Effect of Radioactive Materials On Environmental Health

By CONRAD P. STRAUB, Ph.D.

In a recent discussion relating to environmental health, Mark D. Hollis (*1*) indicated that public health officials will be responsible for protecting the population against the harmful effects of ionizing radiation. Ionizing radiations result from the disintegration of unstable nuclei and are damaging to living tissue. The radiation may originate from an external source or from radioactive materials within the body. Radiation from an external source may affect the body as a whole, if there is no shielding, or may be made to affect only certain portions of the body, as in radium treatment of a tumor. Effects of damage from radioactive materials within the body depend on several factors: the quantity of radioactive material present in the body; the type of radiation, whether alpha, beta, or gamma; and the half-life or rate of decay of the material. Other factors to be considered are the organ or organs of localization; rate of excretion from the body, i. e., the biological half-life; the physical state of the individual; etc. All of these factors are considered in determining the maximum permissible concentration (MPC) for each radioisotope in water or air. The MPC values under consideration for release by the Subcommittee on Internal Dose of the National Committee on Radiation Protection (*2*) are indicated in table 1.

Inasmuch as the Atomic Energy Commission

Table 1. Tentative maximum permissible concentration for certain radioisotopes in water and air

Element	μc/cc. water	μc/cc. air
U Nat. (soluble)	8×10^{-5}	1.7×10^{-11}
U Nat. (insoluble)		1.7×10^{-11}
U^{233} (soluble)	1.5×10^{-4}	1×10^{-10}
U^{233} (insoluble)		1.6×10^{-11}
Ra^{226}	4×10^{-8}	8×10^{-12}
Rn^{222}	2×10^{-6}	1×10^{-8}
Pu^{239} (soluble)	1.5×10^{-6}	2×10^{-12}
Pu^{239} (insoluble)		2×10^{-12}
Po^{210} (soluble)	3×10^{-5}	2×10^{-10}
Po^{210} (insoluble)		7×10^{-11}
C^{14} (CO_2)	3×10^{-3}	5×10^{-7}
H^{3}	0.2	2×10^{-5}
Ca^{45}	5×10^{-4}	4×10^{-8}
P^{32}	2×10^{-4}	1×10^{-7}
K^{42}	1×10^{-2}	2×10^{-6}
S^{35}	5×10^{-3}	1×10^{-6}
Na^{24}	8×10^{-3}	2×10^{-6}
Cl^{36}	2×10^{-3}	4×10^{-7}
Fe^{55}	4×10^{-3}	6×10^{-7}
Fe^{59}	1×10^{-4}	1.5×10^{-8}
Mn^{56}	0.15	3×10^{-6}
Cu^{64}	8×10^{-2}	6×10^{-6}
I^{131}	3×10^{-5}	3×10^{-9}
Sr^{89}	7×10^{-5}	2×10^{-8}
$Sr^{90} + Y^{90}$	8×10^{-7}	2×10^{-10}
A^{41}	5×10^{-4}	5×10^{-7}
Xe^{133}	4×10^{-3}	5×10^{-6}
Xe^{135}	1×10^{-3}	2×10^{-6}
Co^{60}	2×10^{-2}	1×10^{-6}
Au^{198}	3×10^{-3}	1×10^{-7}
Au^{199}	7×10^{-3}	2.5×10^{-7}
Cr^{51}	0.5	8×10^{-6}
Ni^{59}	0.25	2×10^{-5}
Mo^{99}	14	2×10^{-3}

Dr. Straub is a sanitary engineer with the Public Health Service Environmental Health Center, on assignment to the Health Physics Division of the Oak Ridge National Laboratory, Oak Ridge, Tenn. This paper was presented at a meeting of the sanitation section of the Georgia Public Health Association in Savannah, May 7, 1951.

supervises the control and discharge of radioactive wastes from its own operations, State and local health officials are not directly concerned with the waste products which result from operations within AEC-controlled areas. Public health officials will be occupied with the discharge of wastes into the environment beyond the controlled area of operations, with the discharge into the sewerage system of radioisotopes from hospitals and research institutions, and with the industrial use of radioisotopes in manufacturing processes, industrial radiography, etc. Industrial hygiene engineers will find considerable opportunity for the exercise of their talents in the latter fields.

Radioisotopes are being supplied in increasing numbers, as indicated by data available from the Operations Division of the Oak Ridge National Laboratory (*3*). In Georgia, six establishments have been or are receiving radioisotopes: Camp Steel Works, Emory University, Georgia Experiment Station, Public Health Service in Savannah, Medical College of Georgia, and the University of Georgia School of Medicine (*4*). The isotopes shipped to date have included 6 curies of Co^{60} (metal), 23 units of Na^{24} of approximately 15 millicuries (mc.) per unit, 2 curies of I^{131}, 100 mc. of P^{32}, and 5 microcuries (μc.) of Cl^{36} (*4*). Of a total of 1,299.5 curies shipped from the Oak Ridge National Laboratory to non-AEC users from August 1946 through December 1950, a little over 8 curies have been shipped into Georgia.

Hazards

The potential hazards resulting from the use and discharge of these radioisotopes under conditions which exist in Georgia are considered here.

However, the principles and techniques described may be used for evaluating the hazards in any given geographic area, and are not restricted to conditions in Georgia.

External

Cobalt-60 (metal) will not be discharged as a waste. However, unless suitable precautions are taken to protect personnel from its ionizing radiations, it may be hazardous. The technique used in evaluating and reducing the external radiation hazard is illustrated by the following example.

One decay scheme that has been given for Co^{60} (*5*) shows that one beta particle and two gamma quanta are given off in cascade per disintegration. Neglecting the beta radiation, a curie of this isotope will emit quanta of each energy which are equivalent to 1 curie. Substituting in the approximate expression

$$R_f = 6\,C\,E$$

where

R_f=dosage rate in roentgens per hour (r./hr.) at 1 foot

C=number of curies of radioisotope emitting the gamma radiation (assuming 3.7×10^{10} disintegrations per second to be 1 curie)

E=gamma energy in million electron volts (Mev) per disintegration. Co^{60} has gamma energies for 1.1 and 1.3 Mev in cascade.

Then for a 6-curie source

$$R_f = 6\times6\times(1.1+1.3) = 86.4 \text{ roentgens/hour (r./hr.) at 1 foot.}$$

If we assume a dose rate of 0.04 r./week for a 40-hour week, then

$$\frac{0.04}{40} = 0.001 \text{ r./hr. or 1 milliroentgen per hour (mr./hr).}$$

The 6-curie source of Co^{60}, therefore, gives

$$\frac{86.4 \text{ r./hr.}}{0.001 \text{ r./hr.}} = 86{,}400$$

times the permissible dose rate at the 1-foot distance. The thickness of lead shield required to reduce the dose rate to 0.001 r./hr. may be found by means of the expression

$$I = I_0\, e^{-\mu t} \text{ or } \log\frac{I_0}{I} = 0.434\,\mu t$$

where

I_0=initial intensity

I=final intensity

μ=linear absorption coefficient taken as 0.65 cm.$^{-1}$ for lead and for 1.3 Mev gamma energy

t=thickness of absorber in cm.

The thickness of lead required for shielding will be 17.5 cm. or 6.9 inches.

To determine the dose rate at any distance other than 1 foot the inverse square law is applied. For example, if the external radiation at 1 foot is 86.4 r./hr., at 2 feet it will be $\frac{86.4}{(2)^2}$

Table 2. Characteristics of radioisotopes shipped into Georgia

Radioisotope	Suggested MPC value μc/cc.[1]		Radio-active half-life [2]	λ Decay constant [3] sec.$^{-1}$	Mg./curie [4]	MPC Mg./liter [5]
	In air	In water				
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I^{131}	3×10^{-9}	3×10^{-5}	8.0 d	$1\ \ \times10^{-6}$	0.81×10^{-2}	2.43×10^{-10}
P^{32}	1×10^{-7}	2×10^{-4}	14.3 d	5.59×10^{-7}	3.52×10^{-3}	7.04×10^{-10}
Na^{24}	2×10^{-6}	8×10^{-3}	14.9 h	1.29×10^{-5}	1.14×10^{-4}	$9.1\ \times10^{-10}$
Cl^{36}	4×10^{-7}	2×10^{-3}	4.4×10^{5}y	4.99×10^{-14}	4.42×10^{-4}	8.84×10^{-2}
Co^{60}	1×10^{-6}	2×10^{-2}	5.2 y	4.23×10^{-9}	0.87	1.74×10^{-5}

[1] Morgan data.

[2] From National Bureau of Standards Circular NBS–499.

[3] $\lambda\ \text{seconds}^{-1}=\dfrac{0.693}{\text{half-life in seconds}}$

[4] 3.7×10^{10} disintegrations per second $=\dfrac{0.693}{\text{T (half-life in days)}}\times\dfrac{\text{W (gm./curie)}}{\text{A (atomic weight)}}\times6.02\times10^{23}$ (Avagadro's number).
Therefore, W (gm./curie) $=7.67\times10^{-9}\ AT_D$ or W (mg./curie) $=7.67\times10^{-6}\ AT_D$.

[5] $\dfrac{\mu c}{\text{cc.}}\times10^{-6}\times10^{3}\dfrac{\text{cc.}}{\text{liter}}\times\dfrac{\text{mg.}}{\text{curie}}$; MPC value for water $\times\dfrac{\text{mg.}}{\text{curie}}$ value $=10^{-3}\times3\times10^{-5}\times0.81\times10^{-2}=2.43\times10^{-10}$.

or 21.6 r./hr., at 3 feet it will be $\frac{86.4}{(3)^2}$ or 9.6 r./hr., etc.

These calculations may be applied only when a point source of gamma activity is under consideration.

Internal

The remaining substances, I^{131}, P^{32}, Na^{24}, and Cl^{36}, could conceivably be discharged into the sewerage system after use as therapeutic agents or in research. These substances have MPC values in water or air as indicated in table 2. These values indicate that with the exception of Cl^{36} and Co^{60} the amounts dealt with are exceedingly small—quantities of the order of 10^{-10} parts per million (ppm). Concentrations in terms of ppm and ppb (parts per billion) are well known to public health personnel, but these for radioactive substances may be 10 million times lower. The amount of radioactive material which represents 1 curie of each of these substances is also indicated in table 2.

Some sample calculations follow which indicate the methods that may be used for estimating the degree of hazard resulting from the use and disposal of radioisotopes. The examples will be confined to radioisotopes that have been shipped into Georgia. In the initial calculation the following assumptions were made:

1. The activity is assumed constant—no decay. Actually, the radioactive decay of the isotope is not negligible, as will be shown later for I^{131}.
2. The radioisotope is discharged completely—no loss through usage. Again this effect may not be negligible and will be illustrated in the case of I^{131}.
3. Each radioisotope acts independently.
4. All radioisotopes, with the exception of the Co^{60} (metal), are received and discharged in 1 week.

If the number of millicuries of each radioisotope is divided by the tentative MPC value for that radioisotope in water or air, a value in terms of volume is obtained:

$$\text{Millicuries}\times\frac{\text{cubic centimeters}}{\text{millicuries}}=\text{cubic centimeters.}$$

This volume is equivalent to the dilution required to make the given amount of radioisotope innocuous (innocuous in the sense that no detectable injury, based on our present knowledge, will result from continuous exposure to the radioisotope).

Table 3. Dilution required to reduce amount of radioisotope shipped to tolerance

Radioisotope	Amount shipped	Dilution required		
		Cubic centimeters	Metric tons	Million gallons
I^{131}	2 curies	$\frac{2\times10^6\ \mu c}{3\times10^{-5}\ \mu c/cc}=0.67\times10^{11}$	0.67×10^5	17. 7
P^{32}	100 mc	$\frac{100\times10^3}{8\times10^{-4}}=0.50\times10^9$	0.50×10^9	0. 13
Na^{24}	23 units at 15 mc./unit	$\frac{23\,(15)\times10^3}{2\times10^{-3}}=0.44\times10^8$	0.44×10^3	0. 01
Cl^{36}	5 μc	$\frac{5}{2\times10^{-3}}=0.25\times10^4$	0.25×10^{-2}	
Total				17. 84

The volumes of water required to dilute the wastes to the MPC values given in table 2 are determined as indicated in table 3. These calculations show that approximately 17.84 million gallons of water would be required to dilute to the MPC value all of the radioisotopes except Co^{60} (metal) shipped into Georgia. This volume of water is slightly greater than the volume of water—about 14 million gallons per day (mgd)—supplied daily to the inhabitants of Savannah (*6*). With uniform discharge throughout the week, approximately 2.55 mgd would be required for dilution, or a stream having a discharge of approximately 4 cubic feet per second would suffice when radioactive decay is not considered.

The example cited above shows that it is possible to reduce the activity to the MPC value by diluting with water. Another method of dilution proposed is that of isotopic dilution. In isotopic dilution a carrier having chemical characteristics identical to those of the radioactive substance itself is added. The method is based upon the principle that the body (or any living form) does not distinguish between isotopes of the same element. Hence, since it can accept only certain concentrations of a specific nontoxic substance, excesses will be excreted or discharged, and the radioactive form of an element may be diluted with its stable isotope to such a concentration that when taken into the body the amount of the radioactive form retained will be below the maximum permissible concentration. This is one possible means of reducing concentration by lower forms of plant or animal life. Isotopic dilution generally is not required and in most instances is not practical.

Discharge of I^{131} From Hospitals

The effect of decay will now be taken into account. For purposes of illustration, assume that a hospital in Savannah receives 100 mc. of I^{131} for hyperthyroid and cancer therapy, and that a portion of this material will be discharged along with the wastes from the hospital. According to Butrico (*7*) large quantities of iodine are excreted from the kidneys after administration, and close to 100 percent of a large dose may be found in the urine over a period of several days. He reports that other investigators found that over a 5-day period normal individuals had urinary excretions of 80 percent of the administered dose. It may be stated that with most patients approximately 50 or 60 percent of the administered dose is excreted in the first 24 to 48 hours. These urine wastes constitute the bulk of the radioactive wastes resulting from the use of I^{131}.

If we assume that 100 mc. of I^{131} are given to a patient at time zero and that 55 mc. of I^{131} are discharged in the urine during the first day, a curve indicated by the heavy solid line in figure 1 is obtained. This shows that during the first day 8.5 percent of the I^{131} was lost through decay, and that with a discharge of 55 mc. in the urine the patient retained 36.5

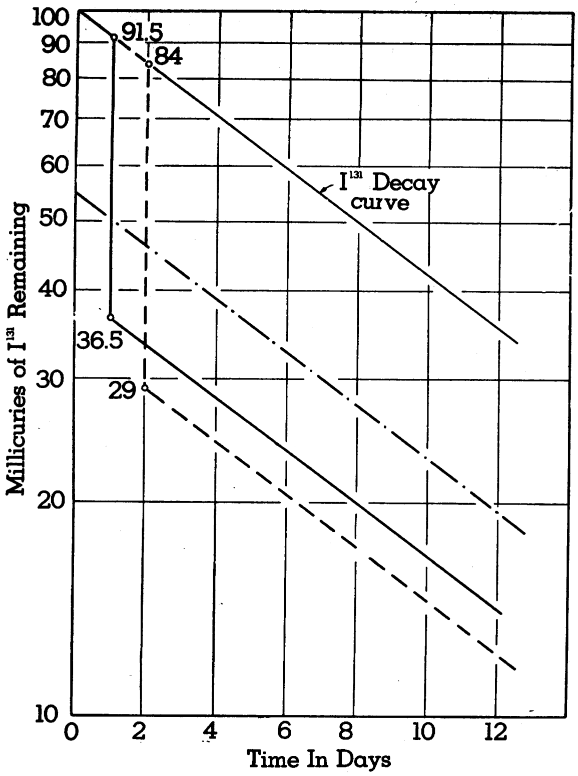

Figure 1. Disposal of I^{131} from a hospital.

mc. of I^{131}. If we assume that 55 mc. of activity are discharged in 48 hours (simplified here to show all discharge—heavy dash line—on the second day) the patient retained 29 mc. of the I^{131}, since 16 percent of the activity is lost through decay. The amount of activity retained by the patient will decrease by decay as shown by the curves. Decay will reduce the 55 mc. of iodine discharged as shown by the dot-and-dash line, so that after 1 day about 50 mc. will remain, after 2 days about 46 mc., and after 8 days, 27.5 mc. The amount of water required to reduce the 55 mc. of I^{131} to the tolerance concentration of 3×10^{-5} μc/cc. will be approximately 0.5 million gallons (mg.). If the 55 mc. of I^{131} are discharged from a 1,000-bed hospital there would be available for dilution only about 200,000 to 400,000 gallons per day of sewage. Therefore, the sewage would contain 1.25 to 2.5 times the maximum permissible concentration of I^{131}, if discharged uniformly throughout the day. This activity would be diluted further by the flow in the sewer. With I^{131}, because of its short half-life, 8 days, there is little likelihood of any radiation hazard.

Disposal of I^{131} by Sewage Treatment

Let us trace the sewage containing I^{131} through the sewer to its ultimate point of discharge—directly to a receiving stream or after passage through a sewage treatment plant. The raw sewage solids will take up some of the radioactive iodine, perhaps up to 20 percent (*8*). Bacterial slime on the sewer wall may also account for the removal of additional amounts of radioiodine. If no sewage treatment plant is available, the wastes containing the 55 mc. of activity noted above (reduced by an amount for decay) will be discharged into the stream as shown by line *A–F–G* in figure 2. The effect of various sewage treatment processes is illustrated in somewhat simplified form. Note the change in horizontal scale after 0 to 1 days.

If primary treatment alone is provided, the activity will be reduced by decay and sedimentation only, as shown by *O–A–B*.

O–A.	Travel time in the sewerage system before entering the sewage treatment plant. The loss here is due to decay only.
A–B.	Removal of radioactive material taken up by suspended solids removed by the primary settling basin. The position of point *B* is found as follows: 20 percent of the I^{131} is taken up by the suspended solids and 60-percent removal of suspended solids is attributed to sedimentation.
B–On	The effect of decay beyond *B* is shown by *B–C* and the dotted line.

If the plant includes primary sedimentation and trickling filters, the activity will be reduced as follows:

O–A.	Travel time in the sewerage system before entering the sewage treatment plant. The loss is due to decay only.
A–B.	Removal of radioactive material by the primary settling basin. See *A–B* above.
B–D.	Removal by trickling filter operating at rate of 2 million gallons per acre per day. Studies by Carter (*9*) indicated 85-percent removal by filter and secondary sedimentation.
D–On.	Loss in effluent due to natural decay. In 20 days' time the activity will have been reduced to about 2.4 percent.

If the plant is of the activated sludge type with primary sedimentation, aeration, and secondary sedimentation, removals as indicated by the dash line in figure 2 may be obtained.

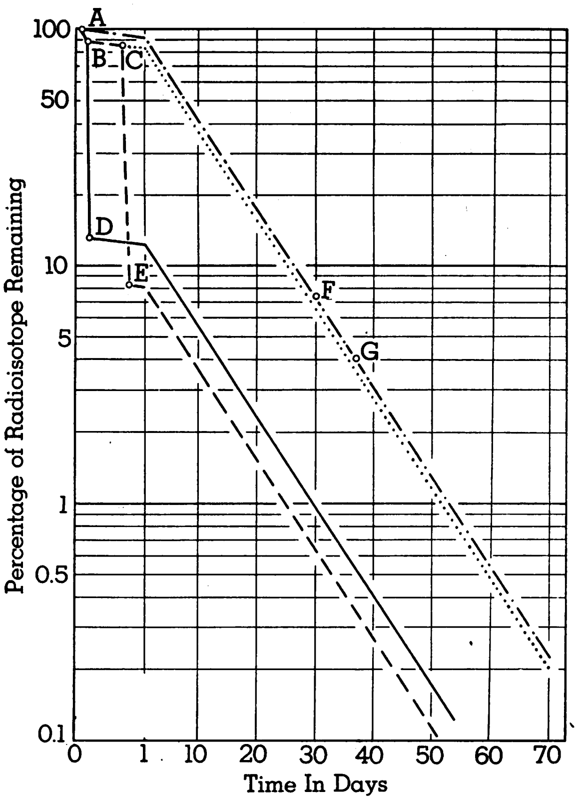

Figure 2. **Removal of I^{131} by sewage treatment processes.**

O–A. Loss due to decay.
A–B. Removal by primary sedimentation.
B–C. Loss due to decay during 12-hour aeration period.
C–E. Loss due to removal of suspended solids in secondary clarifier, assuming 95-percent removal of initial activity (8).
E–On. Loss by decay.
Note change of horizontal scale after 0 to 1 day.

