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DECONTAMINATION OF WATER CONTAINING RADIOLOGICAL
WARFARE AGENTS

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Army Mobility Equipment Research and Development
Center
Fort Belvoir, Virginia

March 1975

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DECONTAMINATION OF WATER CONTAINING
RADIOLOGICAL WARFARE AGENTS

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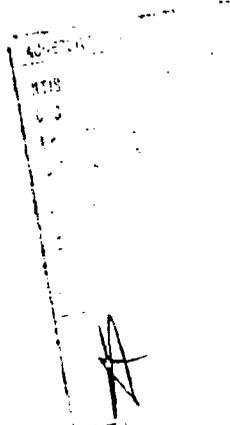


U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

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from water when present as suspended turbidity. The ERDLator Unit will not remove radioactive contaminants present as soluble radioisotopes. The standard Army Ion Exchange Unit, used as a post treatment device after the ERDLator Unit, removes soluble activity. The standard Army vapor compression distillation unit is effective in decontaminating water containing radioactive material. The reverse osmosis water purification process holds promise of a high level of decontamination of radioactivity present in the water in both the soluble and insoluble states.

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SUMMARY

In the event of future war, it is possible that nuclear weapons would be used. It is imperative, therefore, that the United States Army establish defensive measures of all types against nuclear attack. The assigned responsibilities of the Sanitary Sciences Division, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia in the field of water and sanitation require that special consideration be given to the problems associated with the contamination of water supplies. Decontamination measures must be established since it is essential that potable and uncontaminated water be furnished in the field for drinking, washing, culinary, bathing, laundering, and dehydrated food reconstitution purposes. Since 1949, research in this area has been directed toward the evaluation of standard and experimental processes and equipment that could be used for decontamination purposes. This report is a summary of the information obtained.

The report concludes that:

- a. The use of nuclear weapons poses a severe threat to water supplies as a result of contamination with fission products, unfissioned plutonium or uranium, or neutron-activated radioisotopes.
- b. Fallout from a nuclear weapon varies widely in its water solubility, depending primarily upon the nature of the soil in the vicinity of ground zero.
- c. For evaluation of water decontamination processes, a provisional maximum permissible concentration (MPC) of 300,000 picocuries per liter of beta-gamma activity served as an adequate guide.
- d. A semiquantitative check of the level of activity in raw or finished water can be made with a standard PDR-27J beta-gamma radiation meter. The probe is protected with a rubber sheath, inserted into the water, and a conversion made from the meter reading in milliroentgens/hour to picocuries per liter.
- e. The standard Army ERDLator Water Purification Unit is effective for removing radioactive substances from water when present as suspended insoluble turbidity. The ERDLator will not remove radioactive contaminants present as soluble radioisotopes.
- f. The efficiency of the standard ERDLator Water Purification Unit in removing soluble radioisotopes can be improved substantially by pretreating the contaminated water with clay or some other radioisotope adsorbent.

g. The standard Army Vapor Compression Distillation Unit is effective in decontaminating water containing radioactive material.

h. A field expedient method consisting of the following steps is effective in removing chemical, biological, radiological (CBR) contaminants from water: super-hypochlorination and activated carbon adsorption in series in a Lister bag, coagulation, filtration, mixed-bed ion exchange demineralization, and post chlorination.

i. The standard Army Ion Exchange Unit, when used as a post treatment device after the standard ERDLator Unit, is effective for removing soluble radioactive substances from water.

j. The reverse osmosis water purification process is promising for decontaminating water containing radioactivity in both the soluble and insoluble state.

k. Ground water may reasonably be assumed to be free of radioactive substances and should be used whenever the tactical situation permits.

l. Radioactive waste slurries developed as a result of using Army field water purification equipment should be disposed of properly by burial or other appropriate means.

PREFACE

The information in this report was developed by the Sanitary Sciences Division, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia. Basic laboratory and pilot plant studies were conducted at the Oak Ridge National Laboratory. Field testing, under Operations Buster, Jangle, Plumbbob, Hardtack II, and Sunbeam, was accomplished at the Nevada Test Site under the auspices of the Defense Atomic Support Agency (DASA) and the Atomic Energy Commission (AEC). A plutonium water decontamination study conducted at the Los Alamos Scientific Laboratory was accomplished with the cooperation of the University of California. A simulated nuclear study (Operation Snowball) was conducted at the Suffield Experiment Station, Canada, with the Cooperation of the Canadian Department of Defense.

The authority for this work is the task now known as Water and Wastewater Management, IG 762708AH67WA. The period covered is from November 1949 to November 1975.

The preparation of this report was accomplished under the supervision of Maurice Pressman, Group Leader, Sanitary Sciences Division; Richard P. Schmitt, Chief, Sanitary Sciences Division; and Harry L. Ammlung, Chief, Laboratory 2000.

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DECONTAMINATION OF WATER CONTAINING

RADIOLOGICAL WARFARE AGENTS

I. INTRODUCTION

1. **Subject.** This report summarizes research and development studies conducted by the U.S. Army since 1949 on the decontamination of water containing radiological substances. Basic laboratory and pilot plant studies were conducted at the Oak Ridge National Laboratory. Field testing, under Operations Buster, Jangle, Plumbbob, Hardtack II, and Sunbeam, was accomplished at the Nevada Test Site under the auspices of DASA and AEC. The plutonium decontamination study was conducted at the Los Alamos Scientific Laboratory with the cooperation of the University of California. The simulated nuclear study, Operation Snowball, was conducted at the Suffield Experimental Station, Canada, with the cooperation of the Canadian Department of Defense.

2. **History of Nuclear Weapons.** Nuclear history in relation to the Military is traced as follows:

Significant Nuclear Events (Militarily-Oriented)

| Date | Event |
|-----------|---|
| 2 Dec 42 | — First demonstration of sustained nuclear fission, Stagg Stadium, University of Chicago. |
| 16 Jul 45 | — Alamagordo, New Mexico TRINITY shot, 19 kt. |
| 5 Aug 45 | — "Little Boy" atom bomb, Hiroshima, Japan. |
| 9 Aug 45 | — "Fat Man" atom bomb, