PDR

RADIATION SAFETY OFFICE
UNIVERSITY OF MISSOURI
413 CLARK
COLUMBIA, MISSOURI 65211
314-882-3721

Date 10/16/81

TO: Allen Brodsky

Attached is a more complete set of documents on bioassay for tritium than sent to you previously. What I sent earlier was the "final version" of the document with the original p. 18 replaced by a revised p. 18 as approved at the meeting. Included with this more complete package is the original letter of transmittal that included a history and a list of contributors amongst which was Allen Brodsky, Sc. D., of the NRC. There was also a special dedication to Leo Wade, Jr., Ph.D., for reasons left unstated but generally known.

As explained in the report, we did not try to solve all problems relating to tritium exposure. We were addressing the use of tritium in the university where circumstances of use tend to reduce the magnitude of the hazard.

John Tolan

PDR

UNIVERSITY OF MISSOURI

Houston meeting was held July 11-13, 1977; it was the Sixth Biennial Conference of Campus Radiation Safety Officers

Radiation Safety Office
413 Clark Hall
Columbia, Missouri 65201
Telephone: (314) 882-3721

July 28, 1977

MEMORANDUM

OP-713-4

To: University Radiation Safety Officers

Subject: Clarification of Content of Bioassay Guide for Tritium

A suggestion was made during the Houston meeting to clarify the intent of the recommendation made on page 18 of the Final Draft on Guidelines for Bioassay for Exposure to Tritium. The suggestion (from Paul Ziemer) related to the phrase "Bioassays shall be performed at least monthly . . ." on line 9 from which regulators might infer that samples are to be taken and analyzed without interruption regardless of frequency of exposure. Hoping to be the last rather than the first person to concede any leverage to the regulators, I want to remove any uncertainty about the intent of this recommendation. At the meeting, I encouraged everyone to note in the margin of their copy that this sampling frequency was intended to apply only to a period of time in which tritium was in regular use. Otherwise the procedure for "Non-routine Bioassay" on page 19 was to apply. For the benefit of those not at the meeting, I have revised page 18 in an effort to remove this ambiguity.

Other modifications on page 18 include the addition of "or other DNA precursors" to the category of nucleotides on lines 12, 16, 19, and 28 and a change in the Note to remove "calendar quarter" and replace it with the less restrictive "given time span" on lines 21 and 22. These changes are incorporated in the new page 18 attached.

To correct another error, please note that Bobby M. Wilson is still employed by the University of Louisville. Somehow, I got the impression he had left there, but he assured me in Atlanta that he had not. Remove the asterisk following his name on page 4 of the cover letter.

Respectfully submitted,

John

John H. Tolan

JHT/djf

"Criteria for Performing Bioassays for Tritium" in Sixth Campus RSO's Conference, pp 225-238, sponsored by the College of Pharmacy, U. of Houston, Central Campus, Houston, Texas July 11-13, 1977.

This is the revised page p. 18. Page 17 was not revised but was printed so that the sheet containing the old p. 18 could be discarded.

and other detritus of the initial handling step should also be kept within the hood. A container like a one-gallon paint can with a closely-fitting lid should be provided within the hood for these discards. Subsequently, the entire container with its contents will be removed for disposal as solid waste.

Check Hood Operation

Before any activity is released within the hood, the health physicist must be satisfied that an adequate airflow is provided for the hood. Criteria for hood performance as compiled by the Scientific Apparatus Makers Association previously referenced are that a Class A designation requires an average flow of 125 to 150 feet per minute with corresponding minimums at any one point of 100 to 125 feet per minute. For modest quantities of tritium, say in the range of 100 to 1000 mCi as HTO or equivalent in other forms, a Class B designation will be sufficient. This designation requires an average velocity of 100 feet per minute with a minimum at any point of 80 feet per minute.

Recommend Conditions To Committee

If the health physicist has any reservations about the experiment including an assessment of the qualifications of the investigator and his staff, these must be reported to the committee to permit a proper evaluation before an authorization to proceed is approved. If conditions of use need to be imposed, the health physicist must recommend their incorporation in the authorization. The committee may choose to ignore the recommendations, but the health physicist has an obligation to make them anyway. And, if the recommendations are ignored, the health physicist is obliged to do his best to see that the experiment is performed successfully.

Perform Air Monitoring When Needed

For every situation in which as much as 100 mCi of tritium as HTO may escape the hood, air monitoring as close to the breathing zone as possible should be performed. Expressed differently, this guideline means: if the health physicist determines from his evaluation of all the factors involved that there is no likelihood of as much as 100 mCi of tritium as HTO to escape, he will not monitor the air. Based on other criteria, he may be monitoring the participants by bioassay, however.

Bioassay As Required

These guidelines are intended to supplement and complement a standard for bioassay criteria being developed independently* to cover use of tritium in a more general way. For the special circumstances of use in the university as described in this document, there are no other guidelines extant, except those herein. To specify some quantities for this preliminary draft of guidelines to be used in the university environment, the following criteria are anticipated to be compatible with what is recommended for the general conditions of use:

Bioassays shall be performed at least monthly while tritium is in use for all individuals exposed as follows:

1. In open-bench operations, when as much as 1 Ci of tritium as a pure gas, 100 mCi of tritium as HTO or as a labeled organic, or 10 mCi of tritium as a nucleotide or other DNA precursor is used in uncontained form;
2. In a Class B fume hood, when more than 10 Ci but less than 100 Ci of tritium as a pure gas, more than 1 Ci but less than 10 Ci of tritium as HTO or as a labeled organic, or more than 100 mCi but less than 1 Ci of tritium as a nucleotide or other DNA precursor is used in uncontained form; and
3. In a glovebox, when more than 100 Ci of tritium as a pure gas, more than 10 Ci of tritium as HTO or as a labeled organic, or more than 1 Ci of tritium as a nucleotide or other DNA precursor is used.

Note: These quantities may be involved in a single, short-term experiment or they may be the sum total of all tritium used within a given time span. Ten exposures of 100 mCi each within the time span is counted as equivalent to a single exposure of 1 Ci.

In the university, the criteria identified for use of tritium in a fume hood (item #2) will most likely apply because almost all such uses will be performed in a hood. Therefore, bioassays are not required for use in a fume hood when less than 10 Ci of tritium as a pure gas, less than 1 Ci of tritium as HTO or as a labeled organic, or less than 100 mCi of tritium as a nucleotide or other DNA precursor is used in uncontained form. This is not to say the bioassay shall not be performed if the health physicist determines he needs the information; it means only that he has an option to take or not take a bioassay under these use conditions.

