Radiation Safety

Systematic Procedure for Radioactive Waste Disposal

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We describe a simple system to dispose of radioactive wastes from in vivo procedures. It avoids many commonly encountered storage problems, minimizes record keeping, and can reduce radiation exposure to the technologist.

Storage and disposal of radioactive waste materials are on-going problems for the nuclear medicine department. Such waste materials as used or expired radiopharmaceutical vials, contaminated syringes, cotton swabs, rubber gloves, etc. accumulate continuously and must be discarded. Storing radioactive wastes until waste has decayed to background is necessary—because of limits on the amounts of radioactivity that may be disposed via the sewage system or by venting into the atmosphere. The unpredictable status of burial sites also necessitates storage.

Unless a storage procedure is systematically organized, there are several problems that may occur.

Most of the waste from in vivo procedures will be Tc-99m, which is decayed to background and disposed of in a short time. However, if longer lived radionuclides are mixed with technetium waste, the mixture will have to be stored for a much longer time to reach background. This will cause a large increase in the amount of material in storage at any one time and, in turn, cause unnecessary use of storage space and expensive lead bricks for shielding.

With a large amount of material in storage there is a tendency for newer waste to be deposited on top of older materials. Technologists will receive unnecessary radiation exposure when material ready to be discarded must be recovered from underneath the still radioactive upper layers. Frequent disposals may also be required to keep the storage area from filling up. This will compound radiation exposure to the technologist as well as complicate record keeping, since anything disposed must be monitored and recorded.

If disposal of stored materials is not done at predetermined intervals, it can be difficult to estimate when something can be discarded. For example, on January 12 it could be difficult to know whether an iodine-131 vial dated October 25 has been in storage for a minimum of 81 days (10 half lives), without having to count days on a calendar.

Storage Procedure

The procedure we describe avoids these pitfalls by separating Tc-99m from other radionuclides, grouping radionuclides based on similar half lives for the sake of ease of memory, and keeping records. Each "batch" of radionuclides with similar half lives is stored for a minimum of ten half lives of the longest lived radionuclide in the group, as shown in Table 1. It has been our experience since the adoption of this procedure that less storage space is needed, and record keeping is simplified and easily maintained since approximate activity and discard date are known in advance.

Tc-99m

A "day-of-the-week" schedule is used to store technetium waste, based on the system described by Enos and Budzier (*1*). We have modified the storage container to

TABLE 1. Radionuclide Groupings and Decay Periods.

Isotope	Half Life	Time Decayed in Storage
Tc-99m	6 hr	1 week = 28 T½
I-123	13 hr	1 week = 12.9 T½
Mo-99	2.8 days	3 months = 32.1 T½
Tl-201	3 days	3 months = 30 T½
Ga-67	3.25 days	3 months = 27.7 T½
Xe-133	5.3 days	3 months = 17 T½
I-131	8.1 days	3 months = 11.1 T½
P-32	14 days	1 year = 26 T½
Cr-51	27 days	1 year = 13.5 T½
Yb-169	32 days	1 year = 11.4 T½
I-125	60 days	2 years = 12 T½
Se-75	120 days	4 years = 12.16 T½

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FIG. 1. Six chambered box for day-of-the-week storage of technetium.

suit our needs; our chamber contains six chambers, each labeled for a day of the week (Fig. 1).

Each working day the elution vials, radiopharmaceutical kits, contaminated syringes, rubber gloves, etc. are deposited in the appropriate chamber, which is lined with a plastic trash bag. The waste materials remain in the box for one week (for example from a Monday until the following Monday) so they have 28 half lives to decay to background. The following week the contents of that chamber are removed, monitored, and discarded to make room for that day's accumulation and the cycle repeats itself.

Even though curie amounts of technetium are eluted daily from our generators, only nanocurie amounts remain at the time of disposal.

Iodine-123 with its 13-hr half life can be included with the technetium. One week of decay equals 12.9 half lives, so the initial activity is reduced by a factor of about 10,000.

Table 2 shows an example of record keeping for technetium disposal, including disposal dates, activity disposed, and monitoring results.

TABLE 2. Example of Tc-99m Disposal.

