where the testing laboratory and a processor will not be able to agree on matters such as the actual dose that was delivered to a particular dosimeter. The Board would serve as an unbiased mediator for such disputes.

2. The Board would periodically review the calibration, quality control, irradiation, and administrative procedures of the testing laboratory.

3. The Board would issue a certificate of performance to a processor that passed the tests administered by the testing laboratory and would maintain the official list of certified processors.

4. The Board would recommend changes in the Standard to the Health Physics Society Standards Committee whenever the Board had evidence that a change was required.

If a Certification and Review Board is formed, many administrative considerations must be addressed. These include:

1. With what organization will the Board be affiliated (e.g., the Health Physics Society, the American National Standards Institute, the Nuclear Regulatory Commission)?

2. How many members should the Board have?

3. What should be the replacement schedule for members of the Board (e.g., one-third replaced every two years)?

4. What qualifications are required of a Board member (e.g., superior knowledge of personnel dosimetry, experience as a processor)?

5. How will the Board be funded (e.g., by the organization with which it is affiliated, by the testing laboratory from fees collected from the processors)?

The specific conclusions and recommendations given below follow the outline of subjects given in the DISCUSSION section of this Report.

A. An evaluation of the Standard with respect to the feasibility of testing and for meeting the criteria.

In general, the concept of a mandatory personnel dosimetry performance testing program for all processors in the United States appears to be technically and economically feasible. Some of the problems of adapting to the HPSSC Standard that were experienced by the processors in Test #1 were corrected for Test #2 of the pilot study.

We assume that approximately two years, beginning in October, 1979, will be required to implement a mandatory testing program. During that time, processors will have one year to review their results from the two tests of the pilot study and make any changes in their procedures they feel are necessary. During the second year, we assume that a third trial test will be administered to the processors on a voluntary basis. Therefore, by the time a mandatory testing program begins, the processors will have had a total of four years of experience with the procedures required, including three trial tests. These four years should provide an adequate transition to the mandatory testing program for a competent processor.

We conclude that, with the proper effort, most processors could pass any reasonable performance test. We suspect that a few processors will be unwilling or unable to pass even a lenient performance test.

B. Recommendations for revision of the Standard to produce a more successful test program.

We are particularly sensitive to the common complaint of many processors that the Standard requires too many dosimeters and, in general, too much work on their part. Several of our recommended changes are to reduce the magnitude, and therefore the cost, of the Standard without sacrificing the ability of the Standard to distinguish a competent processor from an incompetent one. Table 12 summarizes our recommended changes which are discussed below.

Radiation Categories. We recommend nine radiation categories. These categories include three changes from the current Standard. First, we recommend a separate accident category instead of combining accident and protection intervals in the same category as is done in the present Standard. Second, we recommend that the division between high- and low-energy X rays be at 80 keV instead of at 30 keV as required in the present Standard. This energy boundary will be discussed in Section H below. Third, we recommend that the gamma-plus-X ray category use low-energy X rays instead of high-energy X rays as required in the present Standard. Since most dosimeters respond about the same to high-energy X rays as they do to gamma rays, we believe that mixtures of low-energy X rays and gamma rays would provide a good test of a processor's ability to distinguish mixtures of photons.

Radiation Sources. We recommend two major changes in the radiation sources required for the Standard. First, we recommend cesium-137 as the exclusive gamma-ray source. The present Standard permits either cesium-137 or cobalt-60. Second, we recommend the use of a moderated instead of an unmoderated californium-252 neutron source. In addition to these two major changes, we recommend the use of X-ray techniques from the GSF catalogue[3] that have a narrow range of energies.

Test Ranges. We recommend three changes in the test ranges required for the categories. First, in the new Category 1, shown in Table 12, we recommend an upper limit of 500 rad instead of the present 800 rad. In the pilot study, a processor that was calibrated for accident doses could handle the entire range of 10 to 800 rad with equal ease. The reduction of the upper limit from 800 to 500 rad will save the testing laboratory considerable irradiation time with no sacrifice in testing the performance of a processor. Second, we recommend that the protection categories that require one source (new Categories 2 through 6) have the same test range of 30 to 10,000 mrem. All commercial processors have minimum reported dose equivalents of 10 to 20 mrem. Thus, we believe the test range should have a lower limit closer to the reporting limits of the processors than exists in the present Standard (e.g., 150 mrem for X ray and beta, and 100 mrem for neutron). Third, we recommend that the test ranges for the three mixture categories be 100 to 5,000 mrem. A lower limit of 100 mrem will permit a reasonable division of doses between two sources following the 3:1 maximum mixture rule* of the Standard. The upper limit of 5,000 mrem will provide the same information on the quality of a processor as will the 10,000 mrem upper limit presently required by the Standard for two of the three mixture categories.

Number of Dosimeters. We recommend that the accident category require 10 dosimeters for a complete test and that all other categories require 20 dosimeters. The present Standard requires 10 accident dosimeters for gamma rays and 10 accident dosimeters for X rays. But, as stated above, high-energy X rays and gamma rays are handled with about the same ease by a processor. Thus, it is not apparent that the need exists to test the ability of a processor to measure high doses using both sources. Since the tolerance limit is more restrictive for Category 1, as will be discussed below, fewer dosimeters are proposed for this category than for the others.

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*The HPSSC Standard specifies that, for categories in which two radiation sources are required, the ratio of the delivered doses from the two sources shall not be greater than three to one.

For the 20 dosimeters required in X-ray Categories 3, 4, and 7 as shown in Table 12, we propose that the dosimeters in each category be divided into two groups of 10. Each set of 10 should be irradiated with a different X-ray calibration technique. The techniques used in Category 4 can also be used in Category 7.

For Categories 2 through 9, we recommend that half of the dosimeters be irradiated to dose equivalents greater than 1000 mrem. A similar requirement exists in the present Standard.

These recommendations result in a total of 160 dosimeters for all radiation categories compared to 210 dosimeters required in the present Standard. This represents a significant reduction in the cost and effort required by a processor without a loss in the ability to determine the competency of a processor.

Tolerance Limits. We recommend that a percent error term, P, be calculated as shown in Table 12. This term is the same as the performance index used in the present Standard except that it is expressed as a percent. To pass Category 1, all dosimeters must have values of P that are within ±30%. To pass each of the other categories, all but one dosimeter in each category must have values of P within ±50%. These limits of ±30% for accident doses and ±50% for protection doses follow the health physics needs discussed in the HPSSC Standard. The basis for the recommended change in the method used to determine if a processor's accuracy is within the required tolerance limits is discussed in Section G below.

C. Recommendations on the usefulness and desirability of blind testing.

We recommend that no blind tests be conducted during the first three years of a mandatory testing program. This would give all processors time to adjust completely to the calibration and data handling requirements of the Standard. The possibility of blind testing can be reexamined at that time, although we doubt that it will ever be found to be an effective method to decide the competency of all the processors on a uniform basis.

D. Recommendations on radiation sources, especially neutron and beta sources.

From the list of sources recommended by the processors, it is obvious that a testing program cannot satisfy every processor and, at the same time, be economically feasible to conduct. We recommend that one gamma-ray, one beta-particle, and one neutron source be required by the Standard for testing, and that the selection of these sources be based on a balance between cost (which must ultimately be borne by the processors in the form of testing fees) and applicability to radiation workers. Whatever source is selected for each type of radiation, the onus will be on the local health physicist to evaluate the applicability of that source to the needs of the workers for whom he is responsible and, if necessary, to apply a different correction factor to dosimeters worn by people than is applied to the test dosimeters. If this professional care is taken by the local health physicist (unfortunately, this is beyond the ability of the Standard to monitor), then the sources used in a testing program can be selected based more on cost than on universal applicability.

Recommendations concerning each of the four types of radiation sources required for the HPSSC Standard are given below.

X-Ray Sources. We recommend that the Standard be changed to permit the use of GSF spectra that have narrow energy distributions. This would minimize dosimeter response problems caused by mixing high- and low-energy photons in the same beam.

Gamma-Ray Source. We recommend that cesium-137 be used as the exclusive gamma-ray source required for the Standard.

Beta-Particle Source. We recommend that strontium/yttrium-90, encapsulated in 100 mg/cm^2 of low atomic number material, be continued as the beta-particle source required for the Standard.

Neutron Source. We recommend that a moderated californium-252 source be required and that the moderating material be defined in detail by the Standard.

E. Recommendations on test geometries, including the use of phantoms for irradiations.

We recommend that dosimeters continue to be irradiated on tissue-equivalent phantoms. However, since the use of water-filled Plexiglas phantoms occasionally proved to be troublesome due to leaks, we recommend that phantoms be constructed from solid slabs of acrylic.

We recommend that the HPSSC Standard define the irradiation distance as the distance from the source to the face of a phantom.

F. Recommendations on whether one passed test per year is sufficient.

We recommend the following format for the first three years of a mandatory testing program:

1. There should be four three-month tests offered during each calendar year.

2. A processor should be required to pass one test every twelve months for each radiation category in which the processor desires to be certified. The processor would be certified by the Certification and Review Board for each radiation category they pass during a twelve-month period.

3. A processor could join the testing program only at the beginning of a three-month test.

4. During the first year of the mandatory testing program, a processor could join the program during any of the four tests. Their twelve-month testing year would begin when they joined the program. This would protect the testing laboratory from having all the processors rush to join during the first three-month test.

5. If a processor failed one or more of the radiation categories, they could be retested in those categories during any of the three-month tests.

6. If a processor cannot pass a particular radiation category during their twelve-month testing year, the Certification and Review Board would remove their name from the list of processors certified for that category.

This format is reasonable for the first three years of a mandatory testing program, during which time the processors will continue to become familiar with the radiation sources and administrative procedures required by the Standard. After the first three years, the Standard and the testing schedule should be reviewed critically to determine if both should and could be made more restrictive.

G. Recommendations on the tolerance limits in the Standard.

We recommend that, for the first three years of the mandatory testing program, all dosimeters except one outlier within the protection categories be required to have a P value within ±50%. In the accident category, no outlier should be permitted due to the severe biological consequences of most of the doses, and the tolerance limit should be ±30%. This method:

1. will pass a competent processor and fail an incompetent one.
2. will not permit a processor to pass by reporting a zero dose for all their dosimeters.
3. will result in about half the categories tested being passed.* This will cushion the beginning of a mandatory testing program for an industry not acustomed to equating the failure of a test with the termination of business.
4. calls attention to individual dosimeters instead of to averages and standard deviations. Personnel dosimetry is performed on individuals, not on the average among groups of people.
5. is simple to understand and to explain.

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*Although it is possible to predict the percent of category tests that will be passed, it is not possible to predict the number of processors that will pass every category in which they choose to be tested.

The primary disadvantage appears to be that this method allows processors a liberal range within which to pass. However, the results in Tables 9 and 10 show that, even with this method, many processors will have trouble passing. During the first three years of a mandatory testing program, these processors will have to improve their procedures so they can pass or else cease processing dosimeters. Either decision will represent an improvement in personnel dosimetry. At the end of the first three years, the performance of the processors can be reexamined to determine if the statistical method can be made more restrictive (e.g., reduce the tolerance limit from ±50% to ±30%, eliminate the outlier, place some limit on how far out of tolerance the outlier can be, etc.).

H. Recommendations on the feasibility and desirability of testing in the 15 to 30 keV photon range (Category III in the HPSSC Standard), and whether the upper energy of the range in Category III and the lower energy of the range in Category II should be increased.

Calibration, quality control, and irradiation procedures for Category III were no more difficult than for the other categories. There was essentially the same demand by the processors to be tested in Category III as in the other categories. Therefore, we recommend that a low-energy photon category be retained in the Standard.

We recommend that the energy division between the low- and high-energy X-ray categories be raised from 30 keV to about 80 keV. The low-energy X-ray category would then cover the entire diagnostic energy range used by physicians and dentists.

I. Recommendations on whether there should be two separate categories that include neutron irradiations.

Due to the demand by the processors for these two categories, and due to the interference of gamma rays with the ability of neutron detectors to measure neutron doses accurately, we recommend that two separate neutron categories be continued in the Standard.

J. Recommendations on the appropriateness of varying the X-ray energies in the 15 to 30 keV and 30 to 300 keV categories when the processor does not know the X-ray energy.

Following our recommendation that the energy division between the low- and high-energy X-ray categories be raised from 30 keV to about 80 keV, we recommend that the X-ray energies be varied within these categories without informing the processors of the exact calibration techniques used.

K. The economic feasibility of a self supported testing laboratory to conduct this testing in the future.

If the nine radiation categories shown in Table 12 are adopted for the Standard, we propose that a processor be charged \$200 each for Categories 1 through 6, in which one radiation source is required, and \$400 each for Categories 7 through 9, in which two radiation sources are required in each category. If a processor participated in all nine categories, the total charge would be \$2,400. If the processor failed half the categories and required retesting, the retesting charge would be approximately $1,200 depending on the categories failed. Since the average processor participated in 75% of the categories during the pilot study, the average processor could expect to pay $3,600 x 0.75 = $2,700 per year during the mandatory testing program. We conclude that this cost is economically feasible for most processors.

If all 59 processors participated in the mandatory testing program, a single testing laboratory would have a gross annual income of approximately $160,000, our estimate of the annual operating costs of the testing laboratory, exclusive of building construction and maintenance costs.

Many uncertainties exist with these cost estimates such as the number of processors participating, the failure rate of the processors, and the desired profit of the testing laboratory. The cost estimates do not include funds to support the proposed Certification and Review Board. The testing laboratory might have to adjust their charges up or down after the first year o[illegible]o of operation.

L. Updating the procedures developed in the preliminary phase.

All conclusions and recommendations concerning the procedures actually used during the pilot study are contained in the Procedures Manual.[2]

M. Other observations.

Voided Dosimeters and Reporting Errors. We recommend the following changes in the Standard concerning voided dosimeters and incorrect doses reported by processors:

1. Once a processor has been informed of the doses delivered to their test dosimeters, a reported dose cannot be changed or voided if the processor reported an incorrect dose.
2. If more than 10% of the dosimeters in a category have no reported doses due to problems caused by either the testing laboratory or the processor, the statistical analyses must be held up until replacement dosimeters have been irradiated and their doses reported by the processor.

Reporting Schedule. We recommend that the Standard be amended to include a 60 day time limit on processors to report their doses to the testing laboratory following the completion of a three-month test. If they have not done so within this time limit, it should be interpreted as a flaw in their dosimetry procedures and the irradiations should be voided.

Depth for Deep Dose. Although the Nuclear Regulatory Commission's (NRC) Form 5 differentiates the lens of the eye from other organs, current radiation protection philosophy does not require this distinction. In ICRP 26,[7] the skin and the lens of the eye are considered equally radiosensitive. Therefore, the use of 7 and 1000 mg/cm^2 will, in general, result in conservative estimates of skin (including the lens of the eye) and whole body doses, respectively. We recommend that the HPSSC Standard continue to specify these two depths and that the special consideration given to the lens of the eye on the NRC's Form 5 be eliminated.

Consistency of Performance. We recommend that this requirement be eliminated from the HPSSC Standard.

Angular Dependence. We recommend that this requirement be eliminated from the HPSSC Standard.

Phantom Size. Recent data indicate the 30 cm by 30 cm face of the phantoms used for neutron irradiations is too small.[5] Given the consequences of this being true, we recommend that the problem be investigated thoroughly.

Choice of Radiation Sources. It would be desirable for the testing laboratory to maintain several radiation sources for each category so a processor could choose the sources that best simulate the working conditions of the people who use their dosimeters. However, we believe this would result in an excessively expensive (an increase of approximately 50% in the testing fee would be required) testing program for each processor. We recommend that one radiation source be specified in the Standard for each of the single-source categories.

SUMMARY

The following is an abbreviated list of our major recommendations for the HPSSC Standard and a future mandatory testing program.

1. After the mandatory testing program has been in operation for three years, the Standard and the operation of the testing program should be critically reviewed.

2. A Certification and Review Board should be created.

3. A separate accident category should be defined instead of combining accident and protection dose ranges in the same category.

4. The energy division between the high- and low-energy X-ray categories should be raised from 30 keV to about 80 keV.

5. The gamma-plus-X ray category should use low-energy X rays instead of high-energy X rays.

6. Cesium-137 should be the only gamma-ray source required by the Standard instead of letting a processor choose between cesium-137 and cobalt-60.

7. The beta-particle source required by the Standard should continue to be strontium/yttrium-90.

8. The neutron source required by the Standard should be changed to moderated californium-252, and the moderator should be specified in detail.

9. The Standard should be changed from requiring NBS X-ray techniques (combinations of filtration and kilovoltage) to permit the use of X-ray techniques from the GSF catalogue that have a narrow range of energies.

10. The upper limit of the accident test range should be reduced from 800 rad to 500 rad.

11. All protection categories that require one radiation source should have test ranges of 30 to 10,000 mrem.

12. All protection categories that require the mixture of two radiation sources should have test ranges of 100 to 5,000 mrem.

13. The accident category should require the testing of 10 dosimeters, and the protection categories should require the testing of 20 dosimeters each.

14. The total number of dosimeters required for testing in all the categories should be reduced from 210 to 160.

15. For a processor to pass the accident category, all test dosimeters should have reported doses that are within ±30% of the delivered doses.

16. For a processor to pass the protection categories, all the test dosimeters except for one outlier should have reported doses that are within ±50% of the delivered doses.

17. No blind tests should be conducted during the first three years of a mandatory testing program.

18. A mandatory testing program should require one passed test per year of each radiation category in which a processor wants to be certified.

19. The Standard should continue to contain a low-energy (15 to 80 keV) X-ray category.

20. The Standard should continue to contain a neutron and a neutron-plus-gamma category.

21. X-ray energies should be varied within the limits of the X-ray categories without informing the processors of the exact calibration techniques used by the testing laboratory.

22. Once a processor has been informed of the doses delivered to their test dosimeters, a reported dose should not be changed or voided if the processor reported an incorrect dose.

23. If more than 10% of the dosimeters in a category have no reported doses due to problems caused by either the testing laboratory or the processor, the statistical analyses should be held up until replacement dosimeters have been irradiated and their doses reported by the processor.

24. If a processor has not reported their doses within 60 days of the completion of a test, the irradiations should be voided.

25. The analysis for consistency of performance should be eliminated from the Standard.

26. The analysis of the angular dependence of a dosimeter should be eliminated from the Standard.

27. The size of the phantoms used for neutron irradiations should be examined to determine if they should be larger than specified in the Standard.

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ACKNOWLEDGEMENTS

We would like to express our gratitude to the people at the National Bureau of Standards for the technical support and guidance they have provided during the two-year pilot study. In particular, we are grateful to Margaret Ehrlich, Tom Loftus, Jack Pruitt, Val Spiegel, and Charles Eisenhauer. It is because of Dr. Ehrlich's tireless efforts over the past five years that a dosimetry performance testing program is as close to a reality as it is.

We are also grateful to each of the 59 processors that volunteered to participate in the pilot study. Their cooperation and patience were essential to a successful pilot study.

APPENDIX

The Appendix contains all the tables and figures referenced in the Final Report. All the figures show results from Test #2 of the pilot study.

Table 1. Alphabetical listing of the processors that participated in the pilot study.

Argonne National Laboratory
Arkansas Power & Light Co.
Armed Forces Radiobiological Research Institute
Atomic Energy Industrial Laboratories
Atomic Radiation Laboratory
Baltimore Gas & Electr c Co.
Battelle Pacific Northwest Laboratories
Bethlehem Steel Corporation
Bettis Atomic Power Laboratory
Brookhaven National Laboratory
Broward General Medical Center
Bureau of Medicine & Surgery
Carolina Power & Light Co.
Charleston Naval Shipyard
Consumers Power Co.
Department of Energy, Idaho Operations Office
Duke Power Co.
Duquesne Light Co.
Eberline Instrument Corporation
Florida Power & Light Co.
General Electric Co.
Harvard University
Health Physics Northwest
ICN Pharmaceuticals
Landauer, R.S., Jr. and Co.
Lawrence Radiation Laboratory
Lexington-Bluegrass Army Depot
Los Alamos Scientific Laboratory
Mason & Hanger
Monsanto Research Corporation
National Bureau of Standards
Naval Electronic System Command
Naval Research Laboratory
New England Nuclear
Nuclear Souces and Services
Nurnberger Radiation Protection Service
Oak Ridge National Laboratory
Omaha Public Power District
Public Service Electric & Gas Co.
Radiation Detection Co.
Radiation Management Corporation
Reynolds Electric & Engineering Co.
Rockwell International
Rutgers University
Sandia Laboratories
Savannah River Plant
Searle Analytic
Southern California Edison Co.
Teledyne Isotopes
Tennessee Department of Public Health
Tennessee Valley Authority
Toledo Edison Co.
United States Air Force, Brooks AFB
United States Testing Co.
University of Utah
Virginia Electric & Power Co.
Washington State Dept. of Health
Welex
Yankee Atomic Electric Co.

Table 2. Summary of HPSSC Standard prepared by The University of Michigan

Radiation Category		Interval	Test Range	Number of Dosimeters Per Test	Tolerance Level (L) (see footnotes) Shallow ($7\ mg/cm^2$)	Deep ($1000\ mg/cm^2$)
I.	Gamma (Co-60)	1 Accident:	10-800 rad	10	no test	a
		2 Protection:	30-100 mrem	10	no test	b
		3	101-300 mrem	10	no test	b
		4	301-10,000 mrem	10	no test	b
II.	X Ray (30-300 keV)	1 Accident:	10-800 rad	10	no test	a
		2 Protection:	30-100 mrem	10	c	c
		3	101-300 mrem	10	c	c
		4	301-10,000 mrem	10	c	c
III.	X Ray (15-30 keV)	Accident:	no test	--	--	--
		1 Protection:	150-300 mrem	10	c	c
		2	301-10,000 mrem	10	c	c
IV.	Beta (Sr-90)	Accident:	no test	--	--	--
		1 Protection:	150-300 mrem	10	c	no test
		2	301-10,000 mrem	10	c	no test
V.	Neutrons (Cf-252)	Accident:	no test	--	--	--
		1 Protection:	100-300 mrem	10	no test	c
		2	301-5,000 mrem	10	no test	c
VI.	Photon Mixtures (Cat. I & II)	Accident:	no test	--	--	--
		1 Protection:	50-100 mrem	10	c	c
		2	101-300 mrem	10	c	c
		3	301-10,000 mrem	10	c	c
VII.	Photon and Beta Mixtures (Cat. I or II & IV)	Accident:	no test	--	--	--
		1 Protection:	200-300 mrem	10	c	c
		2	301-10,000 mrem	10	c	c
VIII.	Photon and Neutron Mixtures (Cat. I & V)	Accident:	no test	--	--	--
		1 Protection:	150-300 mrem	10	no test	c
		2	301-5,000 mrem	10	no test	c

For each dosimeter, a performance index is calculated by:

$$P = \frac{H' - H}{H}$$ where: H = delivered quantity
H' = reported quantity

For each depth of each interval, an average performance index, $\bar{P}$, and its standard deviation, S, are calculated.

A processor passes a category if, for each depth of each interval:

$$|\bar{P}| + 2S \leq L$$

where:

a: $L = 0.3$
b: $L = 0.3$ or $6/\sqrt{H}$ whichever is larger
c: $L = 0.5$ or $15/\sqrt{H}$ whichever is larger

TABLE 3: PERFORMANCE TESTING OF PERSONNEL DOSIMETRY SERVICES

Summary of Results for Test #1 (first row) and Test #2 (second row)

Proc[illegible]or An[illegible]	I: Gamma				II: High-Energy X Ray							III: Low-Energy X Ray				IV: Beta		V: Neutron		VI: Gamma plus X Ray						VII: Gamma plus Beta				VIII: Gamma plus Neutron	
	1D	2D	3D	4D	1D	2S	2D	3S	3D	4S	4D	1S	1D	2S	2D	1S	2S	1D	2D	1S	1D	2S	2D	3S	3D	1S	1D	2S	2D	1D	2D
[illegible]	0	0	0	0	0	0	+	0	0	0	0					+	+			+	+	+	+	0	0	+	+	+	+		
[illegible]D	+	+	+	+																											
	+	+	+	+																											
3 TLD	0	+	+	+	0	+	+	+	+	0	0	0	+	0	+	+	+			+	+	+	+	+	+	+	+	+	+		
	+	+	+	0	0	+	+	+	+	0	0	+	+	+	+	+	+			+	+	+	+	0	0	+	+	+	+		
4 Film	0	0	0	0	0	+	+	+	+	+	+	+	+	0	0	+	0			+	+	+	+	+	+	+	+	0	0		
	0	0	+	+	+	+	+	0	0	+	+	+	+	+	+	+	+			+	+	+	+	0	0	+	+	0	+		
5 TLD	0	+	0	0	0	+	+	+	+	0	0	+	+	0	0	+	+	+	0	+	+	+	+	0	+	+	0	+	0	+	0
	0	+	+	0	0	0	0	0	0	0	0	+	+	0	0	+	+	+	0	+	+	0	0	0	0	+	0	+	0	0	0
6 Film	0	0	0	0	0	+	+	+	+	0	0	0	+	0	0	+	0	+	0	+	+	+	+	0	0	+	+	+	0	+	0
	0	+	+	0	0	+	+	+	+	0	0	+	+	0	0	+	0	+	0	+	+	+	+	0	0	+	+	0	+	0	0
7 TLD	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	+	0	0	0	+	+	+	+	+	+	+	+	0	+	0	0
	+	+		0	0	+	+	+	+	0	+	+	+	0	+	+	+	+	0	+	+	+	+	0	+	+	+	+	0	0	0
8 Film	0	0	+	0	0	+	+	0	0	+	+	+	+	0	0	+	0	0	0	+	+	0	0	0	0	+	+	0	0	+	0
	0	+	+	0	0	+	+	0	0	+	+	+	+	0	0	+	0			+	+	0	0	0	0	+	+	0	0		
9 TLD	0	0	0	+	0	+	+	+	+	0	0					+	+	+	+	+	+	+	+	+	0	+	+	+	0	+	+
	0	+	0	+	+	+	+	+	+	0	0					+	0	+	+							0	+	+	0	+	+
10 TLD	0	0	0	0	0	+	+	+	+	0	0	0	0	0	0					+	+	+	+	0	0						
	0	+	0	0	0	+	+	+	+	0	0	0	0	0	0					+	+	+	+	0	0						
11 TLD	0	+	+	+	0	+	+	+	+	0	0									+	+	+	+	+	+						
	0	+	0	0	0	+	+	+	+	+	+									0	0	0	0	+	+						
12 TLD*																															
	0	0	0	0														+	0												
13 TLD	+	+	+	0	+	+	+	+	+	0	0	+	0	+	0	+	0	+	0	+	+	+	+	0	0	0	+	0	+	+	0
	0	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
14 Film	0	0	0	0	0	+	+	+	+	0	0	0	0	0	0	0	0	+	0	+	+	+	+	0	0	0	+	0	0	0	0
15 TLD	+	+	+	+	0	+	+	+	+	0	0	+	+	0	0	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	0
	0	+	+	+	0	+	+	+	+	+	+	+	+	0	0	+	0	0	0	+	+	+	+	+	+	+	+	+	0	0	0
16 TLD	0	+	0	0	0	+	+	+	+	0	0					+	0	+	+	+	+	+	+	0	0	+	+	+	+	+	+
	+	+	+	+	0	+	+	0	0	0	0					+	+	+	+	+	+	+	+	+	+	0	0	+	+	+	+

Note: Intervals shown under each category are defined in Table 1. Key: D = deep, S = shallow, + = pass, 0 = fail. Blank spaces indicate no participation in a particular category. For each category, a processor must pass each depth of each interval in order to pass the category.

* This processor did not participate in Test #1.

Table 3: PERFORMANCE TESTING OF PERSONNEL DOSIMETRY SERVICES

Summary of Results for Test #1 (first row) and Test #2 (second row)

Processor And Type	I; Gamma 1D	2D	3D	4D	II: High-Energy X Ray 1D	2S	2D	3S	3D	4S	4D
17 Film	0	+	+	0	0	+	+	0	0	0	0
	0	+	+	+	0	+	+	+	+	+	+
18 TLD	+	+	+	+	0	+	+	+	+	+	+
	+	+	+	+	+	+	+	+	+	+	+
19 TLD	+	+	+	+							
	+	+	+	+							
20 TLD	0	+	+	0							
21 TLD	0	+	+	+							
	0	0	+	0							
22 TLD	0	+	+	0	0	+	+	0	0	0	+
	0	+	0	0	0	+	+	+	+	+	+
23 TLD	+	0	+	+	+	+	+	+	+	+	+
	+	+	+	+	+	+	+	+	+	+	0
24 TLD	+	+	+	+	0	+	+	+	+	0	0
	+	0	+	+	0	+	+	+	+	0	0
25 TLD											
26 TLD	0	+	+	0							
27 Film											
28 Film*	0	0	0	0	0	0	0	0	0	0	0
29 Film	0	+	0	+	0	+	+	+	+	0	0
	0	+	+	0	0	+	+	+	+	0	0
30 TLD	+	+	+	0	+	+	+	0	+	+	+
	+	+	+	+	+	+	+	+	+	+	+
31 TLD	0	+	+	+							
	0	+	0	0							
32 Film	0	+	+	0							
	0	+	0	0							

Processor And Type	III: Low-Energy X Ray 1S	1D	2S	2D	IV: Beta 1S	2S	V: Neutron 1D	2D
17 Film	0	0	0	0	+	0	0	0
	+	+	0	0	+	0	0	+
18 TLD	+	+	+	0	+	+	0	0
	+	+	+	+	+	+	+	+
19 TLD								
20 TLD					+	+		
21 TLD					0	0		
					+	0		
22 TLD					+	0		
					+	0		
23 TLD	0	+	0	0	0	0	+	+
	0	+	0	0	0	0	+	0
24 TLD	+	+	0	0	+	+	0	0
	+	+	0	0	+	+	0	0
25 TLD								
26 TLD								
27 Film								
	0	0	0	0				
28 Film*								
29 Film	+	0	0	0				
	+	0	0	0				
30 TLD	+	+	0	0			0	0
	+	+	0	0			+	0
31 TLD	0	+	0	+	+	0		
	+	+	+	0	+	0		
32 Film					+	0		
					+	0		

Processor And Type	VI: Gamma plus X Ray 1S	1D	2S	2D	3S	3D	VII: Gamma plus Beta 1S	1D	2S	2D	VIII: Gamma plus Neutron 1D	2D
17 Film	+	+	+	+	0	0	+	+	0	0	+	0
	+	+	+	+	+	+	+	+	0	0	+	+
18 TLD	+	+	+	+	+	+	+	+	0	+	+	+
	+	+	+	+	+	+	+	+	+	+	+	+
19 TLD												
20 TLD							+	+	0	0		
21 TLD							0	+	0	0		
							+	+	0	0		
22 TLD	+	+	+	+	+	+						
	+	+	0	+	+	+						
23 TLD	+	+	+	+	+	+	0	+	0	+		
	+	+	+	+	+	+	0	+	0	+		
24 TLD	+	+	+	+	0	+	+	+	+	+	0	0
	+	+	+	+	0	0	+	+	+	0	+	0
25 TLD							+	+	0	+		
							0	+	0	+		
26 TLD												
27 Film	+	+	+	+	0	0	+	+	0	+	+	0
	+	+	+	+	+	+	+	+	0	+	+	0
28 Film*	0	0	0	0	0	0						
29 Film	+	+	+	+	+	+						
	+	+	+	+	0	0						
30 TLD											+	0
											+	+
31 TLD							+	+	0	0		
							+	+	+	0		
32 Film												

Note: Intervals shown under each category are defined in Table 1. Key: D = deep, S = shallow, + = pass, 0 = fail. Blank spaces indicate no participation in a particular category. For each category, a processor must pass each depth of each interval in order to pass the category.

* This processor did not participate in Test #2.

Table 3: PERFORMANCE TESTING OF PERSONNEL DOSIMETRY SERVICES

Summary of Results for Test #1 (first row) and Test #2 (second row)

Processor And Type	I: Gamma				II: High-Energy X Ray							III: Low-Energy X Ray				IV: Beta		V: Neutron		VI: Gamma plus X Ray						VII: Gamma plus Beta				VIII: Gamma plus Neutron	
	1D	2D	3D	4D	1D	2S	2D	3S	3D	4S	4D	1S	1D	2S	2D	1S	2S	1D	2D	1S	1D	2S	2D	3S	3D	1S	1D	2S	2D	1D	2D
33 Film	0	+	+	0	+	+	+	+	+	0	0	0	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+
	+	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	0
34 Film	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+	0	+	+	+	+	0	0	+	+	+	+	+	0
	+	+	+	+	0	+	+	+	+	0	0	+	+	+	+	+	+	+	0	+	+	+	+	0	0	+	+	+	+		
35 TLD	0	0	0	0	0	+	+	0	0	0	0	0	+	0	0	0	0			+	+	0	0	0	0	0	0	0	0		
36 TLD	0	0	0	0								0	0	0	0			0	0	0	0	0	0	0	0					0	0
	0	0	0	0								+	+	0	0			0	0	+	+	+	+	0	0					0	0
37 TLD	0	+	+	+	0	+	+	+	+	+	+																				
38 TLD	0	+	+	+	0	+	+	+	+	+	+	+	0	+	0			+	0											+	0
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+											+	0
39 TLD*																															
												+	+	0	+	0	0	+	+	+	+	+	+	0	+	+	+	0	+	+	+
40 Film		+	+	+		+	+	+	+	0	0	+	+	0	0	0	0	+	+	+	+	0	+	0	0	+	+	0	+	0	0
		+	+	0		0	0	0	0	0	0	+	+	0	+	0	0	+	+	+	+	0	0	0	0	+	+	0	0	+	+
41 TLD	0	+	+	+												+	+									+	+	+	+		
	+	+	+	+												+	+	0	0							+	+	+	+	+	0
42 TLD	0	+	+	+	0	+	+	+	+	0	0					0	0														
	0	+	0	0	0	+	+	+	+	0	0					+	0	+	0												
43 TLD	0	+	+	0	0	+	+	+	+	+	+	+	0	0	+	+	0	0	0	+	+	+	+	+	+	+	+	+	0	0	0
	0	+	0	0	0	+	+	+	+	0	0	+	+	0	+	+	+	0	0	+	[illegible]	+	+	0	0	+	0	+	0	+	0
44 TLD	0	+	+	+												0	0									+	0	+	0		
	0	+	+	0												+	0									+	+	0	+		
45 TLD																				0	0	0	0	0	0						
46 Film	0	+	0	0	0	+	+	+	0	0	0	+	+	0	0	0	0			+	+	+	+	0	0	0	+	0	+		
	0	+	+	0	0	+	+	0	0	0	0	+	+	0	0	+	0			+	+	+	+	0	0	+	+	0	+		
47 Film*																															
	+	+	+	0	+	+	+	+	+	0	0	0	+	0	0	+	0			+	+	+	+	0	0	+	0	0	+		
48 TLD	+	0	+	0												0	0	+	0							+	+	0	0	+	0
	0	0	0	0												+	+	0	0							+	+	+	0	+	0

Note: Intervals shown under each category are defined in Table 1. Key: D = deep, S = shallow, + = pass, 0 = fail. Blank spaces indicate no participation in a particular category. For each category, a processor must pass each depth of each interval in order to pass the category.

* This processor did not participate in Test #1.