---

* Both the Standards Committee of the Health Physics Society and the NCRP have subgroups working on criteria for bioassay including tritium.

This is the original report and letter of transmittal prepared before the meeting. The content was approved with a slight change in p. 18.

UNIVERSITY OF MISSOURI

Radiation Safety Office

413 Clark Hall
Columbia, Missouri 65201
Telephone: (314) 882-3721

July 11, 1977

MEMORANDUM

To: University Radiation Safety Officers

Subject: Final Draft on Guidelines for Bioassay for Exposure to Tritium

At the Fifth Biennial Conference of University Radiation Safety Officers held at the University of California - Irvine in 1975, an ad hoc committee was organized to draft a set of guidelines suitable for use in the university environment to control the hazard of exposure to tritium. These guidelines were to be presented to a later meeting of the Conference for adoption, if such action was appropriate, or they were to be freely used by Conference participants on an individual basis as an information source, should the Conference deem the adoption to be inappropriate. In the two-year interval since the Irvine Meeting, nothing else has appeared to be quite so amorphous as the problem of contending with control of tritium in the university environment.

Many people continue to wonder what the discussion on tritium bioassay is all about; either their institutions do not use tritium or they are licensed by an Agreement State, which imposes no requirements. Some other people have negotiated a tritium bioassay requirement in their broad-coverage license from the Nuclear Regulatory Commission, and they are completely satisfied with this requirement. A few others are undergoing or have just completed negotiations for license renewal with the NRC, including a tritium bioassay requirement, and are incensed by the intransigence of the NRC license reviewers on the general point of licensee independence and on the particular point of use levels for which bioassays are mandatory. And a few more have completed their negotiations for renewal of their NRC licenses and have a lingering antagonism directed toward the unreasonable bureaucrats who have so distorted their programs. Finally, a small but not trivial number have a concern about the philosophical issues that are involved even though their own positions do not involve them directly in the debate. Wherever you stand, you will find company.

Since 1975, three other groups have been exploring the problems associated with monitoring personnel for exposure from radionucludes deposited within the body. One of these is a subcommittee of the Health Physics Society's Standards Committee charged with developing a standard for ANSI publication on criteria for bioassay for tritium from any source. It is appropriate that this subcommittee is concerned chiefly with chronic exposures to large quantities of tritium as in the industrial environment. The special case of relatively infrequent and acute exposure to small quantities as experienced in the university environment is supposed to be covered but may not be. Feedback from this subcommittee suggests that an unresolved determination of how much tritium of what form in what environment is unsafe is holding up the agreement necessary for publication. A

second group interested in this problem is Scientific Committee 54 of the NCRP, which is considering guidelines for monitoring of internally deposited radionuclides of any type, form, or quantity. This much broader charge touches on use of tritium in the university in only a superficial way. Lastly, the third group is the NRC's own Office of Standards Development where the Regulatory Guides are given birth. Naturally, the final product of all three groups must be compatible wherever each one impinges on another.

There is also a fourth group operating sub rosa. This group is comprised of those NRC staff members who write or impose license conditions. Without a specific reference in 10 CFR 20, without an NCRP recommendation, without an ANSI standard, and without an NRC Regulatory Guide, staff members of the Radioisotopes Licensing Branch, Division of Fuel Cycle and Material Safety, NRC, have been writing regulations without public comment in the form of license conditions. This is not an overt act on their part; it is insidious. Instead of placing their own words in the license, they insist that the licensee write a description of control methods to satisfy the reviewer and then the licensee's words are incorporated in the license by reference. When a licensee objects, he is advised he is the only one giving trouble on this matter, all other licensees with similar programs have complied, and if he doesn't capitulate, his license will be terminated. Any university radiation safety officer who has had a license renewal review within the last four years has experienced this form of ratcheting.

The draft guideline that accompanies this report is not a typical committee effort. This may be either good or bad depending on your point of view. The document grew from the substance of three reports presented at the Irvine Meeting. There was a paper by Harold Berk on action levels for bioassay, there was a paper by Orval Olson on criteria for bioassay, and there was a paper on liquid scintillation counter calibration by Jamie Shotts. The papers by Berk and Olson were distributed in September 1975 to about 50 university radiation safety officers through a regional network of committee members. Comments were solicited and comments were received.

From the comments, a first draft was prepared and forwarded in September 1976 to everyone who had commented on the original mailing plus anyone else who in the meanwhile had expressed an interest. Contact was established with the three groups previously identified, and comments were solicited from them as well. From all of these comments, a second draft was prepared and forwarded in January 1977 to the expanded list of contributors. By this time, respondents were reasonably well satisfied with the content and few additional comments were received. The final draft now in your hands represents the synthesis of comments received from dozens of people, but it in no way represents the opinion of any one of them, although it is hoped that all of them can accept this final version. No pre-meeting circulation of the final draft was made; therefore, the undersigned accepts all blame for errors of fact or of expression.

Along the way, it was hoped that the HPS group would reach some agreement on levels of exposure for which a bioassay was required. If such numbers were agreed upon, they would have been referenced in this draft with much greater confidence of their validity.

This hoped for agreement has not been reached, so the numbers cited in this final draft have only the support of the contributors to this draft. But this is a very impressive group whose collective opinion should be persuasive. It was the intent of the contributors to this document that the effort would be consummated by a resolution of the Conference to adopt the content as its own and to support the guidelines proposed. It is offered, therefore, for such a resolution to be presented at the Sixth Biennial Conference.

Respectfully submitted,

John H. Tolan

John H. Tolan
Chairman

Acknowledgement:

The following individuals have contributed directly or indirectly to the content of these guidelines, and their contributions are hereby acknowledged:

Robert Bell, Auburn University

Harold W. Berk, Ph.D., University of Virginia

Robert M. Boyd, Georgia Institute of Technology

Henry C. Briggs, Indiana University

Allen Brodsky, Sc.D., U.S. Nuclear Regulatory Commission

Leonard H. Brubaker, M.D., University of Missouri - Columbia

B. G. Dunavant, Ph.D., University of Florida

William Dunnette, Mayo Clinic

E. D. Durkosh, University of Pittsburgh

John Evraets, UCLA

William J. Fields, Jr., University of Missouri - Kansas City

Frank E. Gallagher, III, University of California - Santa Barbara

Bruce Gillespie, The Ohio State University

J. W. Harvey, McMaster University

Robert Hight, Ph.D., University of Missouri - St. Louis

Daniel B. Howell, Rutgers University

Stuart E. Hunt, University of Alberta

Paul R. Keenan, University of Missouri

Roger J. Kloepping, San Jose State University

Conrad M. Knight, Duke University

John P. Lambert, Kansas State University

Jerome B. Martin, University of Colorado*

Edward W. Mason, University of Chicago

---

* The asterisk indicates that the individual is no longer at the institution identified, but he was there when the contribution was made.

S. L. Meyers, Virginia Polytechnic Institute and State University

J. Steven Morris, Ph.D., University of Missouri

Orval L. Olson, University of Missouri

Richard V. Osborne, Ph.D., Atomic Energy of Canada Limited

Vincent T. Penikas, Ph.D., University of Connecticut

Andris Peterson, University of California - Berkeley

Eli A. Port, Northwestern University*

R. R. Radtke, The University of Wisconsin

Jamieson G. Shotts, University of Missouri - Columbia

Emery E. Sobottka, Iowa State University

Jerome J. Steerman, University of Illinois at Urbana - Champaign

Daniel J. Strom, University of Connecticut*

John W. Thomas, University of Pennsylvania

Walter F. Wegst, Jr., Ph.D., California Institute of Technology

Bobby M. Wilson, University of Louisville*

And for the special encouragement that precipitated all of this effort, acknowledgement is made to Leo Wade, Jr., Ph.D., of the Radioisotopes Licensing Branch, NRC.

BIOASSAY FOR EXPOSURE TO TRITIUM
HEALTH PHYSICS EVALUATION OF NEED
WHY, WHERE, WHEN, AND HOW

WHY

In university laboratories, tritium is widely used in research applications related to the life sciences. It is found in many forms ranging from tritiated water to labels on complicated molecules. Its physical and chemical form determines how readily it is exchanged and transported into the working environment, how readily it is taken into the body from the working environment, and how readily it is catabolized and metabolized within the body and eliminated. The control measures that are adopted must incorporate a suitable consideration of the behavior of the compound at the point of use. This is where and when the health physicist at the scene can be the most effective in reducing the risk of exposure.

For reasons not entirely clear, the health physics community seems to view tritium as a hazard substantially more worrisome than that posed by external sources of gamma radiations. Maybe, we have become accommodated to the external sources and, knowing more about their behavior, feel more relaxed and comfortable about them. Certainly, the measurement is easier. Personnel monitoring for external sources is also more direct and convenient, although the results leave much to be desired. But, if we accept certain standards of control on the risk of exposure to external sources, why should we impose more stringent standards of control on the risk of exposure to internal sources?

If control of the compound at the point of use can be achieved and maintained, no exposure to individuals will occur and a concern for a routine personnel monitoring program by bioassay of urine specimens can be eliminated. We will still bioassay, but we will have more confidence that the results are worthwhile. Bioassay of urine specimens of individuals with a high risk of exposure to tritium must be continued, but the many negative aspects of this procedure dictate a determination to keep the number at a minimum. What the health physicist must do is to develop a method for urine bioassay

that provides adequate sensitivity, a procedure for collection that involves the least commitment of manpower resources, and a procedure for evaluation of the results that permits the least number of samples to assess the exposure adequately; furthermore, he must also control the conditions of use to minimize the number of individuals being monitored.

Rather than concentrate attention on an assessment of the exposure after it occurs, the health physicist should focus on the proposed use so that adequate control is achieved and maintained before exposure can occur. To monitor the control, air sampling on a grab or continuous basis should be developed where the risk of exposure is high. To say with confidence that the working environment is clean and free of contamination with no bioassay required is far more satisfying than to be so in doubt that bioassays are needed to learn the extent of the exposure. This has been the traditional approach to control of all risks of hazardous exposures to radiation.

To make some sense of the risk of exposure to tritium, we need an analog for the internal compared to the external source. We do not want to be trapped in a situation that requires essentially different evaluations of exposure. A rem of external dose is supposed to be equivalent to a rem of internal dose. A maximum permissible dose equivalent (MPDE) of five rem per year is supposed to apply to an internal dose or to an external dose or to the sum of the two. The International Commission on Radiological Protection (ICRP) has addressed this problem without a completely successful conclusion. The National Council on Radiation Protection and Measurements (NCRP) has struggled with it and has not reached a general solution. In the absence of definitive recommendations from either the ICRP or NCRP, the Nuclear Regulatory Commission (NRC) has set control limits that bear a slight resemblance to the control limits set for external sources.*

The ICRP has provided us with numbers to use to assess the risk of hazardous exposure to tritium.† It cannot be helped, but these numbers are not applicable to the typical university use of tritium. Tritium is a low-risk radionuclide partly because it has a short residence time in the body, and a steady-state exposure must be main-

---

* Dramatically revised on December 29, 1976, by change of 10 CFR 20.103.

† ICRP Publication 2 "Permissible Dose for Internal Radiation."

tained to sustain a given body burden. In an industrial environment where tritium may be used in a continuous or repetitive-batch process, the exposure to tritium is essentially constant. In a nuclear power reactor, some areas of the plant will contain environments in which tritium is present in essentially constant concentrations. But in a university environment, the exposures are more likely to be brief and intermittent. With the maximum permissible body burden (MPBB) based on continuous exposure, the MPBB does not adapt conveniently to the university situation.

For the continuous exposure conditions found in industry, it makes sense to sample the working environment and the workers themselves on a regular basis. Here, control measures can be established to limit individual dose commitments to less than five rem per year. The value corresponding to the MPDE of five rem per year for tritium in the body is the MPBB of 2 mCi, as established by the ICRP. This quantity, evenly distributed in the whole body with one-half of the total in the body water, provides a concentration of about 29 μCi per liter as a steady-state value. If we perform a bioassay on an individual investigator soon after an acute exposure to tritium (allowing enough time for mixing within the body) and we record a measurement of 30 μCi per liter, does this mean the MPDE is exceeded? Absolutely not! But what if we measure this 30 μCi per liter weeks after the exposure? This is quite another matter, and we need to determine the circumstances and the time of the exposure.

Similarly, the maximum permissible concentration for tritium in air (MPCa) is based on a continuous exposure necessary to maintain the MPBB. An acute and isolated exposure to the MPCa for tritium simply does not have the same significance as a similar exposure to any other radionuclide with an extended residence time in the body. In fact, it makes a great deal of sense to define a separate MPCa for tritium to cover the acute, isolated exposure. This problem was ameliorated substantially when the NRC revised §10 CFR 20.103 to permit averaging over a calendar quarter instead of one week.