Date	Activity Eluted (mCi)	Date Disposed	Activity Disposed	Exposure Rate at Time Disposal
1-1-79	1,800	1-8-79	≤ 6.6 nCi	< 0.02 mr/hr
1-2-79	1,404	1-9-79	≤ 5.2 nCi	< 0.02 mr/hr
1-3-79	1,095	1-10-79	≤ 4.0 nCi	< 0.02 mr/hr
1-4-79	855	1-11-79	≤ 3.2 nCi	< 0.02 mr/hr
1-5-79	667	1-12-79	≤ 2.5 nCi	< 0.02 mr/hr
1-6-79	520	1-13-79	≤ 1.9 nCi	< 0.02 mr/hr
1-7-79				
1-8-79	1,780	1-15-79	≤ 6.6 nCi	< 0.02 mr/hr

Mo-99, Ga-67, Tl-201, Xe-133 and I-131

These radionuclides are grouped together because of their similar half lives. They are accumulated and decayed on the basis of calendar quarters. Each batch is allowed to accumulate for three months, then sealed to decay for three months. After this time it is monitored with a survey meter to assure that the exposure rate is down to background levels, then discarded. Whenever a batch is discarded the date and exposure rate must be recorded. No more than two batches will be on hand at any one time: one accumulating and one decaying. An example is shown in Table 3; note that this represent two years' worth of record keeping for the longer lived radionuclides.

The number of half lives decayed is shown for each radionuclide in Table 1. Note that the number of half lives indicated is actually a minimum; the last material to go into a batch will have been stored for that many half lives, but earlier material will have been stored for a longer period, during which time it will have decayed even more.

TABLE 3. Disposal of Longer Lived Radionuclides.

Batch Number	Radionuclides	Inclusive Dates		Disposal Dates		Exposure Rate
		Date Begun	Date Sealed	To Be Held Until	Date Disposed	
I-1	I-131, Xe-133 Mo-99, Ga-67, Tl-201	Jan. 1	Mar. 30	July 1	July 3	0.02 mr/hr
I-2	I-131 etc.	Apr. 1	June 30	Oct. 1	Oct. 1	0.02 mr/hr
I-3	I-131 etc.	July 1	Sept. 31	Jan. 1	Jan. 2	0.02 mr/hr
I-4	I-131 etc.	Oct. 1	Dec. 31	Apr. 1	Apr. 1	0.02 mr/hr
Y-1	Yb-169, P-32, Cr-51	Jan. 1, 1978	Dec. 31, 1978	Jan. 1, 1980		
Se-1	Se-75, I-125	Jan. 1 to present	—	—	—	—
I-5	I-131 etc.	Jan. 1	Mar. 30	July 1	July 5	0.02 mr/hr
I-6	I-131 etc.	Apr. 1	June 30	Oct. 1		
I-7	I-131 etc.	July 1	Sept. 30	Jan. 1		
I-8	I-131 etc.	Oct. 1	Dec. 31	Apr. 1		
Y-2	Yb-169 etc.	Jan. 1, 1979	Dec. 31, 1979			

Inclusion of Mo-99 with I-131 holds it up for 32 half lives. This apparent "overkill" serves a useful purpose, since initial activity of generator cores is so high and longer lived radionuclides may be present as contaminants. Three months of decay reduces the initial activity by a factor of more than a billion. If therapeutic doses of I-131 are used, three months of decay may not be long enough to reach background; a 4-month accumulation and decay cycle would then be recommended to allow 15 half lives for decay.

P-32, Cr-51, and Yb-169

These radionuclides are grouped together because they accumulate slowly and require a long time to decay. Batching is performed annually; as with the previous group there is only an accumulating batch and a decaying batch on hand at any one time. An example of the record keeping for this group is shown in Table 2. The half lives are 14, 27, and 32 days respectively so annual batching allows 26-, 13-, and 11.4-half lives for decay.

I-125 and Se-75

These two radionuclides are a problem because their half lives are comparatively long. Our I-125 fibrinogen is transferred to the radiation therapy department for inclusion with their I-125 surgical implant seeds, which are handled by a slightly different but related batching system.

For hospitals without a therapy department, I-125 could be included with Se-75 for batching. A 3½-year storage period would be required to equal 10 half lives, so this isotope could be batched on a 3½- or 4-year basis. This radionuclide accumulates very slowly, so the long accumulation and decay period does not cause a space problem.

Alternate Procedure for Small Hospitals

The procedure described above is followed by our large central hospital, whose nuclear medicine department generates a large volume of waste. Our satellite hospitals, 174 beds each, have much smaller volumes of waste. Their situation is also simplified by infrequent use of any radionuclide with a half life longer than that of I-131. Therefore, they use a batching procedure that is smaller in scale but identical in principle to ours.

They use a plywood box, 16in. × 16in. × 14in. (outside dimensions), internally divided into 4 equal chambers (Fig. 2). Each chamber has a lid lined with ⅛in. lead. Forty-four of the standard 8in. × 4in. × 2in. lead bricks are sufficient to shield the chamber underneath and on all four sides.

Two of the chambers are for Tc-99m waste, batched on a weekly basis. A plastic trash bag is placed in one chamber at the beginning of the week; all Tc-99m waste will be deposited in that chamber for that week. The following week, all waste goes into the second chamber while the contents of the first side decay for a week. The contents are then monitored and discarded, a new trash bag is inserted, and the cycle is repeated. The other two chambers are for the longer lived radionuclides, batched by alternate calendar quarters. Record keeping would be similar to that illustrated in Table 3.

Infection Control in Waste Disposal

The goal of the storage procedures we describe is to decay radioactive waste to background levels, so it may be safely handled as if no longer radioactive. Therefore, the monitoring of material to be discarded is essential. One

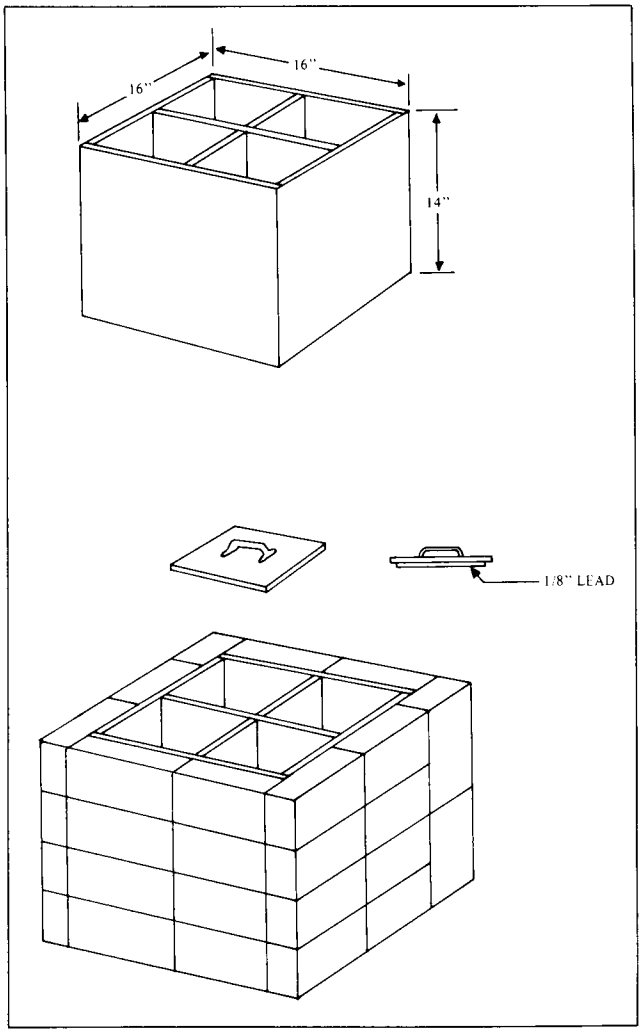

FIG. 2. Four chambered storage box for smaller hospitals. Two chambers are for Tc-99m batched by alternate weeks; two are for longer lived isotopes batched by alternate 3-month intervals.

cannot rely strictly on a preset storage period or a preset number of half lives. Longer lived radionuclides must not be deposited accidentally in shorter lived batches.

Once this has been accomplished, the waste may still be subject to infection control restrictions because syringes used to inject materials into patients are considered biologically hazardous materials. Sterilization or incineration may be required; appropriate arrangements should be made with the Infection Control Officer.

Estimation of Activity Disposed

It is required that activity disposed be recorded. This can be calculated easily for Tc-99m and I-123 by multiplying original activity by the appropriate decay factors for 28 and 13 half lives of decay, respectively. (This is actually a worst case estimate since it assumes all activity is decayed, i.e., none is administered to patients).

Estimation is more difficult for longer lived radionuclides because material already present in a batch is decaying even while newer material is still being accumulated. Ra-

dionuclides being batched will reach or approach a steady state situation in which activity already present decays as fast as new activity is added. Then when the batch is sealed, all accumulated activity is decayed for a predetermined number of half lives.

Most of our longer lived radionuclides are received on a standing order basis, so as an equal amount is received each week or month. The amount disposed may be calculated by use of the equation derived below—for example, 150 mCi of Xe-133 is routinely received per week; each batch is accumulated for three months (13 weeks), then decayed for an equal period. If all activity was deposited in storage, the accumulated activity would equal:

$$A_{acc} = A_t + A_t e^{-\lambda t} + A_t e^{-\lambda 2t} + A_t e^{-\lambda 3t} + \ldots A_t e^{-\lambda 12t}; \quad \text{(Eq. 1)}$$

where A_{acc} = accumulated activity;

A_t = activity received at routine interval t (i.e., 150 mCi/week);

λ = decay constant of the radionuclide; and

t = routine interval at which radionuclide is received (i.e., 7 days).

Equation 1 is simplified to:

$$A_{acc} = A_t (1 + e^{-\lambda t} + e^{-\lambda 2t} + e^{-\lambda 3t} + \ldots e^{-\lambda 12t}) \quad \text{(Eq. 2)}$$

There are 13 terms within the parenthesis because the batch is accumulated for 13 weeks. At the time the batch is sealed, some of the xenon present has been decaying for two weeks, some for three weeks, and so on up to 12 weeks.

Activity finally disposed will become:

$$A_{disp} = A_{acc}\, e^{-\lambda t_s} \quad \text{(Eq. 3)}$$

where A_{disp} = activity disposed, and

t_s = time of storage = 91 days.

Combining equations 2 and 3, we arrive at

$$A_{disp} = A_t\, M,$$

where $M = (e^{-\lambda t_s})(1 + e^{-\lambda t} + e^{-\lambda 2t} + e^{-3t} + \ldots e^{-\lambda 12t})$.

M is designated "accumulation and decay factor" because it corrects for decay during both the accumulation and storage period. The value of M is determined by the decay constant and the receipt and storage intervals. This value would therefore be a constant for any particular radionuclide. In the case of xenon, $M = 1.204 \times 10^{-5}$.

$$A_{disp} = 150 \text{ mCi/week} \times 1.204 \times 10^{-5}.$$

$$A_{disp} = 0.0018 \text{ mCi} = 1.8 \ \mu\text{Ci } \textit{per batch.}$$

M values are listed in Table 4. These values only apply to the receipt and storage intervals described here but can be easily calculated for different intervals. For any radionuclide, multiplication of the amount routinely received by this constant will give a "worst case" estimate of total activity disposed per batch, since it assumes all activity received is placed in storage.

TABLE 4. Accumulation/Decay Factors for Radionuclides.

Radionuclide	t	M Value
Tc-99m		3.7×10^{-9}
I-123		1.3×10^{-4}
Mo-99	weekly	2.10×10^{-10}
Tl-201	weekly	1.54×10^{-9}
Ga-67	weekly	6.27×10^{-9}
Xe-133	weekly	1.20×10^{-5}
I-131	weekly	9.69×10^{-4}
P-32	monthly	2.73×10^{-8}
Cr-51	monthly	2.10×10^{-4}
Yb-169	monthly	8.84×10^{-4}
I-125	monthly	1.60×10^{-7}
Se-75	monthly	1.39×10^{-3}

Summary

A streamlined, systematic procedure for disposal of radioactive waste is described that avoids many commonly encountered storage problems. This system is based on grouping of radionuclides with similar half lives, and decay periods based on calendar units rather than a specific number of half lives.

Advantages of this system include:

1. record keeping is minimal
2. volume of material in storage is minimized; this avoids wasting storage area or lead bricks for shielding
3. radiation exposure to the technologist is minimized for the same reason; material ready for disposal does not have to be recovered from underneath newer and still radioactive material
4. uncertainty about time for disposal is eliminated because disposal dates are predetermined
5. approximate activity at the time of disposal can be easily calculated
6. need to have waste material shipped for burial is eliminated because all radiopharmaceuticals used in in vivo nuclear medicine procedures may be disposed of by decaying to background.

Reference

1. Enos GW, Budzier AD: Devices for reducing personnel radiation exposure. *J Nucl Med Technol* 6: 89–91, 1978