Table 3: PERFORMANCE TESTING OF PERSONNEL DOSIMETRY SERVICES

Summary of Results for Test #1 (first row) and Test #2 (second row)

Processor And Type	I: Gamma				II: High-Energy X Ray							III: Low-Energy X Ray				IV: Beta		V: Neutron		VI: Gamma plus X Ray						VII: Gamma plus Beta				VIII: Gamma plus Neutron	
	1D	2D	3D	4D	1D	2S	2D	3S	3D	4S	4D	1S	1D	2S	2D	1S	2S	1D	2D	1S	1D	2S	2D	3S	3D	1S	1D	2S	2D	1D	2D
49 TLD	+	+	0	0	0	+	+	+	+	0	0	+	+	+	0	+	+	+	+	+	+	+	+	0	+	+	+	+	+	+	0
	+	+	+	+	0	+	+	+	+	0	0	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
50 Film	0	0	+	+	0	+	+	+	+	+	+	+	+	0	0	+	0	0	+	+	+	+	+	0	0	+	+	+	+	+	+
51 TLD	0	+	+	0												0	0	+	0							0	+	0	0	+	0
	0	+	+	+												0	0	+	0							0	+	0	0	+	0
52 TLD	0	0	+	+	0	+	+	+	+	0	0							+	+							+	+	0	0	+	0
	0	0	[illegible]	0	0	+	+	+	+	0	0							0	0							+	0	0	0	0	+
53 Film	0	+	0	0	0	+	+	+	+	0	0	[illegible]	+	0		+	0									+	+	+	0		
54 (withdrew)																															
55 TLD																				+	+	+	+	+	+						
																				+	+	+	+	+	+						
56 TLD	0	+	0	+	0	+	+	+	+	+	+	+	+	+	0	+	+		0	+	+	+	+	+	+	+	0	+	0	+	
	0	+	+	0	0	+	+	+	+	+	+	0	0	0	0	+	+	+	0	+	+	+	+	+	+	0	+	0	+	+	0
57 TLD	0	0	0	0	0	+	+	0	0	0	0																				
58 TLD*																															
	+	+	+	+												+	+	0	0							+	+	+	+	0	0
59 (withdrew)																															
60 TLD	+	0	+	0																											
	0	+	+	0																											
61 TLD	+	+	+	0	+	+	+	+	+	0	0					0	0			+	+	+	+	+	+	+	+	0	0		
	+	+	+	+	0	+	+	+	+	+	0					+	+			+	+	+	+	+	+	+	+	0	0		

Note: Intervals shown under each category are defined in Table 1. Key: D = deep, S = shallow, + = pass, 0 = fail. Blank spaces indicate no participation in a particular category. For each category, a processor must pass each depth of each interval in order to pass the category.

* This processor did not participate in Test #1.

Table 4: PERFORMANCE TESTING OF PERSONNEL DOSIMETRY SERVICES

Summary of Results for Test #1 (first row) and Test #2 (second row)

Processor And Type	I: Gamma				II: High-Energy X Ray							III: Low-Energy X Ray				IV: Beta		V: Neutron		VI: Gamma plus X Ray						VII: Gamma plus Beta				VIII: Gamma plus Neutron	
	1D	2D	3D	4D	1D	2S	2D	3S	3D	4S	4D	1S	1D	2S	2D	1S	2S	1D	2D	1S	1D	2S	2D	3S	3D	1S	1D	2S	2D	1D	2D
70 TLD	0	+	+	0	0	+	+	+	+	+	+	+	+	0	0	+	+			+	+	+	+	+	+	+	+	+	0		
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+		
71 TLD	0	0	0	0																											
	0	0	0	0																											
72 TLD	0	+	+	0	0	+	+	+	+	0	0	+	0	0	0	+	0			+	+	+	+	+	+						
73 NTA																		0	0											0	0
																		+	0											+	0
74 TLD	+	+	+	+																											
	+	+	+	0																											
75 TLD	+	+	0	+	0	+	+	+	+	0	0	+	0	+	+	+	+			+	+	+	+	+	+	+	+	+	+		
	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+		
76 TLD	+	+	+	+		+	+	+	+	+	+							+	0	+	+	+	+	+	+					+	+
	+	+	+	+		+	+	+	+	+	+							+	0	+	+	+	+	+	+					+	+
77 Track Etch																		+	0											+	+
																		+	+											+	+
78 Albedo																		+	0											+	+
																		+	+											+	+
79 TLD	+	+	+	+																											
	+	+	+	+																											
80 TLD																				0	0	0	0	0	0						
81 Albedo																														0	0
																														0	0
82 Ring*	0	0	0	0	0	+	+	+	+	0	0																				
83 TLD	0	+	+	+	0	+	+	+	+	0	0	0	0	0	0	+	0			+	+	+	+	+	+	+	+	+	+		
	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	0	0		
84 TLD	0	+	+	+	0	+	+	+	+	0	0	+	+	+	0	+	0			+	+	0	+	0	0	+	0	+	+		
	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	0	0	+	0	+	0		
85 TLD	+	+	+	+																											
	0	+	+	0																											
86 TLD**																															
	0	+	+	0	0	0	0	0	0	+	+	0	0	+	0	+	0			+	+	+	+	+	+	0	+	0	0		

Note: Intervals shown under each category are defined in Table 1. Key: D = deep, S = shallow, + = pass, 0 = fail. Blank spaces indicate no participation in a particular category. Fore each category, a processor must pass each depth of each interval in order to pass the category.

* This processor did not participate in Test #2.

** This processor did not participate in Test #1.

Table 5: PERFORMANCE TESTING OF PERSONNEL DOSIMETRY SERVICES

Summary of Results for Test #1 (first row) and Test #2 (second row)

Processor	I: Gamma				II: High-Energy X Ray							III: Low-Energy X Ray				IV: Beta		V: Neutron		VI: Gamma plus X Ray						VII: Gamma plus Beta				VIII: Gamma plus Neutron	
And Type	1D	2D	3D	4D	1D	2S	2D	3S	3D	4S	4D	1S	1D	2S	2D	1S	2S	1D	2D	1S	1D	2S	2D	3S	3D	1S	1D	2S	2D	1D	2D
91 Film	0	+	+	+												0	0	0	0							+	+	0	+	+	+
	0	0	+	0												+	0	+	0							+	+	0	+	+	0
92 Film	0	+	0	0												0	0	0	0							0	+	0	+	+	0
	0	+	+	+												+	0	0	0							0	+	0	+	+	0
93 Film	0	+	0	0												+	0	+	0							0	+	0	0	0	+
	0	+	+	0												+	0	0	0							+	+	0	0	+	0
94 film	0	0	+	0												0	0	0	0							+	+	0	0	0	0
	0	0	+	0												+	0	0	0							+	+	0	0	0	0
95 TLD	0	+	+	+												+	+	0	0							[illegible]	+	+	0	+	0
	0	+	+	0												+	+	+	0							+	[illegible]	+	0	0	0
96 TLD	0	+	+	+												+	0	0	0							+	+	+	+	+	0
	+	0	+	+												+	0	+	0							+	+	+	+	+	0
97 Film	0	0	0	0												0	0	0	0							0	+	0	0	+	0
	0	0	0	0												0	0	0	0							0	+	0	0	0	0

Note: Intervals shown under each category are defined in Table 1. Key: D = deep, S = shallow, + = pass, 0 = fail. Blank spaces indicate no participation in a particular category. For each category, a processor must pass each depth of each interval in order to pass the category.

Table 6. Summary of all intervals and categories passed for the open tests of Tests #1 and #2

Category	Test	Total No. of Processors	Percent Passing Interval 1 Shallow	Interval 1 Deep	Interval 2 Shallow	Interval 2 Deep	Interval 3 Shallow	Interval 3 Deep	Interval 4 Shallow	Interval 4 Deep	by Category
I	#1	62		30%		67%		66%		42%	18%
	#2	54		45		83		78		48	35
II	#1	46		16	96	98	80	80	28	30	4
	#2	37		29	92	92	84	84	51	49	16
III	#1	35	67	58	27	18					3
	#2	34	76	82	41	41					32
IV	#1	42	71		33						38
	#2	39	90		54						51
V	#1	30		70		23					20
	#2	32		72		34					31
VI	#1	42	90	90	78	83	46	51			40
	#2	36	97	97	86	89	56	58			44
VII	#1	40	80	90	49	54					33
	#2	39	72	77	51	54					26
VIII	#1	30		71		26					27
	#2	29		72		41					41

* * * * * * * * * * * * * * * * * * *

Test	Total No. of Categories Tested	Total No. of Categories Passed	Total No. of Intervals Tested	Total No. of Intervals Passed
#1	327	23%	912	54%
#2	300	35	818	67

Table 7. Summary of all intervals and categories passed for the blind tests of Tests #1 and #2

Category	Test	Total No. of Processors	Percent Passing: Interval 1 Shallow	Interval 1 Deep	Interval 2 Shallow	Interval 2 Deep	Interval 3 Shallow	Interval 3 Deep	Interval 4 Shallow	Interval 4 Deep	by Category
I	#1	7		0%		71%		57%		43%	0%
	#2	7		14		43		86		29	0
II	#1										
	#2										
III	#1										
	#2										
IV	#1	7	43		14						14
	#2	7	86		14						14
V	#1	7		14		0					0
	#2	7		43		0					0
VI	#1										
	#2										
VII	#1	7	57	100	29	43					14
	#2	7	71	100	29	43					14
VIII	#1	7		71		29					14
	#2	7		57		0					0

* *

Test	Total No. of Categories: Tested	Total No. of Categories: Passed	Total No. of Intervals: Tested	Total No. of Intervals: Passed
#1	35	9%	84	36%
#2	35	6	84	39

Table 8. X-ray techniques used for The University of Michigan dosimetry performance pilot study.

Category	Interval	kVp	Filtration (mm) Be	Al	Cu	Sn	Pb	NBS Technique	GSF* Measured [illegible] (keV)
II	1	200	4.75	4.85	5.00			MFK	[illegible].1
II	2	250	4.75	3.97	0.60	1.03	2.65	HFK	204.2
II	3	150	4.75	4.00	4.00	1.46		HFG	117.5
II	4	100	4.75	6.31				MFG	53.9
III	1 and 2	30	0.25	0.37				L-G	19.7

*GSF: Gesellschaft für Strahlen-und Umweltforschung mbH, (reference 3).

Table 9. Percent of processors passing each category of the HPSSC Standard for Test #1 as determined by alternative statistical methods.

Category		Statistics done on each interval		Statistics done on entire category		All dosimeters within ±0.3		All dosimeters within ±0.5		Number of Processors
		$\lvert\bar{P}\rvert+2S\leq L$	$\lvert\bar{P}\rvert+1S\leq L$	$\lvert\bar{P}\rvert+2S\leq 0.3$	$\lvert\bar{P}\rvert+2S\leq 0.5$	no outlier	one outlier	no outlier	one outlier	
I.	Gamma	18%	32%	15%	34%	15%	18%	31%	32%	62
II.	High-energy X ray	4	11	0	15	0	7	13	20	46
III.	Low-energy X ray	3	9	3	3	3	3	9	9	35
IV.	Beta	38	52	14	38	12	19	31	50	42
V.	Neutron	20	33	3	13	3	3	17	27	30
VI.	High X ray + Gamma	40	52	7	36	10	17	19	29	42
VII.	Beta + Gamma	33	43	5	25	5	13	25	45	40
VIII.	Neutron + Gamma	27	40	0	17	0	7	13	33	30
	Weighted Average	23%	34%	7%	24%	7%	12%	21%	31%	327
I.	Accident Interval	30%	43%	31%	48%	33%	41%	52%	54%	61
I.	Protection Interval	32	52	29	52	24	34	44	60	62
II.	Accident Interval	16	25	14	30	14	30	34	45	44
II.	Protection Interval	26	37	7	28	4	9	22	28	46

Table 10. Percent of processors passing each category of the HPSSC Standard for Test #2 as determined by alternative statistical methods.

	Statistics done on each interval		Statistics done on entire category		All dosimeters within ±0.3		All dosimeters within ±0.5		Number of Processors
Category	$\lvert\bar{P}\rvert+2S\leq L$	$\lvert\bar{P}\rvert+1S\leq L$	$\lvert\bar{P}\rvert+2S\leq 0.3$	$\lvert\bar{P}\rvert+2S\leq 0.5$	no outlier	one outlier	no outlier	one outlier	
I. Gamma	35%	46%	35%	50%	31%	54%	44%	67%	54
II. High-energy X ray	16	32	11	32	8	11	30	41	37
III. Low-energy X ray	32	56	18	24	18	24	21	29	34
IV. Beta	51	69	36	54	49	49	49	69	39
V. Neutron	31	50	9	19	6	13	16	34	32
VI. High X ray + Gamma	44	58	22	44	11	14	36	39	36
VII. Beta + Gamma	26	44	15	31	15	18	26	36	39
VIII. Neutron + Gamma	41	59	3	24	3	7	21	45	29
Weighted Average	35%	51%	20%	36%	19%	26%	32%	47%	300
I. Accident Interval	45%	62%	45%	64%	49%	60%	66%	77%	53
I. Protection Interval	39	67	35	70	33	52	52	76	54
II. Accident Interval	29	40	29	51	31	43	60	71	37
II. Protection Interval	30	54	11	35	11	14	30	41	35

Table 11. Percent of all depths of all intervals of all categories tested in the pilot study that meet each combination of performance (pass or fail) and consistency.

				Probability Level	
Test #1	Test #2	Std. Dev.	Bias	0.1%	1.0%
Pass	Pass	Consistent	Consistent	33%	26%
Fail	Fail	Consistent	Consistent	18	18
Fail	Pass	Consistent	Consistent	11	9
Pass	Fail	Consistent	Consistent	2	1
Pass	Pass	Inconsistent	Inconsistent	2	3
Fail	Fail	Inconsistent	Inconsistent	2	2
Fail	Pass	Inconsistent	Inconsistent	0	0
Pass	Fail	Inconsistent	Inconsistent	2	3
Pass	Pass	Inconsistent	Consistent	1	2
Fail	Fail	Inconsistent	Consistent	1	1
Fail	Pass	Inconsistent	Consistent	0	0
Pass	Fail	Inconsistent	Consistent	1	2
Pass	Pass	Consistent	Inconsistent	14	18
Fail	Fail	Consistent	Inconsistent	5	6
Fail	Pass	Consistent	Inconsistent	6	7
Pass	Fail	Consistent	Inconsistent	2	2

SUMMARY:	Std. Dev. - consistent	91%	87%
	Bias - consistent	68%	56%
	Test #1 passed, Test #2 passed	51%	51%
	Test #1 failed, Test #2 failed	25%	25%
	Test #1 failed, Test #2 passed	17%	17%
	Test #1 passed, Test #2 failed	7%	7%

Table 12. Proposed categories, ranges, and tolerance limits to replace those required in the present HPSSC Standard.

Radiation Category	Test Range	Number of Dosimeters Per Test	Tolerance Limit Shallow ($7\ mg/cm^2$)	Deep ($1000\ mg/cm^2$)	Neutron ($1000\ mg/cm^2$)
1. Accident (Cs-137)	10-500 rad	10	no test	±30%	no test
2. Gamma (Cs-137)	30-10,000 mrem	20	no test	±50%	no test
3. High-Energy X Ray (80-300 keV)	30-10,000 mrem	20	±50%	±50%	no test
4. Low-Energy X Ray (15-80 keV)	30-10,000 mrem	20	±50%	±50%	no test
5. Beta (natural uranium)	30-10,000 mrem	20	±50%	no test	no test
6. Neutron (moderated Cf-252)	30-10,000 mrem	20	no test	no test	±50%
7. Gamma plus X Ray (Cat. 2 & 4)	100-5,000 mrem	20	±50%	±50%	no test
8. Gamma plus Beta (Cat. 2 & 5)	100-5,000 mrem	20	±50%	±50%	no test
9. Gamma plus Neutron (Cat. 2 & 6)	100-5,000 mrem	20	no test	±50%	±50%

For each dosimeter, a percent error is calculated by:

$$P = \left(\frac{\text{reported} - \text{delivered}}{\text{delivered}}\right) \times 100$$

For Category 1, a processor passes if all 10 dosimeters have values of P that are less than ±30%.

For Categories 2 through 9, a processor passes a category if 19 out of 20 of the dosimeters have values of P that are less than ±50% for all relevant depths.

In Categories 3, 4, and 7, at least two appropriate X ray techniques must be used for each category.

In Categories 2 through 9, half of the dosimeters required for each category must be irradiated to dose equivalents greater than 1000 mrem.

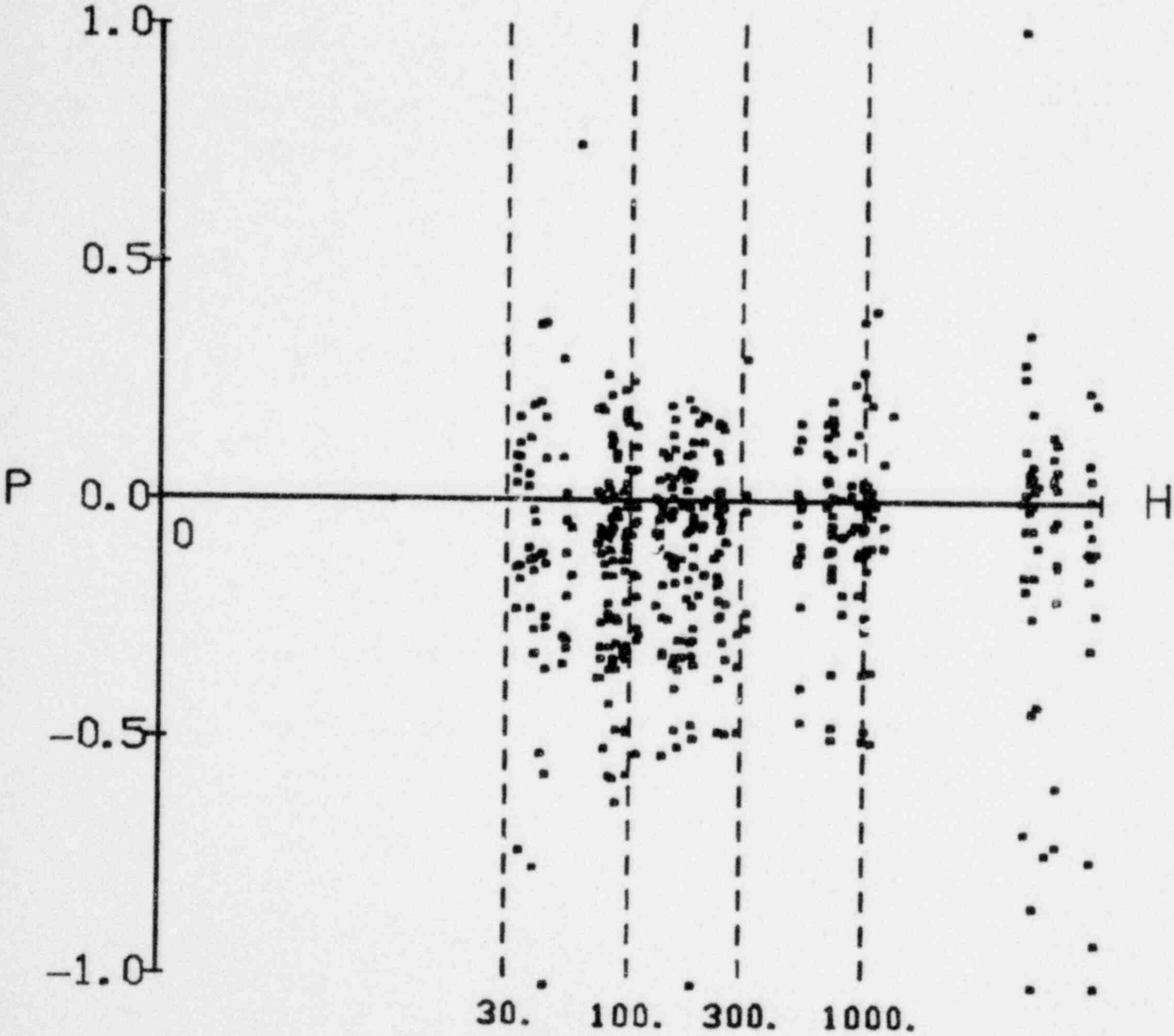


FIGURE 1.
CATEGORY I GAMMA
INTERVALS 2, 3, AND 4
FILM (DEEP)

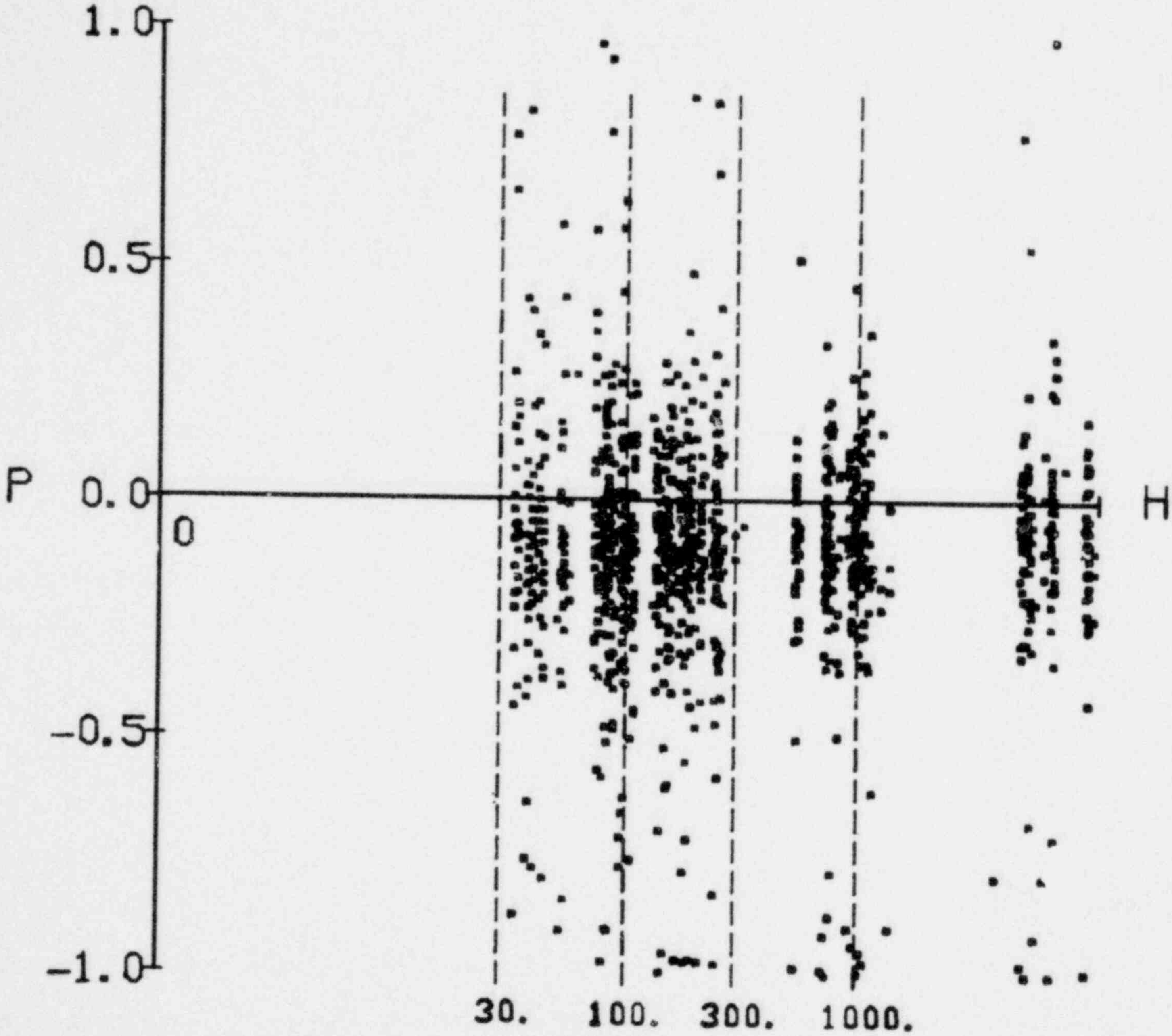


FIGURE 2.
CATEGORY I GAMMA
INTERVALS 2, 3, AND 4
TLD (DEEP)

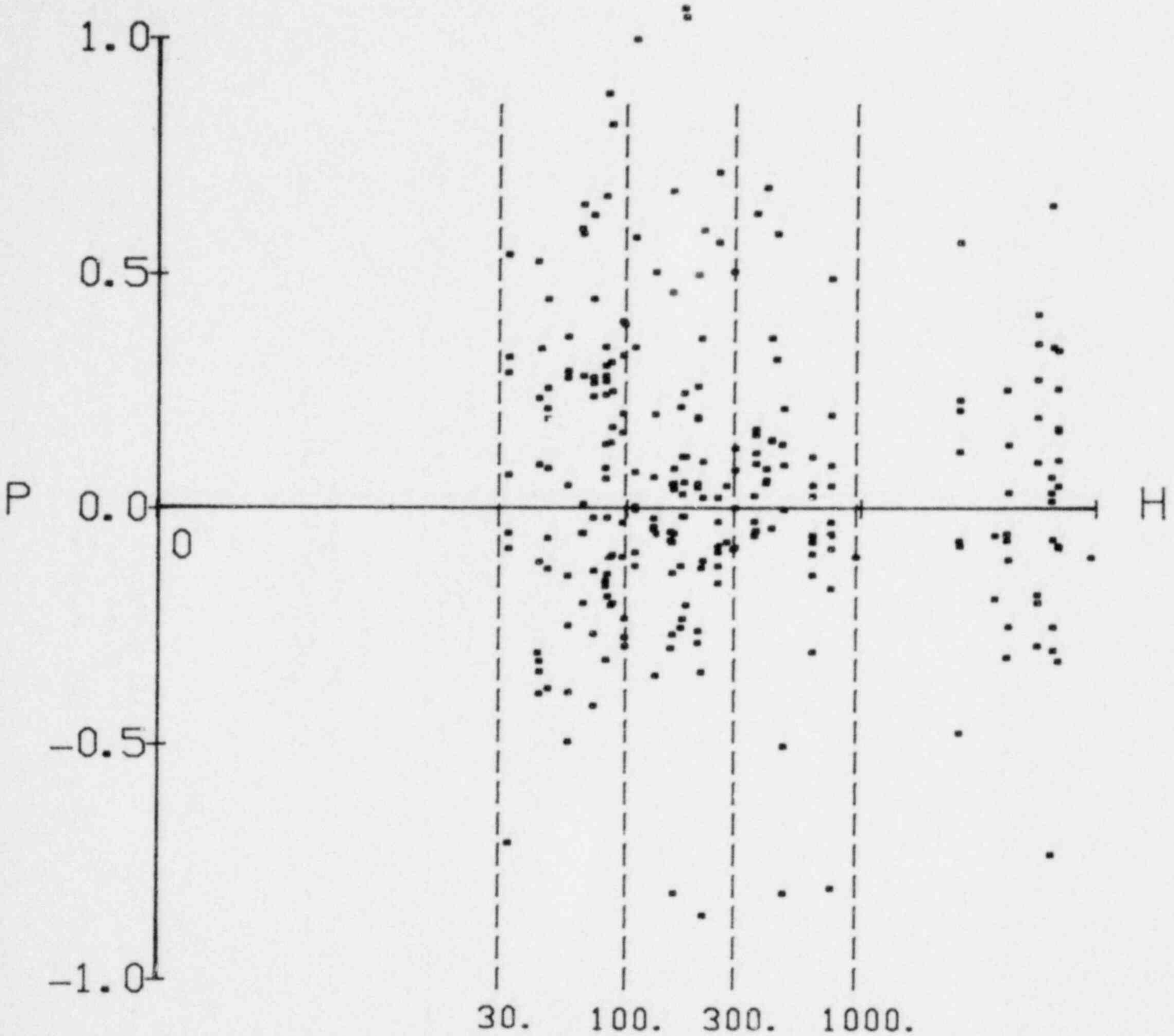


FIGURE 3.
CATEGORY II X-RAY
INTERVALS 2, 3, AND 4
FILM (SHALLOW)

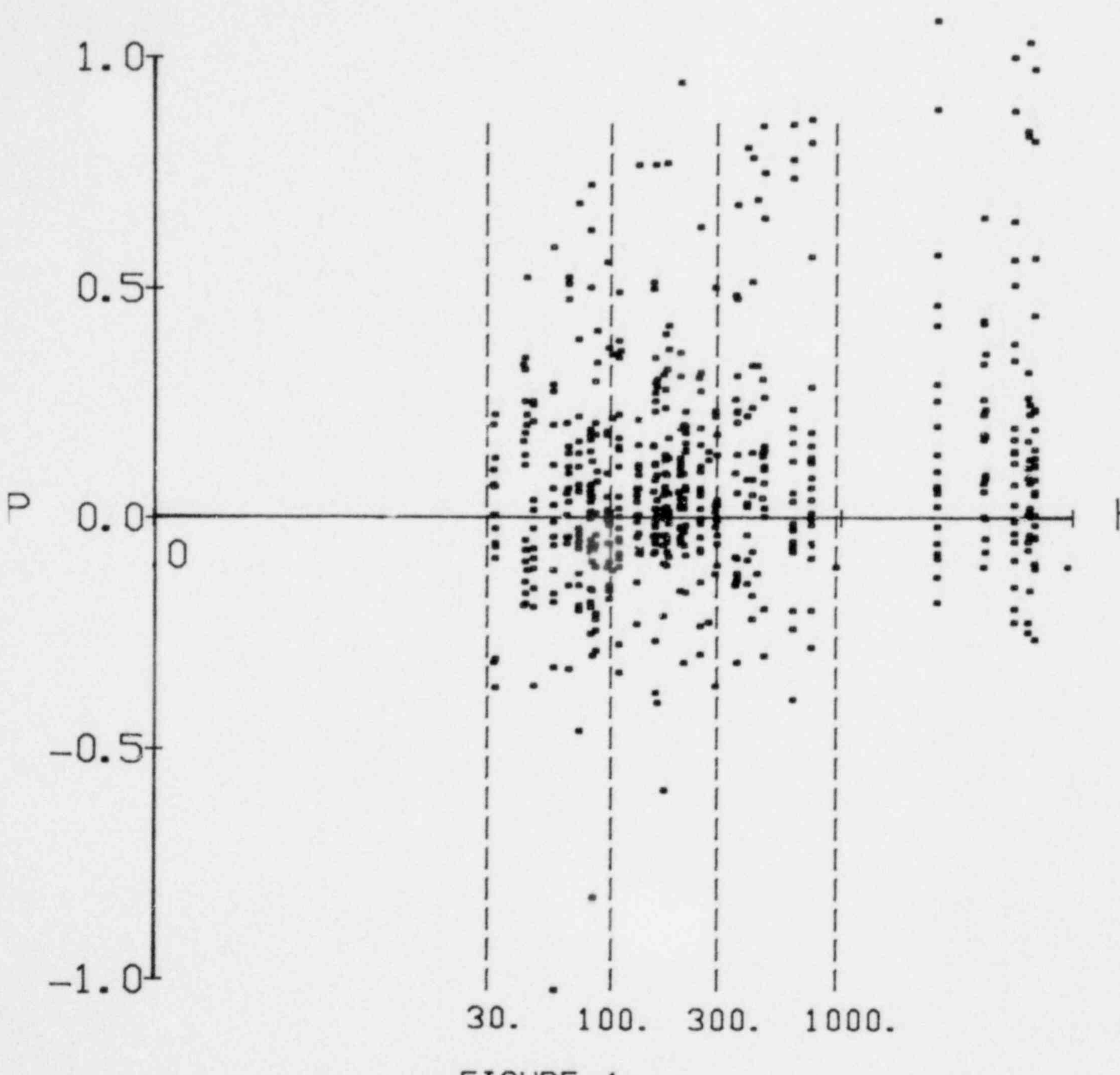


FIGURE 4.
CATEGORY II X-RAY
INTERVALS 2, 3, AND 4
TLD (SHALLOW)

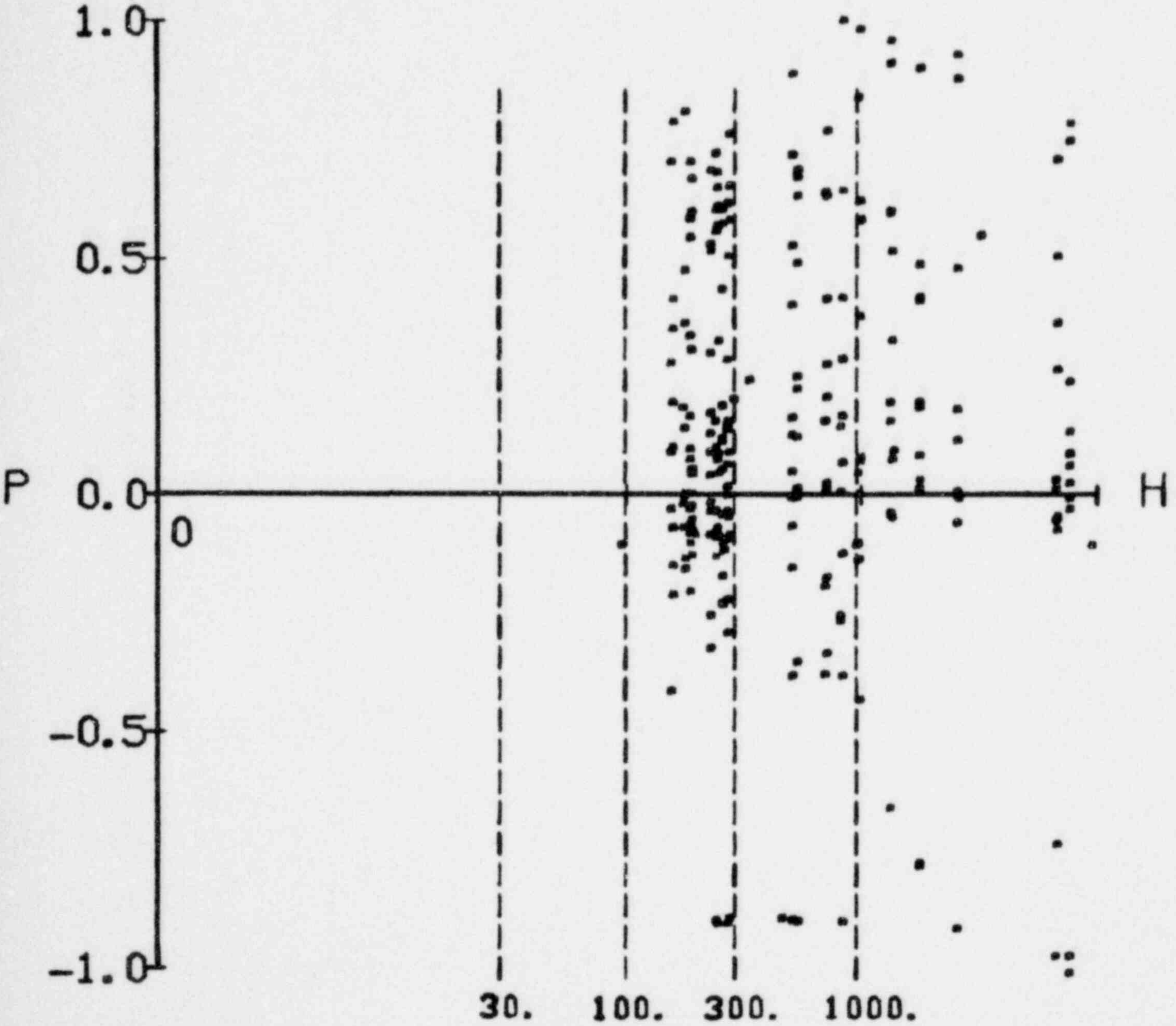


FIGURE 5.
CATEGORY IV BETA
INTERVALS 1 AND 2
FILM (SHALLOW)

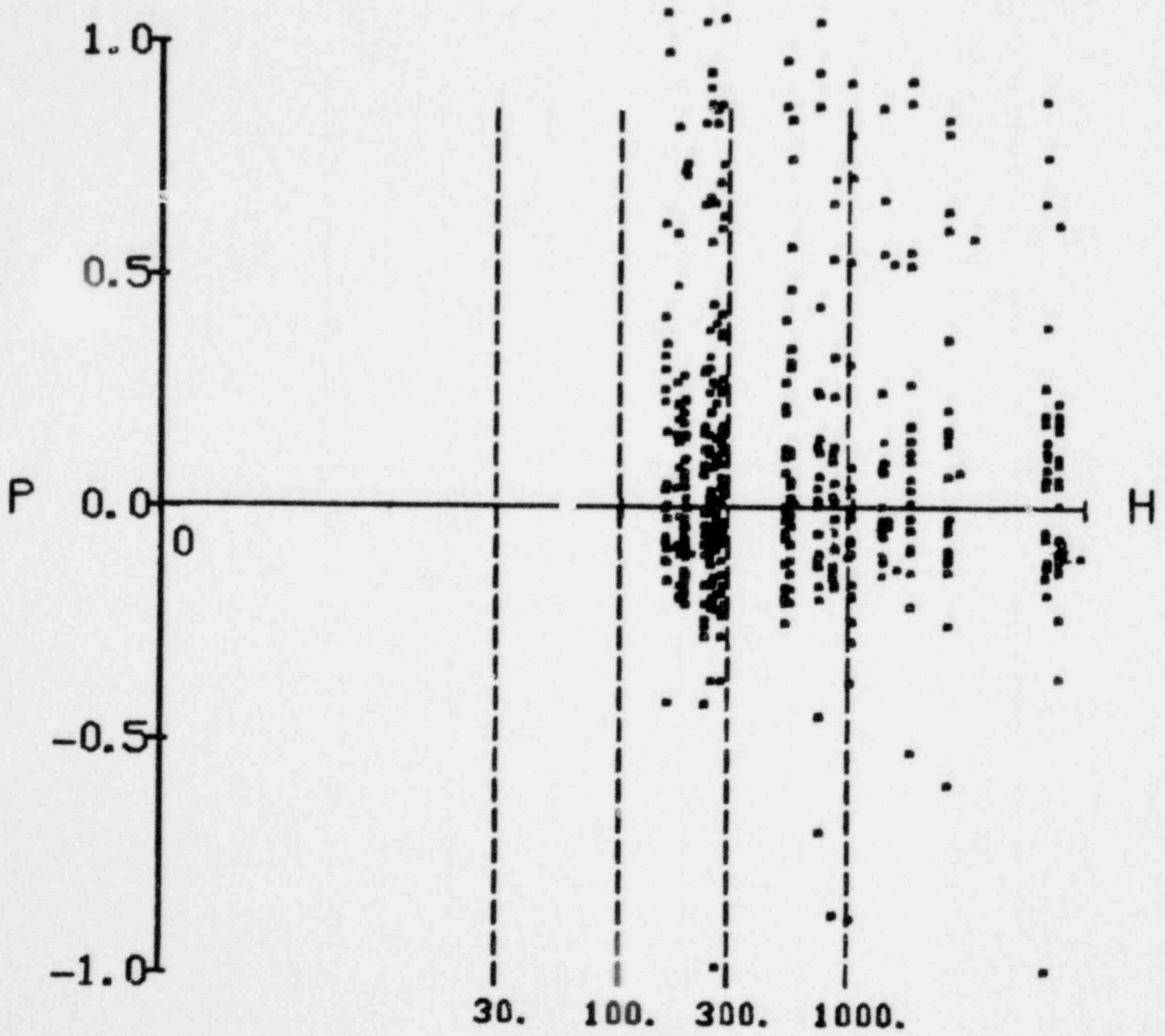


FIGURE 6.
CATEGORY IV BETA
INTERVALS 1 AND 2
TLD (SHALLOW)

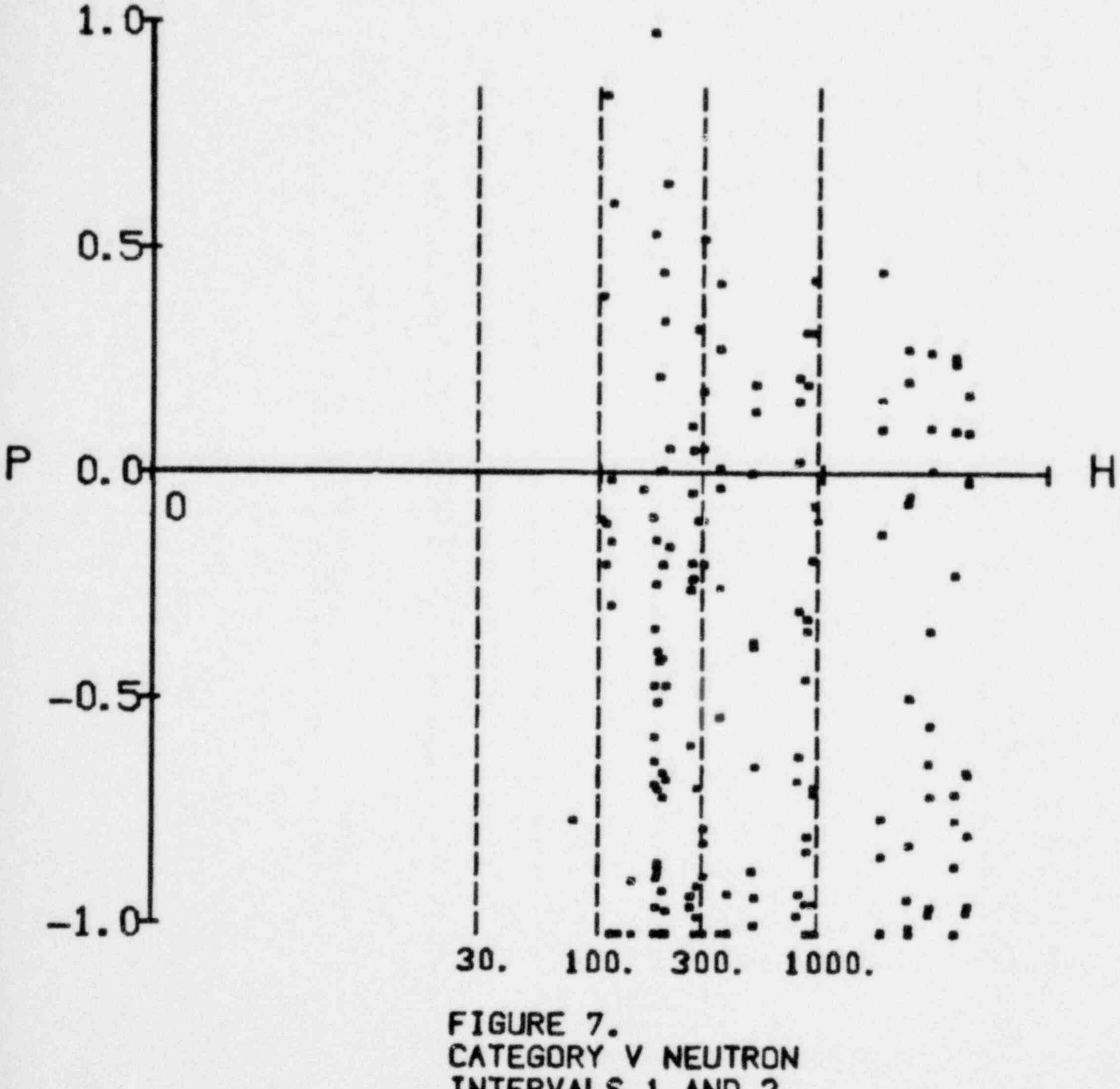


FIGURE 7.
CATEGORY V NEUTRON
INTERVALS 1 AND 2
FILM (DEEP)

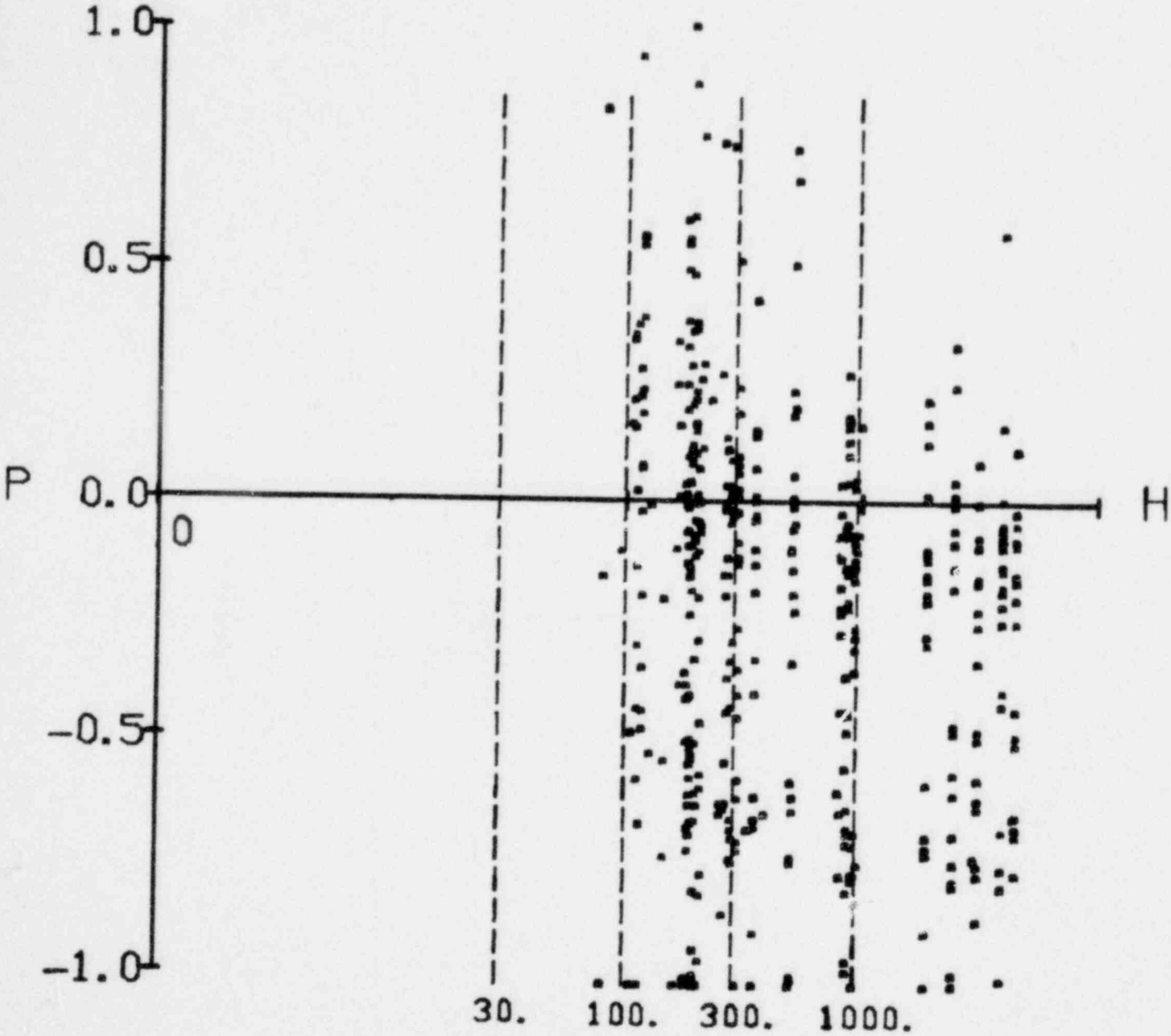


FIGURE 8.
CATEGORY V NEUTRON
INTERVALS 1 AND 2
ALBEDO (DEEP)

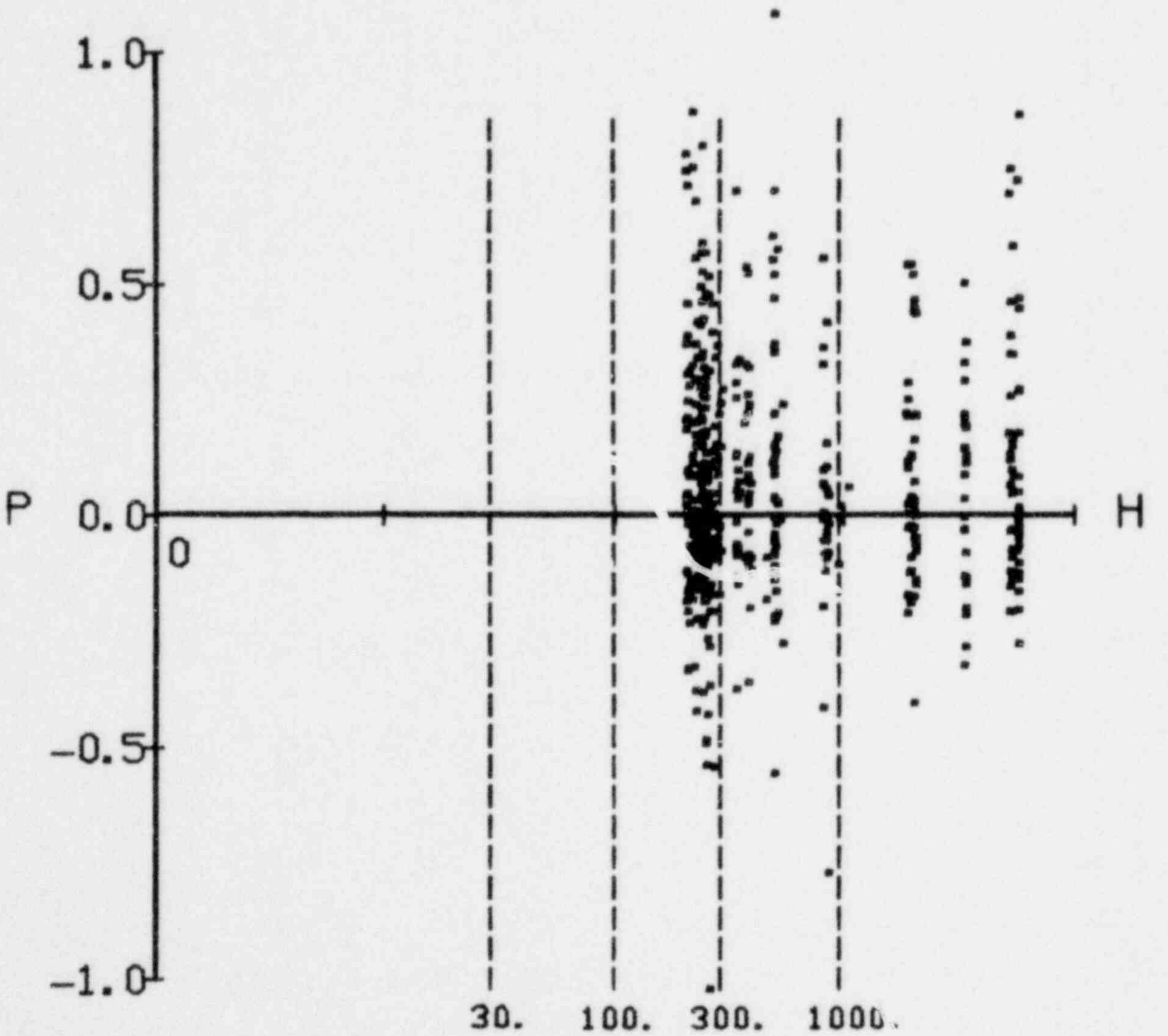


FIGURE 9.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
TLD (SHALLOW)

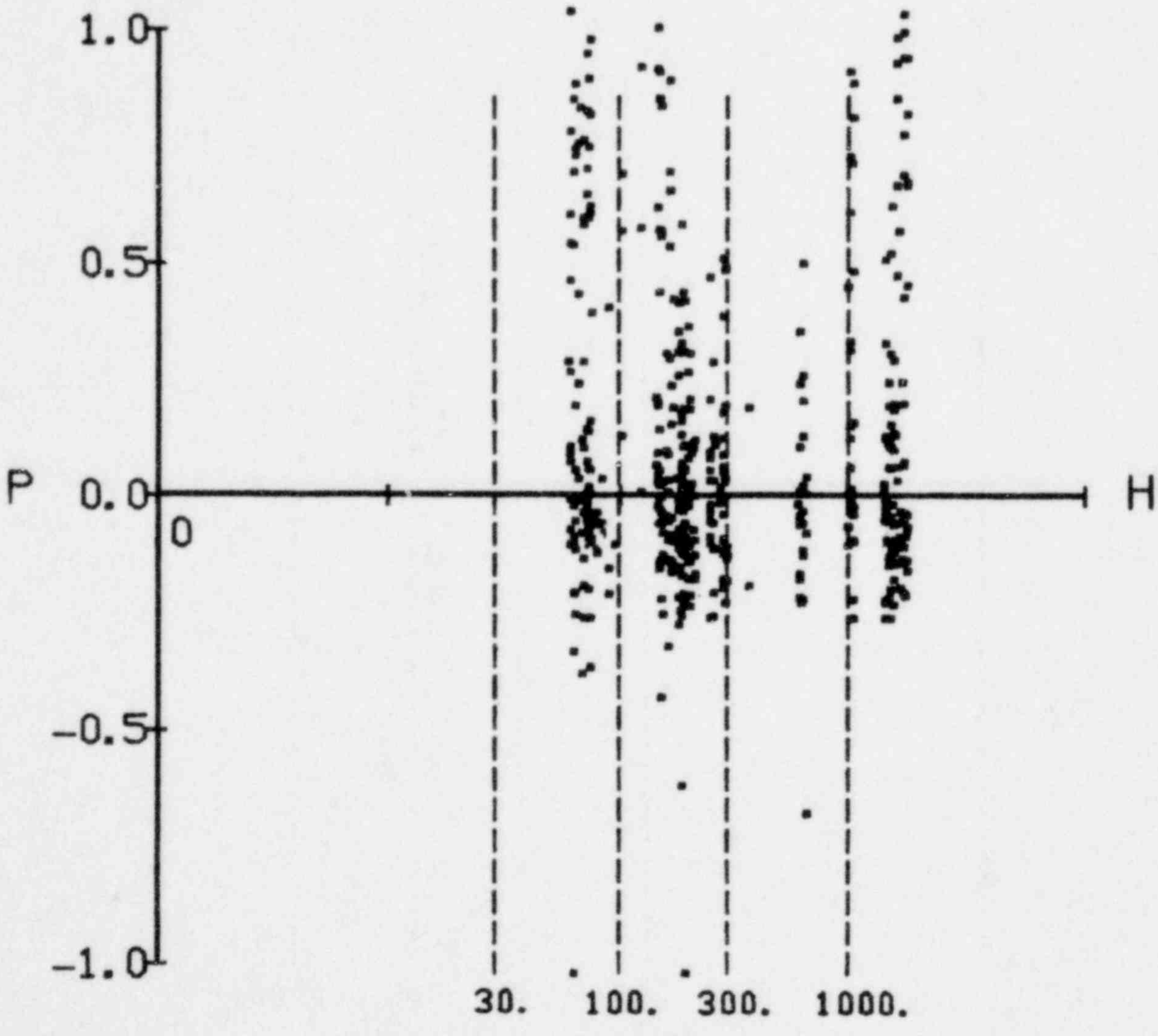


FIGURE 10.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
TLD (DEEP)

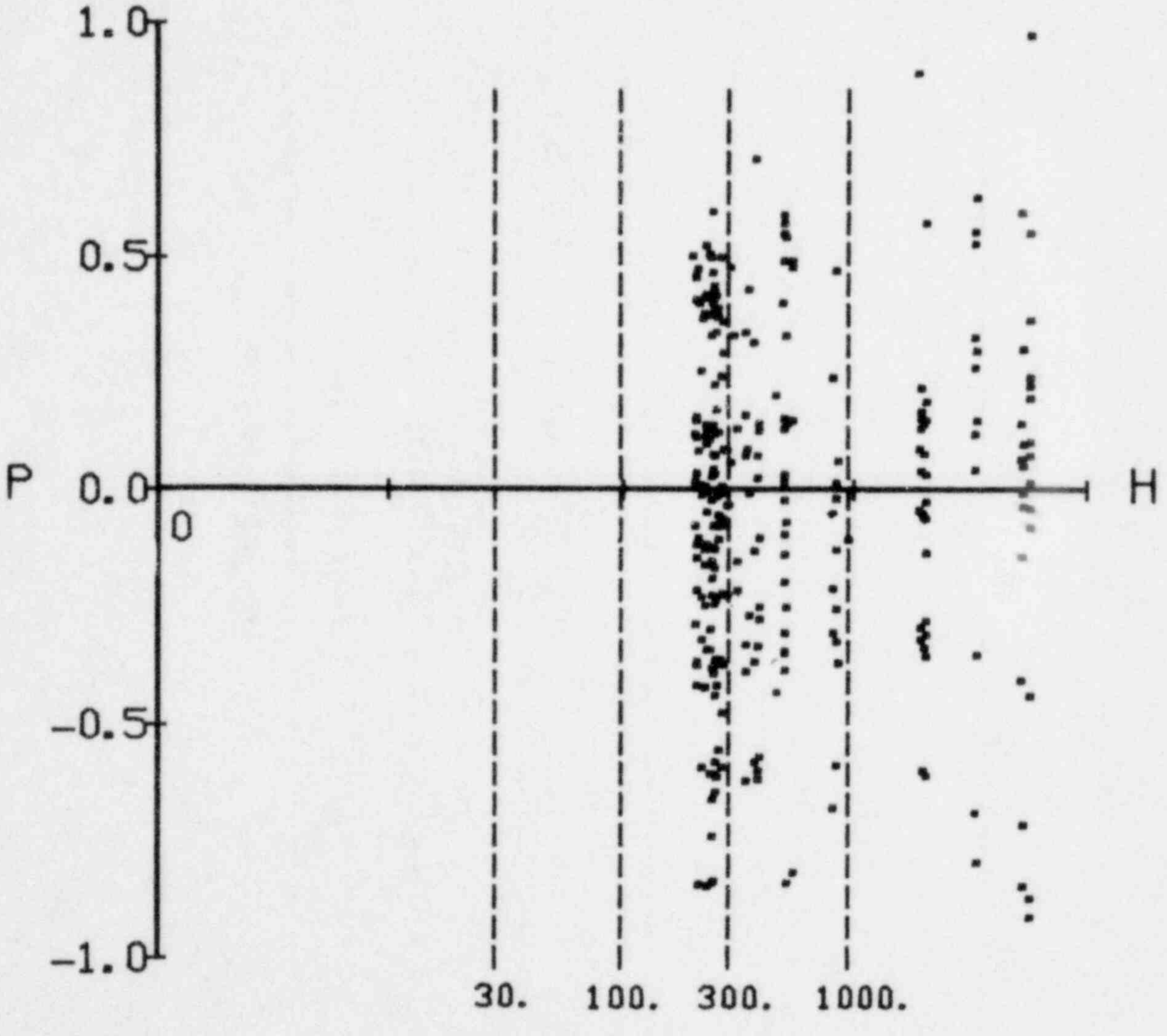


FIGURE 11.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
FILM (SHALLOW)

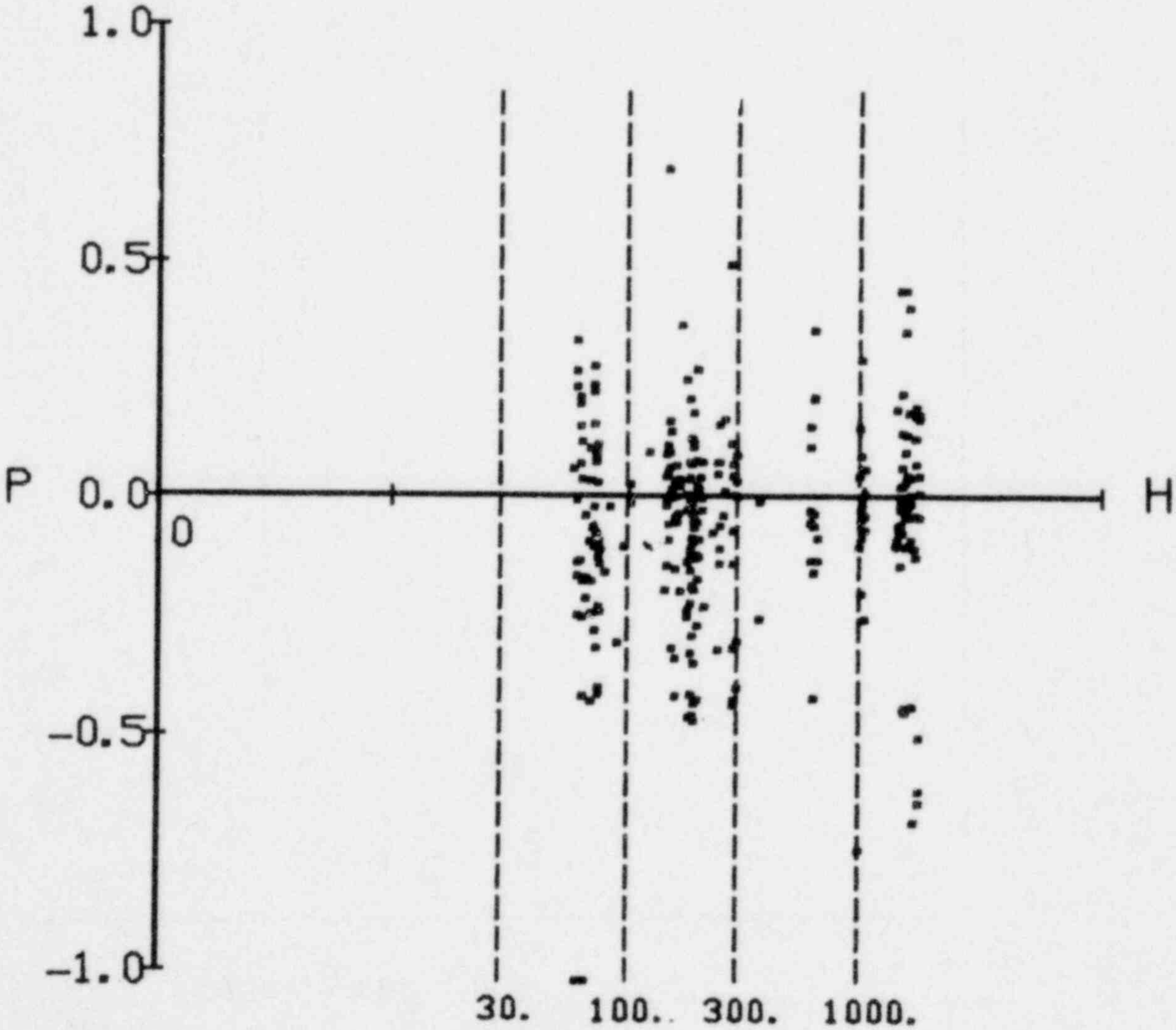
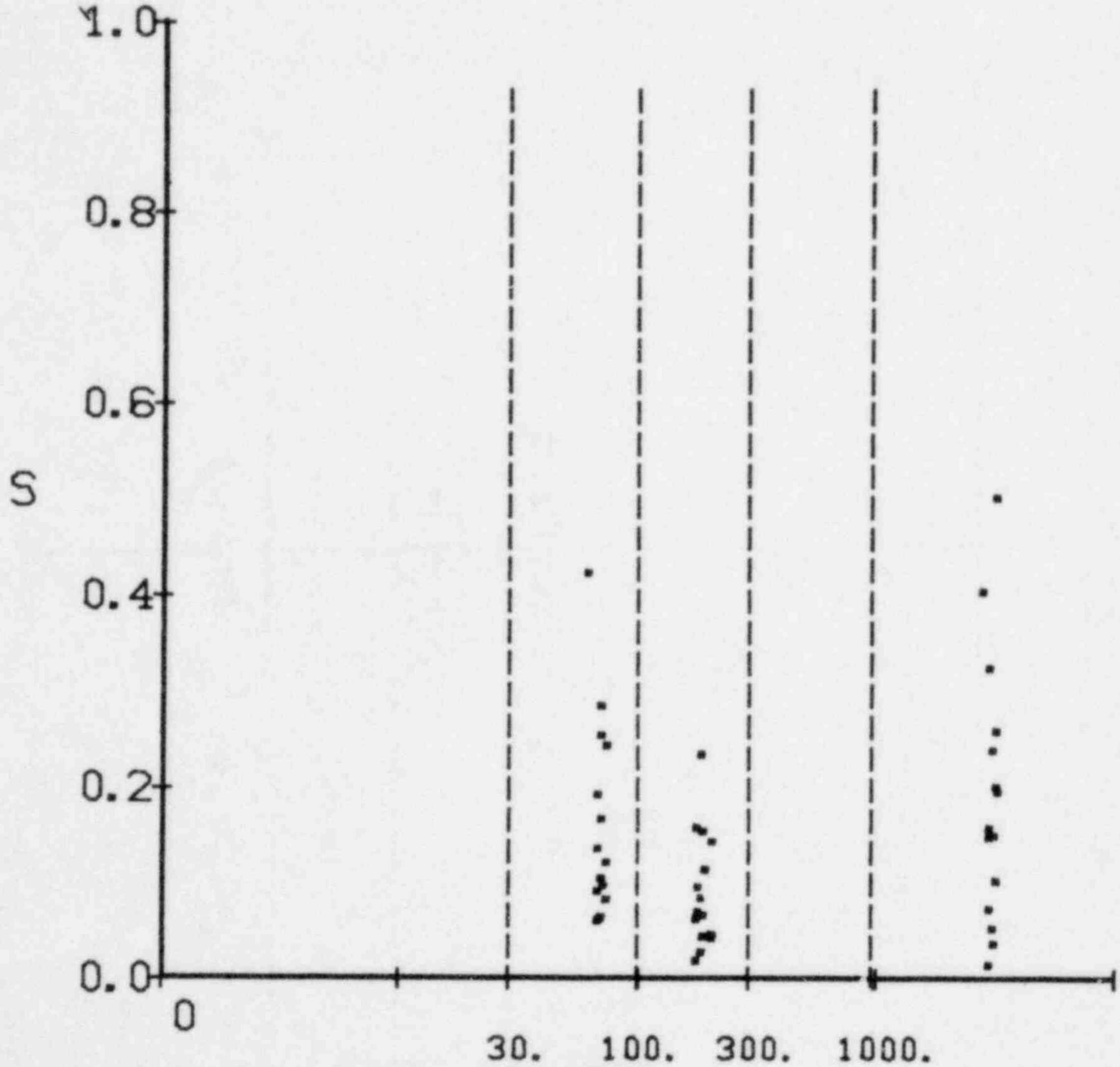


FIGURE 12.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
FILM (DEEP)



LOG HBAR
FIGURE 13.
CATEGORY I GAMMA
INTERVALS 2, 3, AND 4
FILM (DEEP)

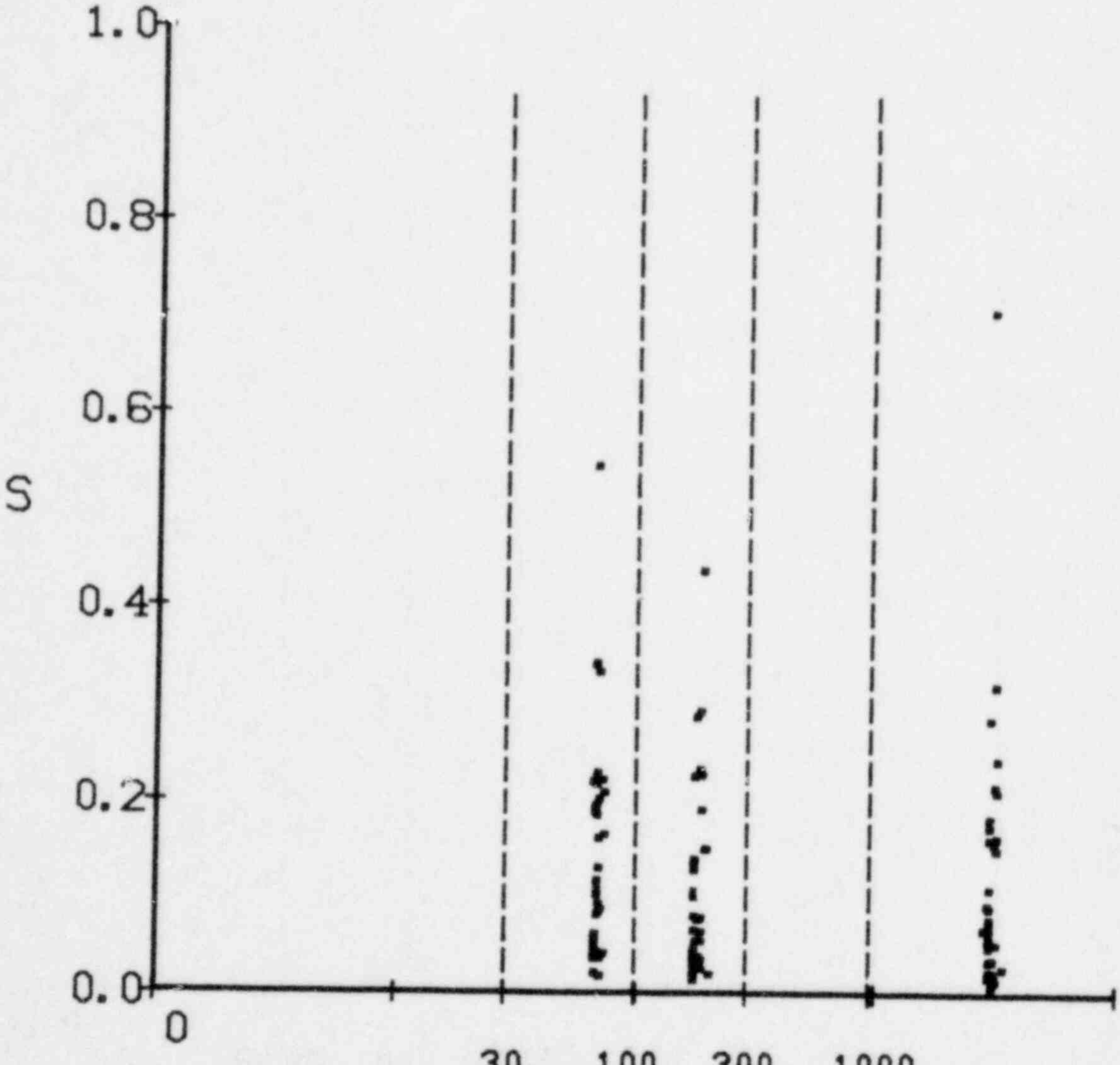


FIGURE 14.
CATEGORY I GAMMA
INTERVALS 2, 3, AND 4
TLD (DEEP)

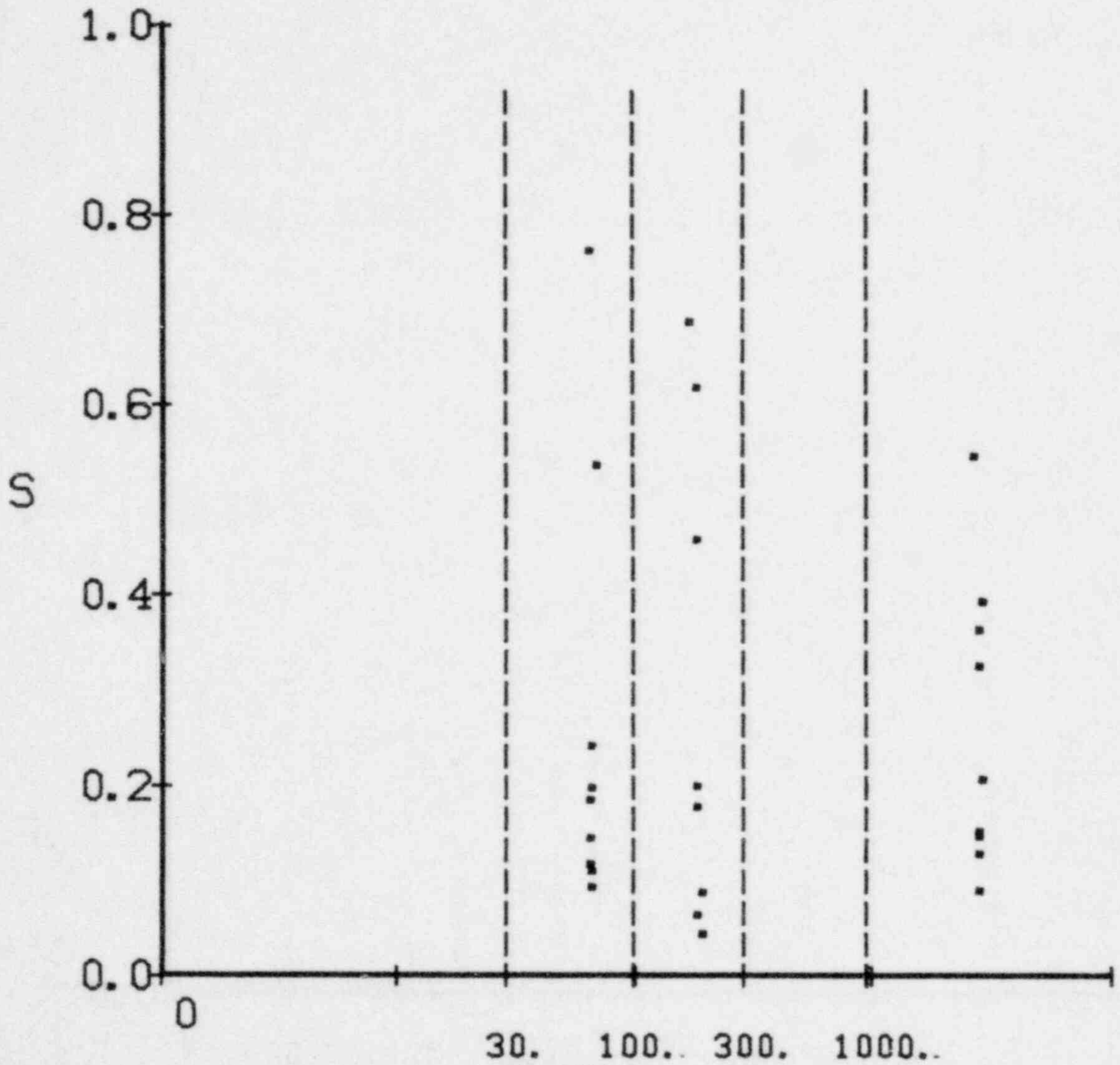
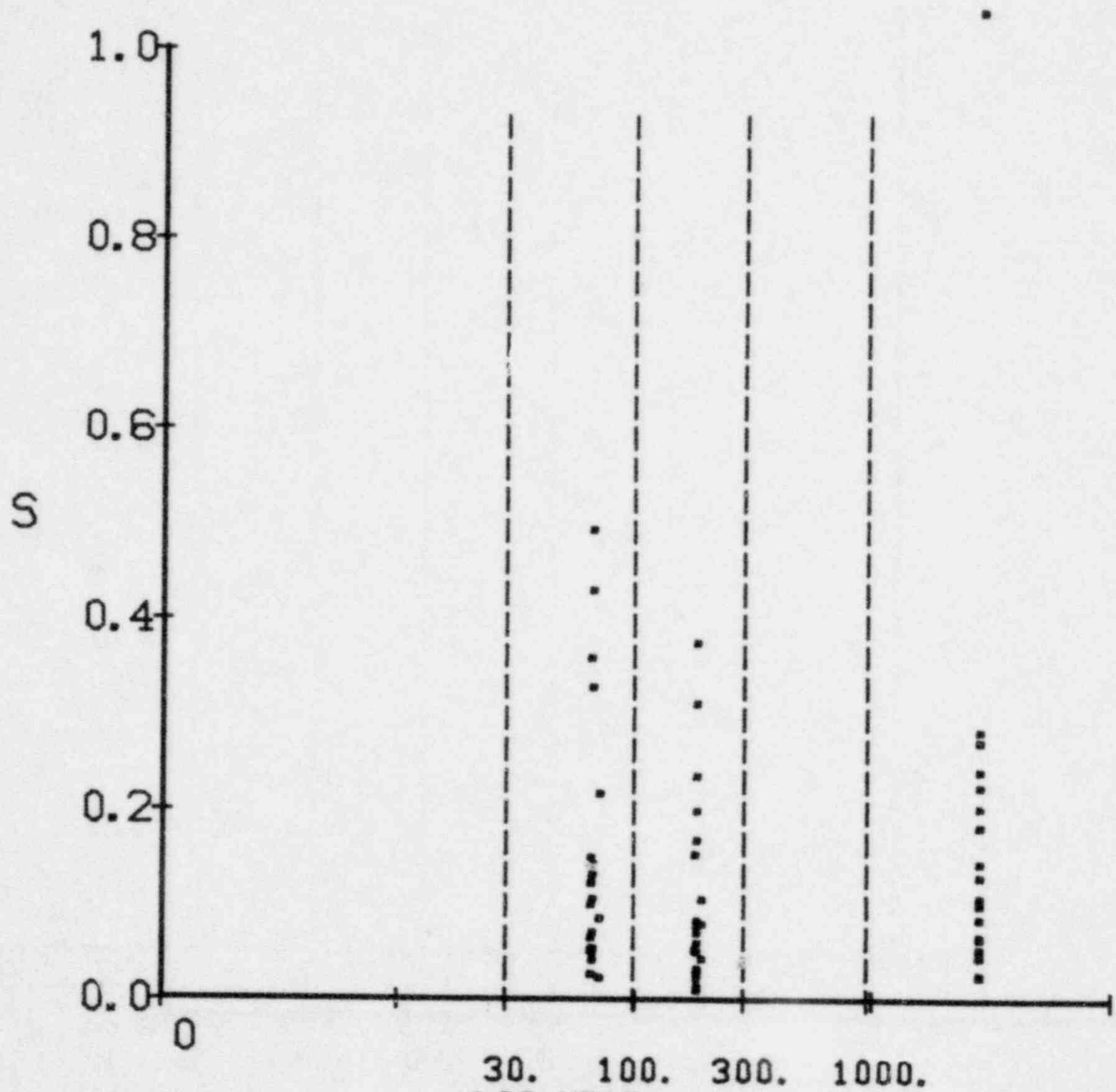


FIGURE 15.
CATEGORY II XRAY
INTERVALS 2, 3, AND 4
FILM (SHALLOW)



LOG HBAR
FIGURE 16.
CATEGORY II XRAY
INTERVALS 2, 3, AND 4
TLD (SHALLOW)

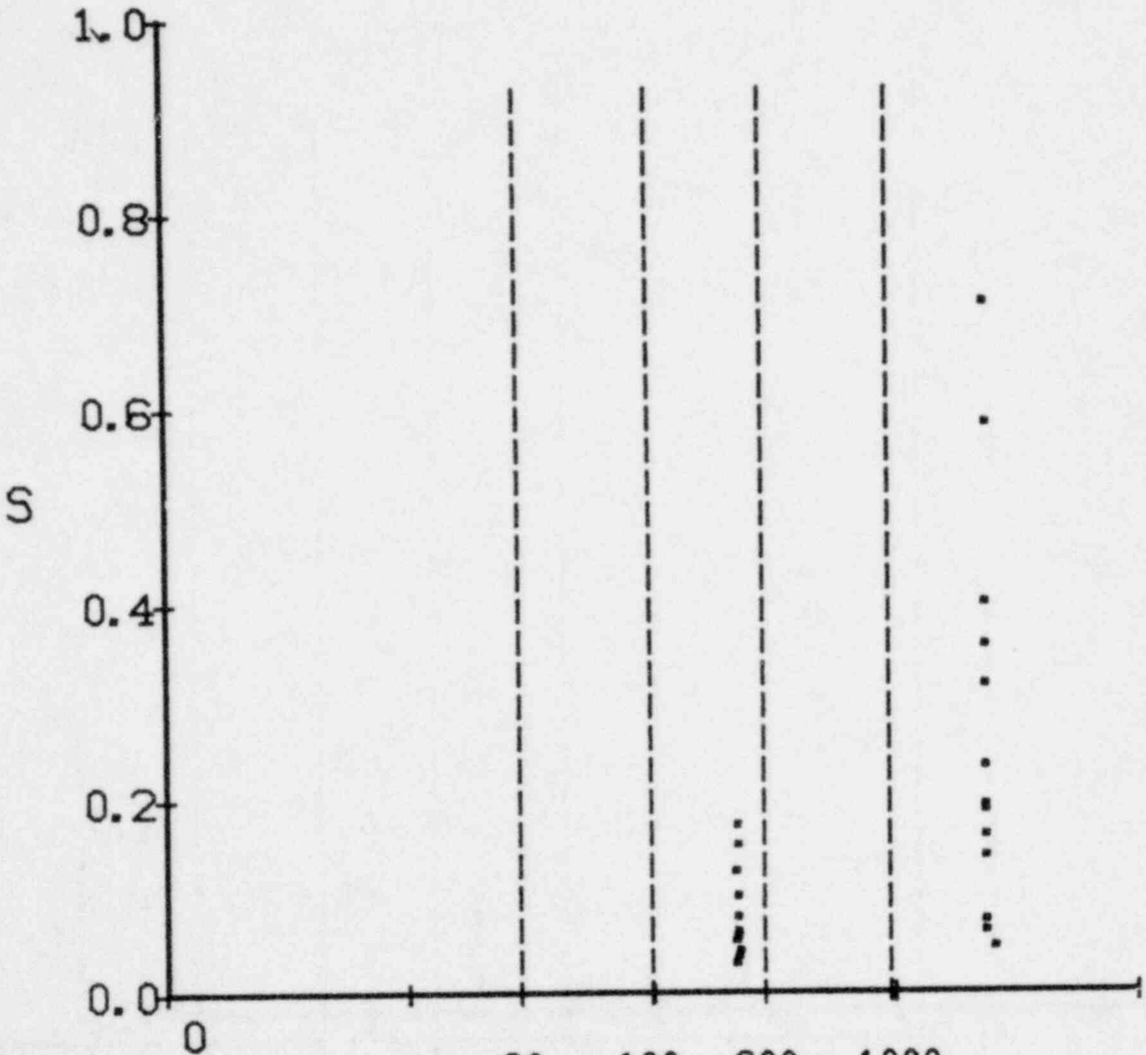


FIGURE 17.
CATEGORY IV BETA
INTERVALS 1 AND 2
FILM (SHALLOW)

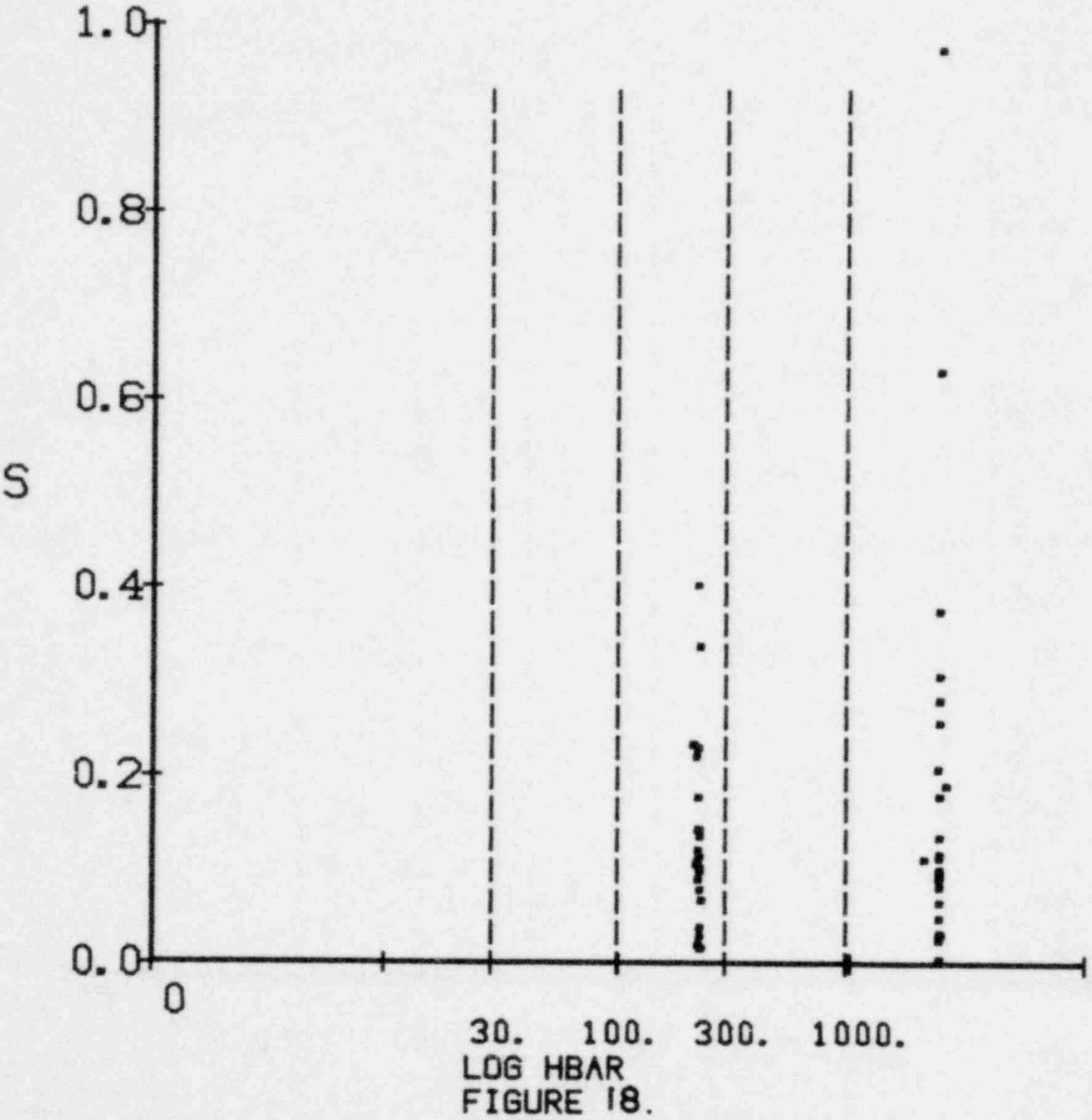


FIGURE 18.
CATEGORY IV BETA
INTERVALS 1 AND 2
TLD (SHALLOW)

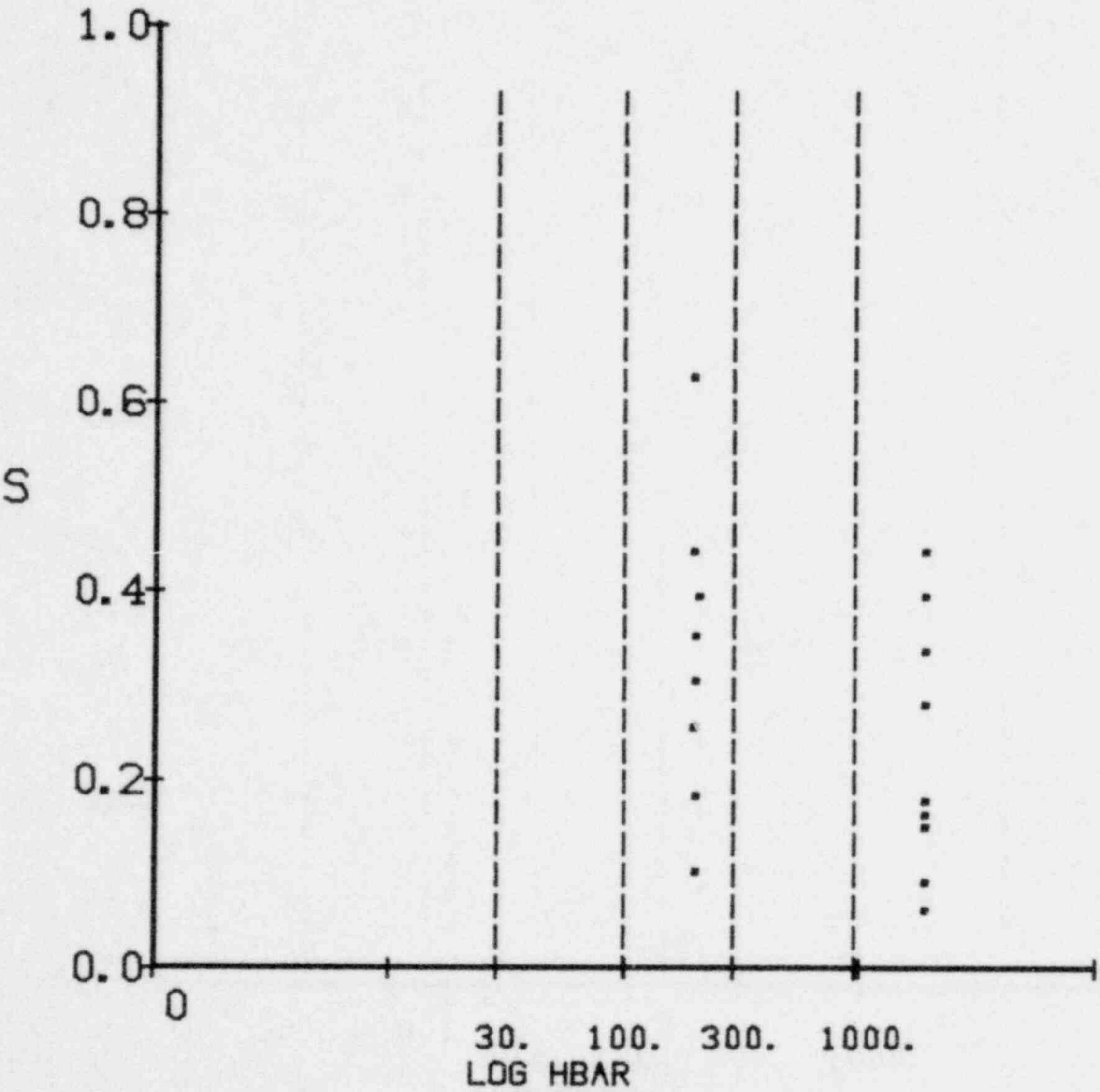


FIGURE 19.
CATEGORY V NEUTRON
INTERVALS 1 AND 2
FILM [DEEP]

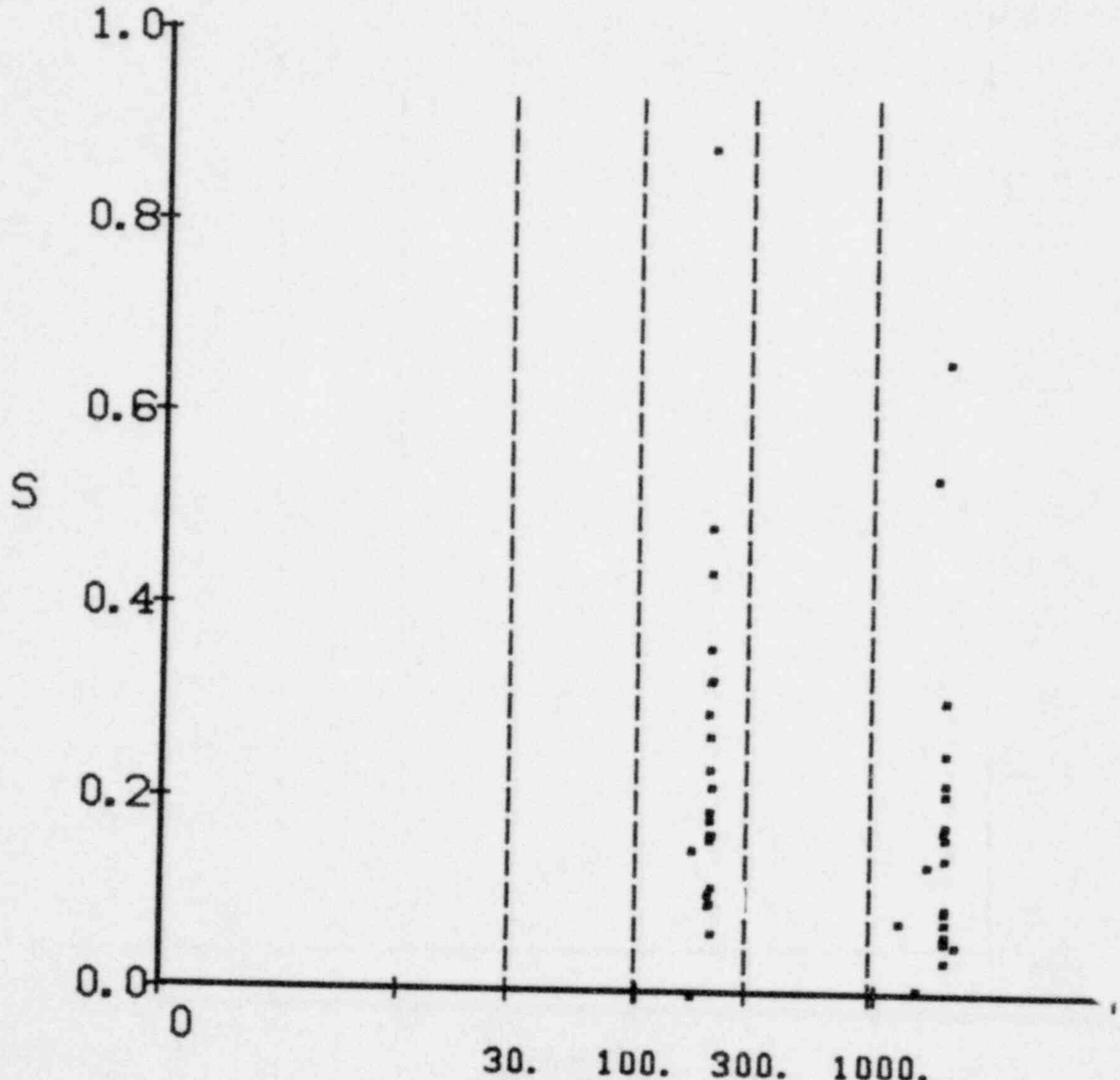


FIGURE 20.
CATEGORY V NEUTRON
INTERVALS 1 AND 2
ALBEDO (DEEP)

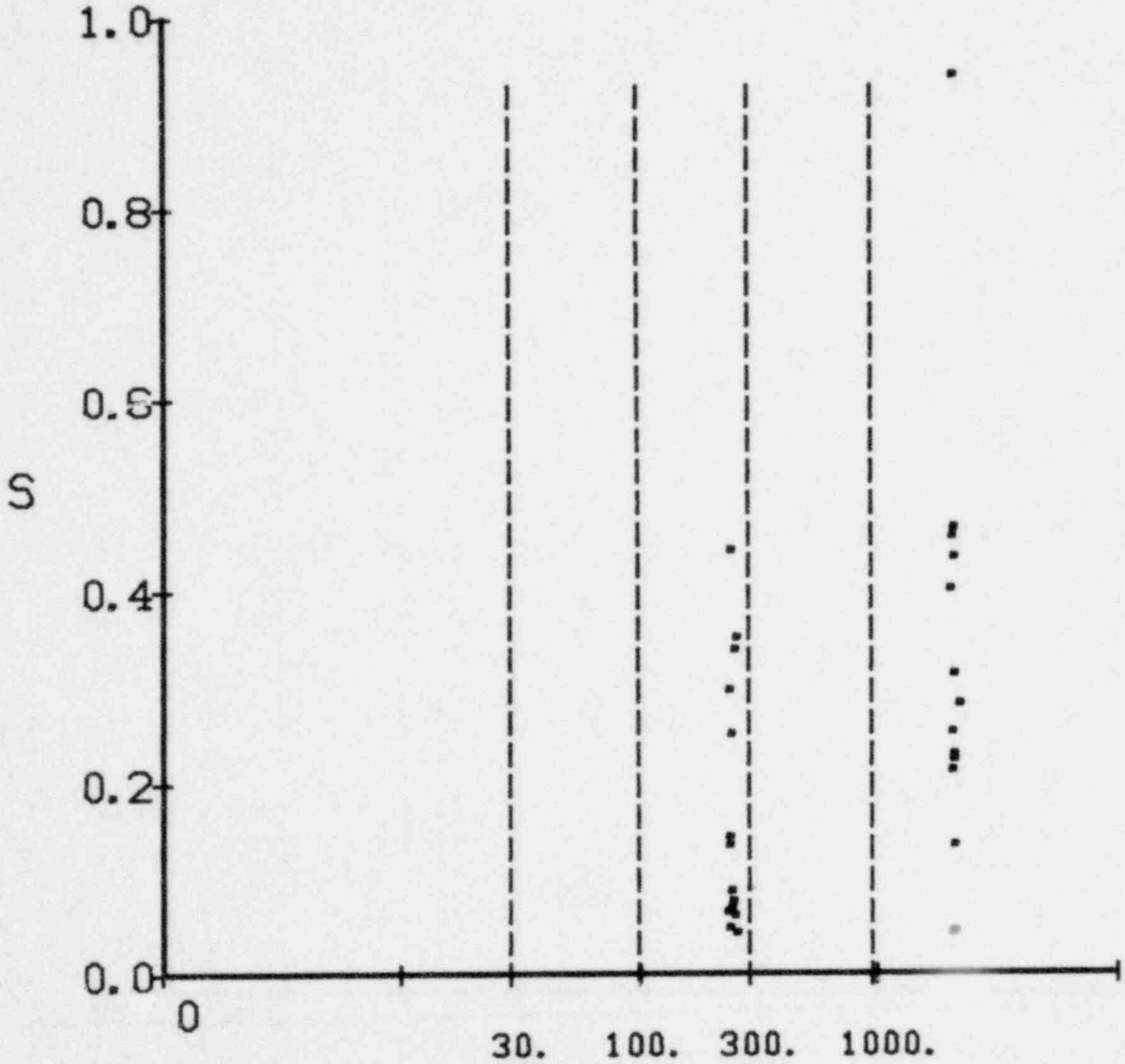
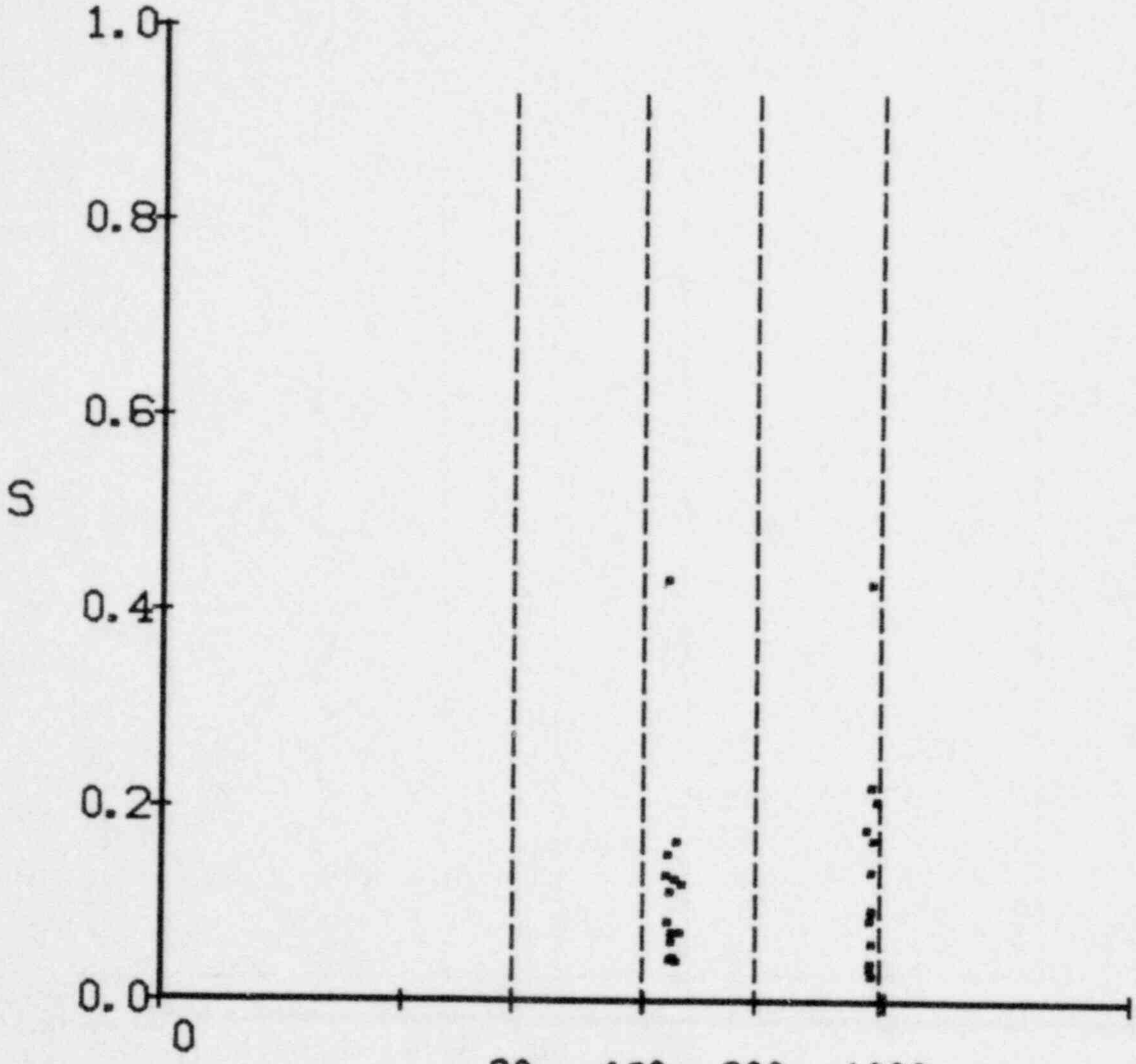


FIGURE 21.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
FILM (SHALLOW)



LOG HBAR
FIGURE 22.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
FILM (DEEP)

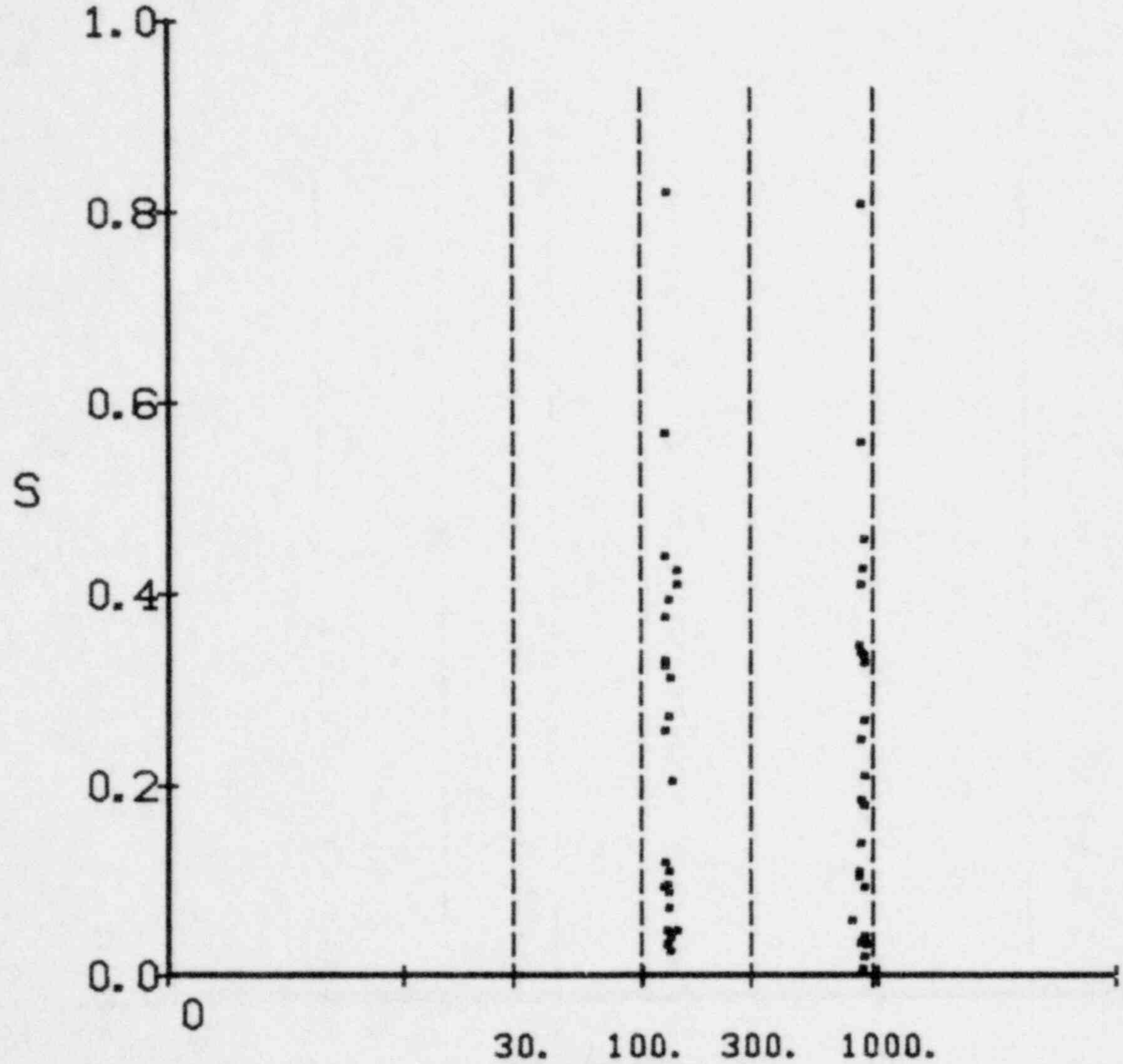


FIGURE 23.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
TLD (DEEP)

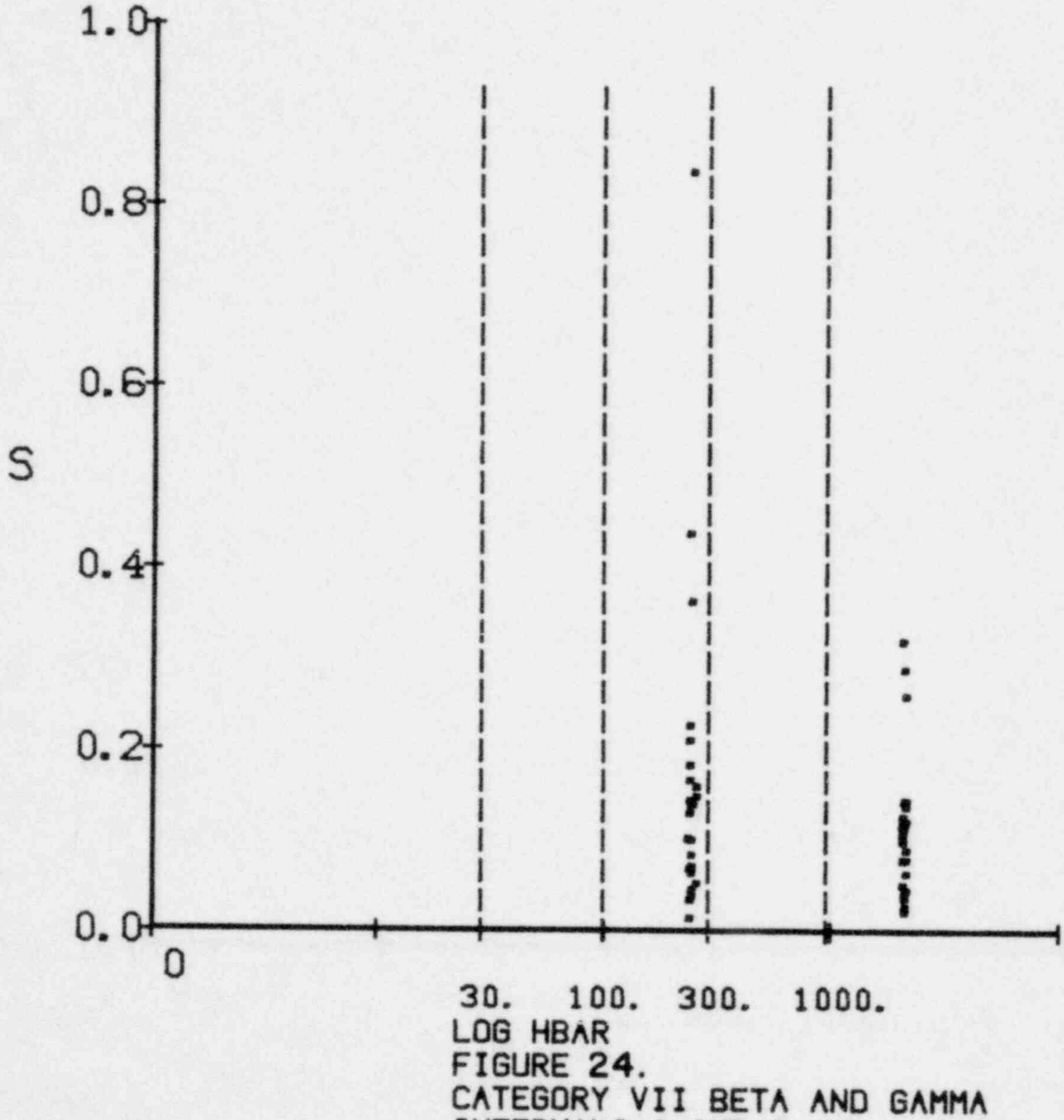


FIGURE 24.
CATEGORY VII BETA AND GAMMA
INTERVALS 1 AND 2
TLD (SHALLOW)

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16. ABSTRACT (200 words or less)

The University of Michigan conducted a two-year pilot study of the Health Physics Society Standards Committee (HPSSC) Standard, "Criteria for Testing Personnel Dosimetry Performance." Pilot study objectives were: 1. To give processors an opportunity to correct any problems that are uncovered. 2. To develop operational and administrative procedures to be used later by a permanent testing laboratory. 3. To determine whether the proposed HPSSC Standard provides an adequate and practical test of dosimetry performance.

Fifty-nine dosimetry processors volunteered to submit dosimeters for test irradiations according to the requirements of the HPSSC Standard. These tests satisfied the first objective of the pilot study.

The operational and administrative procedures developed during the pilot study are described in the Procedures Manual issued on August 14, 1979, NUREG/CR-1063. The Procedures Manual satisfies the second objective of the pilot study.

The Final Report discusses the feasibility of using the HPSSC Standard for a future mandatory testing program for personnel dosimetry processors, the third objective of the pilot study. This report contains the results of the pilot study and recommendations for revisions in the Standard that will make a mandatory testing program useful to regulatory agencies, dosimetry processors, and radiation workers that use personnel dosimeters.

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