While we want to draw some comparisons between the external versus internal maximum permissible doses, it is not easy to do. Such comparisons become even more difficult when the same individual has a potential for exposure to both. When we have

reasonable assurance that only external exposure will be experienced, we survey the working environment and monitor the individual with both the MPDE of five rem per year and the "as low as reasonably achievable" (ALARA) concep in mind. We work with the individual to modify procedures or apparatus to keep the actual dose to a minimum, but we do not panic and stop the operation if a short-term dose exceeds the rate of five rem per year. In fact, 10 CFR 20 provides exactly this operational philosophy for external exposures.

The ICRP addresses this question with the concept of the Investigation Level* set at such an intake as will result in a dose of one-twentieth the annual MPDE. Nothing is wrong with this approach except in its application. We find that the Investigation Level of 1.5 mCi intake and its corresponding body water concentration of 35 μCi per liter is sometimes viewed as the maximum permissible amount instead of what it is supposed to be - a level requiring an investigation.

WHERE

Conditions vary from one laboratory to another, and details of what can be expected for each situation cannot be predicted; however, a few identifiable features are common to each and can be discussed. Each proposed use has required a prior review and evaluation of the form, quantity, frequency of use, and intended procedure by an approval process involving the health physicist and a committee. The description of the intended procedure incorporates the specifications for protective devices or apparatus to be employed. After approval, each experiment can be monitored by the health physicist both visually and with instruments. Each investigator can be guided or assisted by the health physicist in the conduct of the part of the experiment in which the source is most likely to escape control. Many contact points occur where mechanisms of control can be applied.

Review of the Proposed Use

What combination of factors changes a situation from one that permits a casual surveillance by the health physicist to one that requires a bioassay of a urine specimen? Or, does the situation really change so dramatically without passing through one or more intermediate steps? It is likely that many gradations can be defined. But if such

---

* ICRP Publication 10 "Evaluation of Radiation Doses to Body Tissues from internal Contamination due to Occupational Exposure."

gradations are defined, do they not limit individual judgment by admitting an infinity of interpretations? Nevertheless, certain quantifiable factors can be listed, placed into positions of relative importance, and from them a judgment of the risk involved can be made. We need to know quantity, form, frequency, and type of use. From these data, we determine the ease by which the material can escape its immediate environment. Note that toxicity is not considered at this point, nor are external containment systems considered. These will be considered as modifying factors. For the form, we are concerned initially only with whether the material will freely volatilize* or not. For this type of use, what we want to know is whether the experimental system is closed or open to the air and how much.

For a closed system with a non-volatile form, we can expect none of the material will escape, and any amount within the limits we are likely to experience is safe. For an open system with a volatile form, quantities less than 100 mCi are safe enough. If the material can be introduced into a closed system without mishap and if we can expect it to stay there, any quantity, volatile or non-volatile, is safe. But what if it is spilled in transfer, or what if the apparatus leaks? Then we have an open system. Do we consider a closed system as open if there is some small but finite chance of a spill or a system leak? No, but we must be prepared for the consequences of a closed system becoming open. In the context of deciding to bioassay or not, all we need be concerned about is an open system of a volatile form containing more than 100 mCi. We can assign relative risk numbers for this situation as the quantity in process increases by uniform factors. For example, we can say we have a risk factor of one for quantities less than 100 mCi, a risk factor of two for quantities between 100 and 1000 mCi, a risk factor of three for quantities between 1000 and 10 000 mCi, and so on. All of these are for open systems with volatile compounds.

---

* Tritium used in the university environment is supplied usually in an aqueous or as an alcohol solution. These may then be mixed with solvents having a higher vapor pressure, but at most the relative volatility is about a factor of ten greater than water. It is the vapor pressure of the compound rather than that of the solvent that is of interest.

Application and interpretation of the assigned risk factors as modified by the hazard-reducing properties of protective devices is what the health physicist is trained to do. He analyzes the features of the proposed experiment, he considers what measures, if any, are needed to reduce the risk of exposure, and he recommends to the investigator those measures or adjustments determined to be necessary. Compromises may be required. The health physicist may not understand the experiment well enough to predict what influence on its successful performance his recommendations will have if incorporated. It is expected that the investigator will tell him, and the health physicist will propose alternatives to accomplish the equivalent result. Finally, the experiment can proceed with both the investigator and the health physicist better satisfied about the outcome. No one away from the scene can provide this give-and-take adjustment of the parameters of the experiment.

Protective Devices and Apparatus

An open system is considered to be one for which no containment of evolving vapors or gases is operating. The bottle, vial, flask, beaker, or whatever is open to the atmosphere - the contents may even have spilled onto a bench top or onto the floor. A volatile form of the material means that prompt exchange with room air will take place by diffusion and the room will quickly fill with the material to a uniform concentration. If the room air is mechanically pumped to other locations by return flow from forced-air heating or air conditioning systems, the air contamination will go with it. Or, if the room has an open door, the air contamination will spread promptly to adjoining spaces.

With an MPCa for tritium of 5×10^{-6} μCi per milliliter for monitored personnel, a room of $4 \times 6 \times 2.5$ meters needs a source of only 0.3 mCi to provide this concentration after complete mixing. It can be argued that MPCa values are needlessly conservative for tritium, but the point to be made here is that not much activity in the source is needed when it is open to the air to produce significant concentrations. A less volatile source, on the other hand, will lose some of its activity by diffusion, but most of it will stay in place where it was spilled. An increase in activity as much as a factor of ten must be spilled before the equivalent air concentration is achieved. A conservative-minded radiation safety program will attempt to limit such spills to the rare category of an accident. The limitation will be provided by the committee approval process

by the expedient of denial of any application that proposed use of this or any other radionuclide in quantities and for an experiment that can result in an air concentration above the MPC value. But any radiation safety program worthy of the name is doing this routinely.

Consider the same forms of tritium in use in a fume hood. What should we consider the protective effect of the hood to be? In the example cited above, a closed space of 60 cubic meters without air exchange required only 0.3 mCi of tritium in volatile form to provide the MPCa of 5×10^{-6} μCi per milliliter after mixing in the closed space. If the tritium is spilled on the floor of a fume hood that exhausts 1.5×10^{7} milliliters per minute (approximately 100 linear feet per minute through an opening 1.5×3 feet), the air in the room is exhausted and replaced every four minutes. Now, just to maintain an MPCa in the exhaust duct, we need the source to volatilize 0.3 mCi every four minutes. If the capture efficiency of the hood is only 90-percent because of random disturbances of the room air, ten times as much activity must be released every four minutes to create an MPC in the room air. This requires a spill or a steady leak of 3 mCi every four minutes. Quantities in the less volatile forms must be correspondingly higher. Clearly, the fume hood provides an environment that permits very sloppy operations before much risk of exposure is evident outside of the hood.

With several possible pathways of entry into the body, the MPCa for tritium is determined from the sum of all pathways contributing to the burden of the radionuclide in the body. The obvious pathway of inhalation into the lung is mainly prevented by the fume hood because common sense dictates that performance of an experiment in a fume hood is accomplished with the individual's breathing apparatus kept outside. It is not likely that otherwise qualified investigators will be placing their heads inside the hood to examine the experiment. But they do need to place their hands and arms inside. Volatilized tritium as HTO will enter the body through the skin as readily as by inhalation. This factor dictates that protective coverings impermeable to tritium be worn over all of the skin exposed to the environment within the hood.

Unfortunately, there is almost nothing impermeable to tritium, although for short

periods of time there are materials that will reduce the quantity absorbed by the skin. What must be done first is to limit the time that the skin is exposed by planning the experiment with enough care so that hands-on adjustments are minimized. Then, protective coverings like plastic, surgeon's gloves can be worn (in multiple layers if necessary) to limit the skin exposure. Each thickness of the plastic provides protection for only about 15 minutes, in which time the tritium has passed through to contaminate the hand. What needs to be done, therefore, if prolonged operation in high concentrations is required, is to wear two or three gloves and peel them off layer by layer every 15 minutes or so. The contaminated gloves, when removed, must be safely enclosed in a tightly-covered container within the hood. Gloves that cover part or all of the forearm are preferred to those that cover only the hand and wrist. Even heavy-rubber, acid-resistant gloves are permeable to tritium and will become contaminated after not too long a time.

Another mode of entry is by ingestion. For tritium as HTO, ingestion compared to inhalation or absorption through the skin is of negligible concern. But for tritium as a labeled organic, ingestion may be the only significant mode of entry, unless the organic compound itself has a high vapor pressure. Ingestion as an intake pathway is more easily controlled. We do not need to repeat the experience of the radium dial painters to determine that radioactive material must not be placed in the mouth. We must also insure that foods and beverages are not stored or consumed where non-volatile forms of tritium are being used.

Altogether, we can conclude that quite substantial quantities of volatile-form tritium can be handled safely in a properly functioning fume hood as long as we take reasonable precautions to limit spills and wear protective covers on exposed skin. Furthermore, we can conclude that even larger quantities of less volatile tritium can be handled safely in a fume hood provided we take common sense measures to avoid ingestion. The radiation safety program must take account of the operating characteristics of the hood,* the precautions taken to avoid spills, the physical form of the tritium

---

* See the Scientific Apparatus Makers Association [SAMA] "Standards for Laboratory Fume Hoods," LF7-1975, 1140 Connecticut Ave., N.W. Washington, D. C. 20036.

compound, the use and disposal of gloves, the precautions taken to avoid ingestion, and the general features of the conduct of the experiment that may lead to release of contamination.

Another and higher level of containment can be provided by use of a glovebox, although such sophistication is rarely found in the university simply because quantities of tritium for which the glovebox becomes essential are not used in the university. Actually, most university-based experiments with tritium do not require even the fume hood for safe handling. If required, however, by the scope of the project proposed, the health physicist must insist that a glovebox be used or that the project be scaled down to that suitable for a fume hood. Other than a consideration of scale, the observations made previously about the fume hood apply as well to the glovebox. Of special concern is the contamination of the gloves. After only limited use, the glovebox gloves will be contaminated, and separate gloves in addition to the glovebox gloves must be worn with the same attention to time limits as apply to use of gloves in the fume hood.

Monitoring Techniques

Monitoring for tritium is difficult. Conventional techniques satisfactory for most other radionuclides won't work. We are faced with developing special methods that are far more time consuming and, hence, costly than are the methods employed for all but a few of the alpha emitters that are not often found in the university environment.

In the non-volatile form, tritium contamination from surfaces can be picked up on routine wipe samples, and the degree of contamination can be assessed provided we have access to a suitable instrument to measure the low-energy beta emissions. For practical purposes, this means an access to a liquid scintillation counter. Many radiation safety programs have been obliged to invest the $12-$15,000 necessary to purchase this instrument dedicated to health physics use just because access to another instrument was impossible or impractical.

Even with the instrument available, sample preparation will require extra care and some additional investment in apparatus. A budgeted radiation safety program has a tendency to ignore unit costs because there is no accounting process imposed upon them. Take what you have, get the job done the best way possible but don't

look back to analyze how you did it. In this accounting, time spent is not listed as a cost factor. What does count is what you have to spend for supplies and equipment, especially when requests for special appropriations must be made.

Tritium is extremely difficult to capture and measure. What we must do is to convert the water vapor to a non-volatile form and keep it that way until the activity is measured. The human body performs this operation for us by converting tritium taken into the body to HTO in body water. Then, the body collects a portion of this body water in the bladder and provides an on-off control so that aliquots can be drawn off almost at will. In the university environment, everyone working in proximity to the tritium becomes a monitor of the volatile-form tritium (and of the non-volatile form also even though, as previously mentioned, non-volatile form tritium does not as easily enter the body). If this monitor would stay put and be conveniently accessible to obtain a sample, it would be ideal. Usually, however, when the schedule for the sample comes up, our monitor has just left for New York, taking his bladder with him.

Another way the conversion of volatile-form tritium to non-volatile form can be accomplished is by duplicating in simplified form what the human body does. That is, an equivalent system needs a pump to force air containing the vapor through a medium like water where the vapor is condensed and trapped. A typical system* will cost about $400, and it is not subject to the damage experienced by the human body when exposed to tritium. At this cost, it will not be possible to install one permanently at every location where tritium is used, but the cost is not so excessive that one or more cannot be obtained for placement while tritium handling is in progress. Care must

---

* For example, the system might include a Micronair pump and battery charger (Baird-Atomic 952-963 @ $340) and a micro impinger and holder (Baird-Atomic 952-976 @ $44). This system has the advantage of small size for portability, freedom from electrical power for flexibility, and short sampling times for convenience.

Another example is the use of a commercial, household-type dehumidifier modified so as to empty directly into a sample bottle. With a separate measurement of the air temperature and relative humidity, the quantity of the condensate can be used to calculate the total volume of air pumped through the system. The activity in the condensate divided by the volume of air pumped through will yield the average concentration of HTO in the ambient air. This system is bulkier, requires an electrical power source, and needs a longer sampling time.

be taken to sample the air at the breathing zone or between the breathing zone and the source.

Of course, it does not matter from whence the sample came; from any source, it remains necessary to have the means at hand to measure the activity in the sample to a sufficient precision for assessment of the hazard. The liquid scintillation counter provides enough sensitivity. Depending partially on the care taken with sample preparation and instrument calibration, a minimum detectable concentration of tritium can be less than 10^{-5} μCi per milliliter of sample. From this baseline, a modest pumping rate through the sampling device, and a sufficient time to accumulate activity in the medium chosen, the concentration of the tritium in the air should be measureable down to a fraction of the MPCa*. Measure of one-percent of the MPCa is attainable. Uncertainty of the method to quantify precisely the concentration of tritium in the air because of the variability in the exchange rate to be expected from the water vapor is not thought to be of serious concern, although methods are available to reduce the uncertainties.

The advantage of the inanimate monitor over the animate one is that it stays in place and provides its sample at the convenience of the health physicist. While some sampling of the animate monitor will be necessary to establish correlation factors, most one-shot, acute-exposure situations can be assessed with the inanimate monitor. A program that incorporates air monitoring on a regular basis should be permitted to substitute the inanimate form for the animate at low levels of exposure. This substitution will not work as effectively when non-volatile-form tritium is being handled. When ingestion is the only or most likely path of entry into the body, monitoring with wipe samples must replace the air-sampling device.

Assisting the Investigator

The radiation safety program in the university exists to serve the investigator. Indirectly, a cooperative, supportive, and professional relationship with the investigator will also serve the university administration and the regulatory agencies, although

---

* If ten percent of the tritium is trapped upon passing through an impinger containing ten milliliters of water at a flow rate of two liters per minute, the time required to attain a concentration of 10^{-5} μCi per milliliter of the sample at the MPCa is about 0.1 minute.

these other groups may not always perceive the benefit derived. What this support of the investigator means in terms of our concern with tritium is that when a special problem arises, the investigator will solicit and welcome the help of the health physicist in the performance of the experiment. (Imagine how easily this function can be performed by an outside agency in a remote location.) Preliminary safeguards will be taken, the plan of the experiment will be developed, protective devices will be made ready, an emergency procedure will be devised, monitoring apparatus will be assembled, and so on. A conscientious investigator can do all of these things for himself, and he should if a health physicist is not available; but a prudent investigator will realize he will need all the help he can get when he undertakes something new and different. When the experiment becomes repetitive with all the bugs worked out, the procedure can be turned over to an assistant. Whatever the risk involved in the experiment conducted for the first time, it can be reduced by at least a factor of ten by having the health physicist present as a participant.

WHEN

In a real sense, we are doing things backward if we sample by bioassay promptly after a large exposure and much later after a small exposure. The NRC is currently requiring licensees to perform a bioassay within one week of an exposure to 100 mCi or more of tritium as HTO and to bioassay within one quarter of an exposure to 10 to 100 mCi as HTO. Setting aside for the moment the argument that these limits are too small by a factor of ten, a body burden of 10 μCi derived from an exposure to 10 mCi on the day after the quarter begins will be reduced to about 10^{-2} μCi after 90 days. A body burden of 10 μCi will be reflected in the bioassay as a concentration of about 1.5×10^{-1} μCi per liter initially and about 1.5×10^{-4} μCi per liter after 90 days. The initial concentration is within the sensitivity of the instrument, but the final concentration is not. What do we make of this? Was the initial concentration meaningful in terms of its contribution to the dose of the individual? A body burden of 10 μCi equates to a dose less than two millirem - hardly worth mentioning. If even the initial quantity is practically lost in the background, why sample at all for this level of exposure? Provided that we have some assurance that an exposure at whatever level will result in a body burden of 10 μCi or less, we should be permitted to eliminate the bioassay procedure.

We are inclined to sample more promptly after large exposures just to reduce the chance that a previous exposure did not result in an excessive dose to the individual. If a body burden of 10 μCi results in a dose less than two millirem, what kind of dose do we want to be concerned about? For external exposures, we monitor with film badges or TLDs; and we usually investigate monthly, whole-body exposures reported as 100 millirem or higher. A body burden of 600 μCi produces a dose of 100 millirem, so comparatively we would want to examine every situation that resulted in a body burden of 600 μCi to find out why and to correct any procedural errors producing the higher dose. On the film badge (or TLD) report, we have no result for an exposure reported as less than ten millirem of x or gamma radiations and 40 millirem for neutrons. We do not count this as zero, but we do not attempt to assign a number to it either. The body burden equivalent of ten millirem is 60 μCi of tritium.

If our minimum detectable concentration is 10^{-2} μCi per liter of sample and what we are trying to detect is 60 μCi, we need to know how long we can wait after the exposure before taking the sample. Our minimum detectable concentration equates to a body burden of approximately 0.6 μCi, or about one-percent of what we are looking for. This means that we have the sensitivity to detect a body burden that may have been as high as 60 μCi within the past month.* On this basis, bioassay sampling more frequently than once per month is wasteful, except when we know a significant exposure has been received.

The ALARA concept embodies a cost-benefit analysis. In its recommendation† on ALARA, the ICRP specifically incorporates the tangible and intangible factors to be considered. Different standards for internal compared to external hazards are not implied. Nor are there implied any performance criteria for

---

* A factor of one hundred reduction is about seven half-lives, and with each half-life being about ten days, about 70 days will pass before the body burden reduces by one hundred.

† ICRP Publication 22 "Implications of Commission Recommendations that Doses be kept as Low as Readily Achievable." Readily is changed to reasonably in the conclusions.

personnel monitoring that suggest an internal hazard needs to be evaluated more stringently than an external hazard. Even if internal doses can be measured in microrem, the ALARA concept does not require that occupational exposures be monitored to such low levels. For comparison, the instrument sensitivity previously cited of 10^{-2} μCi per liter of body water is equivalent to a single intake of 0.6 μCi which results in a dose of 100 microrem. Because of the short residence time for tritium in the body, we need some of the extra sensitivity to properly assess prior exposure within the sampling period. We do not, however, need to look diligently for exposures at this level any more than we need to be concerned about external exposures at or near natural background levels.

What we do need is some idea of what fraction of tritium will get into the body under various exposure conditions. Unfortunately, we are not even certain of what fraction of the tritium in an experiment will escape the containment of the fume hood to expose the body. For these transfer functions, we need much more air monitoring data than are now available. The point at which the ALARA concept applies in the university is when the protective devices are specified in the original design of the experiment. Is a hood needed? Is a glovebox needed? What form for the tritium will provide the least likelihood of intake? Should air monitoring be provided? These are the questions that involve the cost-benefit analysis. Oh yes, do not forget the intangible benefit to the investigator if the need to supply a urine specimen for a bioassay is removed.

There are both tangible and intangible costs involved in a program to monitor personnel by bioassay of urine specimens. Tangible costs include the time taken by all parties involved, the costs of supplies, the costs of equipment and space, the costs of recordkeeping, the costs of followup when required, and the miscellaneous costs of instrument calibration, sample preparation, ordering and stocking of supplies, and the non-productive time associated with a change in direction from one task to another. Intangible costs include the nuisance factor imposed upon the investigator to provide the urine specimen and to hold it for pickup. Typical values for the tangible costs may be identified as follows:

Time: 40 minutes for the health physicist to obtain the sample.
10 minutes per sample to load the machine, record the results, and unload the machine.

10 minutes per sample to prepare solutions and calibrate and maintain the machine.

60 minutes total time per sample. Cost for this time is about $15 allowing for a modest salary, fringe benefits, and other support costs.

Supplies: About $2 per sample will pay for the scintillation fluid, vials, and specimen bottles. (And, maybe, it will also cover the cost of getting rid of the scintillation fluid.)

Equipment: A liquid scintillation counter costing $15,000 initially will need to be replaced every five years or so and will need maintenance in the meanwhile. If 1000 samples are processed each year (including wipe samples), the equipment cost per sample is $3.

Total cost per sample = $20.

These costs are estimated on the conservative side. Some individuals will choose to ignore the cost of the time because the salaries and indirect costs are budgeted annually, and the cost of the equipment may be ignored because use of someone else's machine is bootlegged. This leaves only a $2 per sample cost for supplies. If only 50 or so samples are processed each year, merely $100 is hardly worth worrying about. On the other hand, this same program may be confronted with the requirement of processing 1000 or more samples per year, and even the supplies become a cost factor to be reckoned with.

HOW

What these guidelines are intending to accomplish is to provide a consistent approach to the problems associated with use of tritium in the university environment and to reduce the number of bioassays performed. The lower limit of this reduction is intended to be the least number providing meaningful results. Each of the suggestions for accomplishing these benefits is accompanied by a comment outlining the rationalization for its inclusion.

Assure Access To a Liquid Scintillation Counter

This states the obvious, but it is mentioned merely because there is no point in proceeding further without convenient access to this instrument being assured. As

mentioned earlier in the text, a sensitivity for tritium in body water (urine) of 10^{-2} μCi per liter is more than enough. A calibration procedure is attached for reference as Appendix A.

Review the Application With the Investigator

With due respect for the evaluations that come later, the key step of the review process is the initial interview of the health physicist with the investigator. At this point, the details of the project are still somewhat pliable, and one thing or another can be kneaded into a form that simultaneously satisfies the investigator while still reducing the scope of the health physics problems. Among the parameters to be reviewed for which adjustments will be sought are:

- Reduce, if possible, the quantity of tritium to be handled
- Change the form, if possible, to that presenting the least chance of exposure
- Reduce, if possible, the number of individual exposures during the life of the experiment
- Compare the experimental protocol with both the form and activity of the material to seek options to reduce the risk of exposure.

Obtain Baseline Urine Specimen Upon Initial Application

At the earliest convenient opportunity after the application to use tritium is filed, a urine specimen should be obtained from the investigator and from all subordinate personnel likely to be exposed so that baseline concentrations can be measured and recorded. Subsequently, similar baseline data should be obtained for additional personnel assigned to the project. At the time of evaluation of the application, a determination must be made by the health physicist whether or not sufficient tritium will be handled to warrant regular or random bioassay during the life of the project. Baseline specimens should not be taken from personnel for whom subsequent specimens are not warranted. That is, don't clutter the files with baseline data not expected to be followed by regular monitoring.

Contain the Activity

As much as possible, the health physicist should attempt to keep the activity contained within the experimental system, and the entire system should be contained within the fume hood. All discarded gloves, wipes of spills, empty vials, discharged syringes,

and other detritus of the initial handling step should also be kept within the hood. A container like a one-gallon paint can with a closely-fitting lid should be provided within the hood for these discards. Subsequently, the entire container with its contents will be removed for disposal as solid waste.

Check Hood Operation

Before any activity is released within the hood, the health physicist must be satisfied that an adequate airflow is provided for the hood. Criteria for hood performance as compiled by the Scientific Apparatus Makers Association previously referenced are that a Class A designation requires an average flow of 125 to 150 feet per minute with corresponding minimums at any one point of 100 to 125 feet per minute. For modest quantities of tritium, say in the range of 100 to 1000 mCi as HTO or equivalent in other forms, a Class B designation will be sufficient. This designation requires an average velocity of 100 feet per minute with a minimum at any point of 80 feet per minute.

Recommend Conditions To Committee

If the health physicist has any reservations about the experiment including an assessment of the qualifications of the investigator and his staff, these must be reported to the committee to permit a proper evaluation before an authorization to proceed is approved. If conditions of use need to be imposed, the health physicist must recommend their incorporation in the authorization. The committee may choose to ignore the recommendations, but the health physicist has an obligation to make them anyway. And, if the recommendations are ignored, the health physicist is obliged to do his best to see that the experiment is performed successfully.

Perform Air Monitoring When Needed

For every situation in which as much as 100 mCi of tritium as HTO may escape the hood, air monitoring as close to the breathing zone as possible should be performed. Expressed differently, this guideline means: if the health physicist determines from his evaluation of all the factors involved that there is no likelihood of as much as 100 mCi of tritium as HTO to escape, he will not monitor the air. Based on other criteria, he may be monitoring the participants by bioassay, however.

This page was modified slightly during a discussion at the meeting. A revised page was then prepared and sent to all attendees.