The sludge which accumulates from primary and secondary sedimentation may be digested and the activity contained therein will reduce according to the dot-and-dash line. Point *F* indicates the percent reduction in activity following 30 days' digestion and point *G* represents additional decay due to 7 days' drying on sand beds. If the sludge is stored, activity will decrease as indicated beyond point *G*.

Other treatment processes have been suggested for different radioisotopes. The methods that have been investigated include evaporation, co-precipitation, ion exchange, biological processes, metallic displacement, sand filtration, and crystallization. Until the use of radioisotopes becomes much more widespread, or reactors are built for power or other purposes, the radioactive waste disposal problem probably will be a minor one in most States.

Removal of I^{131} and P^{32} by Water Treatment Processes

Let us now consider what takes place when a stream which contains I^{131} or P^{32} is used as a source of water supply (fig. 3). In this case assume that 2 weeks' storage is provided in a reservoir before treatment and the plant includes orthodox coagulation, settling, and filtration. Consider first a source containing I^{131}.

Two weeks' storage will reduce the activity to that represented by point *B*. If alum coagulation is used along with sedimentation and filtration no appreciable removal of I^{131} (less than 0.4 percent) will be obtained (*10*). However, the addition of small amounts of carbon, copper, or silver may increase removals to 75 percent. This removal is indicated by point *C*. Chlorination and storage have no effect on removal, although there will be some reduction due to decay as shown by the heavy solid line beyond *C*.

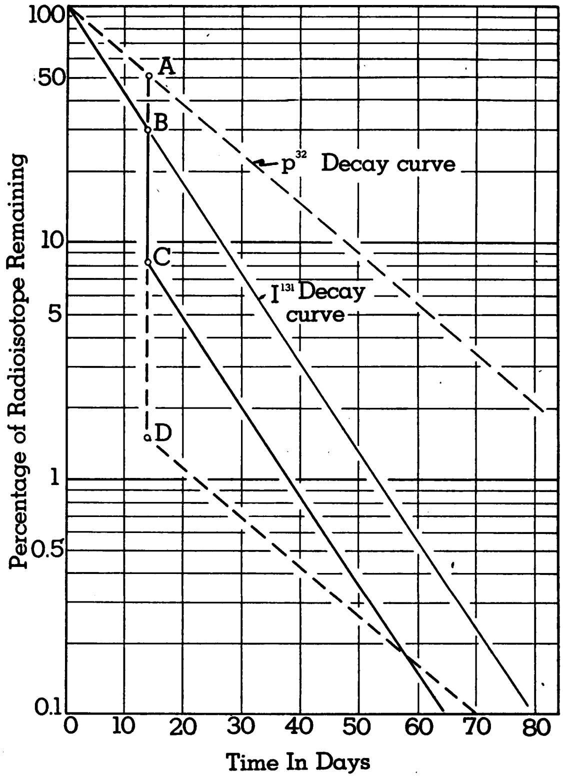

Figure 3. **Removal of I^{131} and P^{32} by water treatment processes.**

If the surface source of supply contains P^{32}, which has a half-life of 14.3 days, 2 weeks' storage will reduce the activity to the value indicated for point *A*. Alum coagulation, settling, and filtration will account for a removal of 96 to 98 percent (*10*), which reduces the activity to the value shown at *D*. Beyond this point decay will account for additional reductions as indicated by the dash line.

Mixtures of radioisotopes may or may not be removed, depending upon the radioisotopes comprising the mixture. Mixed fission products activity, for example, may be reduced by approximately 50 percent by coagulation and settling, and filtration may increase removals to 70 percent (*8*).

At this time a point should be discussed which is obvious to many but may be somewhat confusing to some and that has to do with percent removal. The percent removal has little significance unless one knows the original concentration of radioactive material. If, for example, a waste contained an I^{131} concentration of 1 mc./cc., it would be necessary to obtain a removal of 99.999997 percent to reduce the original I^{131} present to the MPC. If our processes will effect a 95-percent reduction, the highest initial concentration of I^{131} that would be permissible in order to meet these requirements after treatment would be 6×10^{-4} μc/cc. Any concentration greater than this would result in an effluent containing concentrations in excess of the MPC values.

Explosion of a nuclear bomb will result in the release of considerable amounts of radioactivity. The effect of this on the water supply will depend upon the nature of the blast and atmospheric conditions at the time of the blast. Georgia is perhaps a little more fortunate than many States with respect to contamination of surface water supplies following a nuclear explosion, since about 30 percent of the population served by public water supplies use ground water sources of supply. Approximately 66 percent of the public water supplies are from deep wells (*6*) . There is little likelihood that these would become contaminated during an emergency, and they should serve as a source of supply if the distribution systems are not destroyed or damaged.

Concluding Statement

With the emphasis that is being placed on civil defense activities at present, much has been said about the need for providing facilities for measuring radioactivity. This equipment is rather expensive and may even be in relatively short supply. It is my personal belief that much can be accomplished now through the cooperative use of existing facilities in hospitals and research centers to familiarize public health personnel with the techniques of counting, sample preparation, and measurement of radioactive materials. Such cooperative effort will permit water and sewage treatment plant operators to determine for themselves the amounts of radioactive materials that are being discharged into sewerage systems and water courses and to evaluate the possible potential hazard from this discharge.

ACKNOWLEDGMENT

The author acknowledges the assistance of Dr. K. Z. Morgan, for granting permission to use the data in table 1; of the Operations Division of the Oak Ridge National Laboratory, for data on radioisotope shipments; and of Dr. Elda E. Anderson and Dr. Forrest Western, for review of the material and for their suggestions. The work described in this report was performed at the Oak Ridge National Laboratory for the Atomic Energy Commission under contract No. W-7405-Eng-26.

REFERENCES

(*1*) Hollis, Mark D.: Environmental health. A critique. Pub. Health Rep. 66: 13, 400–409 (1951).

(*2*) Morgan, K. Z., chairman, Subcommittee on Internal Dose of the National Committee on Radiation Protection: Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water, September 21, 1951.

(*3*) Straub, Conrad P.: Disposal of radioisotopes—A method of evaluating potential hazard. Unpublished information. Oak Ridge National Laboratory, Oak Ridge, Tenn., 1951.

(*4*) Oak Ridge National Laboratory, Oak Ridge, Tenn., Operations Division: Unpublished communication.

(*5*) Morgan, G. S.: Some practical considerations in radiation shielding. Circular B-4 Oak Ridge, Tenn., U. S. Atomic Energy Commission, Isotopes Division, 1948.

(*6*) U. S. Public Health Service: Inventory of water and sewage facilities in the United States, 1945. Cincinnati, Ohio, 1948.

(7) Butrico, Frank A.: Disposal of radioactive wastes from Massachusetts General Hospital. (NP-1623. Massachusetts Institute of Technology). Oak Ridge, Tenn., U. S. Atomic Energy Commission, Technical Information Division, ORE.
(8) Straub, Conrad P.: Treatment and disposal of liquid radioactive wastes. *In* Industrial wastes treatment. Reinhold Corp., N. Y., 1952.
(9) Carter, Melvin W.: Study on the removal of radioactive iodine (I^{131}) by laboratory sewage trickling filters. Master's thesis. Atlanta, Ga., Georgia Institute of Technology, 1951.
(10) Straub, Conrad P.: Observations on the removal of radioactive materials from waste solutions. Sewage & Indust. Wastes 23: 188–193 (1951).

Excess Mortality From Influenza and Pneumonia

Excess mortality from influenza and pneumonia is used as the best available measure of epidemic periods and of the size and importance of an epidemic. The chart shows the excess mortality per 100,000 population during the whole of each epidemic in groups of cities in the United States, 1918 to 1951.

The decrease in excess mortality may be related to one or more of several things: (1) The mortality of diseases designated as influenza may be decreasing by reason of change in what is now diagnosed as influenza, because of recently acquired knowledge of the etiology and the early clinical manifestations of the disease; (2) influenza fatality may be decreasing by reason of (*a*) greater natural immunity acquired by more individual contact with the disease because of greater movement of the population; (*b*) milder strains of the virus becoming widespread; or (*c*) more successful treatment of influenza and its most frequent complication, pneumonia, by the use of the newer chemotherapies.

Aside from epidemic peaks, the death rate from influenza and pneumonia in the United States decreased from roughly 200 per 100,000 in 1900 to 100 in 1937, when the trend turned sharply down, to about 35 in 1950. (See "Trends and Epidemics of Influenza and Pneumonia, 1918–51," by Selwyn D. Collins and Josephine Lehmann, *Public Health Reports*, Vol. 66, No. 46, November 16, 1951.)