Bioassay As Required

These guidelines are intended to supplement and complement a standard for bioassay criteria being developed independently* to cover use of tritium in a more general way. For the special circumstances of use in the university as described in this document, there are no other guidelines extant, except those herein. To specify some quantities for this preliminary draft of guidelines to be used in the university environment, the following criteria are anticipated to be compatible with what is recommended for the general conditions of use:

Bioassays shall be performed at least monthly for all individuals exposed as follows:

1. In open-bench operations, when as much as 1 Ci of tritium as a pure gas, 100 mCi of tritium as HTO or as a labeled organic, or 10 mCi of tritium as a nucleotide is used in uncontained form;
2. In a Class B fume hood, when more than 10 Ci but less than 100 Ci of tritium as a pure gas, more than 1 Ci but less than 10 Ci of tritium as HTO or as a labeled organic, or more than 100 mCi but less than 1 Ci of tritium as a nucleotide is used in uncontained form; and
3. In a glovebox, when more than 100 Ci of tritium as a pure gas, more than 10 Ci of tritium as HTO or as a labeled organic, or more than 1 Ci of tritium as a nucleotide is used.

Note: These quantities may be involved in a single, short-term experiment or they may be the sum total of all tritium used within a calendar quarter. Ten exposures of 100 mCi each within a calendar quarter is counted as equivalent to a single exposure of 1 Ci.

In the university, the criteria identified for use of tritium in a fume hood (item #2) will most likely apply because almost all such uses will be performed in a hood. Therefore, bioassays are not required for use in a fume hood when less than 10 Ci of tritium as a pure gas, less than 1 Ci of tritium as HTO or as a labeled organic, or less than 100 mCi of tritium as a nucleotide is used in uncontained form. This is not to say the bioassay shall not be performed if the health physicist determines he needs the information; it means only that he has an option to take or not take a bioassay under these use conditions.

---

* Both the Standards Committee of the Health Physics Society and the NCRP have subgroups working on criteria for bioassay including tritium.

Tritium in the pure gas form will not be encountered in the university environment. Sources of gaseous-form tritium that may be found are contained in the metallic hydrides used in proton-beam neutron generators and in detector cells for gas chromatographs. However, the gaseous-form tritium entrapped by the metal hydride will oxidize immediately upon contact with room air to form HTO. Consequently, the risk of exposure to gaseous-form tritium in the university environment can be taken to be near zero. With respect to the tritium targets for neutron generators, it is worth nothing that in use these targets lose a significant fraction of the tritium to contamination of the equipment and especially the vacuum pump oil. Care must be taken, therefore, when targets are changed or other maintenance operations are performed to avoid a needless exposure.

Non-routine Bioassay

In the university under normal use conditions, investigators employing tritium in their experiments will not be using it on a regular basis or using quantities that will require a regular bioassay sampling. The health physicist will want to be satisfied that no significant intakes are experienced. For this purpose, the health physicist will be surveying the laboratory on a regular schedule, and the tritium use rate will be noted as part of the inspection protocol. Periodically, individuals from such a laboratory should be invited to submit urine specimens for bioassay the results of which will serve as a supplement to the survey results. Because the likelihood of a significant uptake is small for this situation, the bioassay should be performed soon after the exposure but not necessarily after each exposure. To accumulate the highly desired transfer function relating exposure to intake, notes on the circumstances of the exposure should be recorded.

Evaluation

With a sensitivity for detecting tritium in the urine of about 10^{-2} μCi per liter by this method, there is much more sensitivity available than required to detect significant concentrations. In a university, where monitoring by bioassay of urine specimens is directed to detecting single, isolated, acute uptakes, the ICRP Investigation Level is what we want to detect. This single intake of 1.5 mCi pro-

duces a tritium concentration in the urine of 35 μCi per liter. If we are sampling monthly, an initial concentration of 35 μCi per liter can be reduced to about 5 μCi per liter at the time the sample is taken if the intake occurred at the beginning of the month. We are, therefore, interested in exposures that result in urine concentrations of the order of 1 μCi per liter, and we have more than enough sensitivity for that.

Should there be a condition in the university laboratory of a chronic rather than an acute exposure, the ICRP Derived Investigation Level* provides a method by which the total intake averaged over a number of days can be correlated with the Investigation Level based on an acute uptake. That is, if the quantity of 1.5 mCi is actually acquired over a time of ten days, the uptake per day is 0.15 mCi and the body burden at the end of the ten days is just above one mCi. Concentration of tritium in the urine at that time is proportional to remaining activity rather than the total uptake.

---

* ICRP Publication 10A "The Assessment of Internal Contamination Resulting from Recurrent or Prolonged Uptakes."

APPENDIX A

TECHNIQUE FOR BIOASSAY FOR TRITIUM IN URINE*

Preliminary Steps

1. A counting standard is prepared from a known activity of tritiated water to yield a concentration of about 1 nCi per milliliter. The actual concentration must be known and be traceable to an NBS Standard, but the known value can be more or less than 1 nCi per milliliter. With provisions for containment† of the HTO vapors, a quantity of this counting standard can be prepared at one time sufficient to last several months.
2. A "background urine" vial is prepared with one milliliter of uncontaminated urine and ten milliliters of scintillation fluid, and the contents are sealed to serve as the perpetual source for the background count to be taken with each sample.
3. An operational check is performed on the instrument to insure its proper condition for use.

Procedure

1. A urine specimen is collected in a disposable specimen container of about eight fluid ounces capacity.
2. Three each, low-background, glass vials are prepared with ten milliliters of scintillation fluid. The vials are labeled "a," "b," and "c." (Other labels of choice may be substituted by those preferring something more exotic.)
3. One milliliter of the urine specimen is added to each of the "b" and "c" vials.
4. One milliliter of the counting standard is added to each of the "a" and "b" vials.
5. The "a" vial is counted to insure that the instrument is adjusted properly to respond to the expected count rate of the standard.

---

* This procedure is utilized by the Health Physics Services, University of Missouri-Columbia, and has been found to be convenient and reliable for the assessment of tritium concentration in urine specimens.

† Containment should be glass rather than plastic as otherwise some of the tritium will escape through the wall. See "Loss of ^{14}C and ^{3}H from Liquid Scintillation Counting Vials," reported by Joseph L. Thompson and David A. Olehy in the May 1977 issue of Environmental Science & Technology, pp. 513-4.

6. The "background urine" vial and the "b" and "c" vials are counted for ten minutes each.

7. Net count rates "B" and "C" are determined by subtracting the count rate obtained for the "background urine" vial from the count rates measured for the "b" and "c" vials.

8. Tritium activity is calculated by the equation:

$$TA = \frac{S \times C \times 10^3}{(B-C) \times 2.22 \times 10^6} \ \mu Ci \text{ per liter,}$$

where S = activity in one milliliter of the counting standard expressed in disintegrations per minute,

B = net counts per minute of "b" vial, and

C = net counts per minute of "c" vial.

Having urine in both the "b" and "c" vials automatically cancels the quenching effect of the urine.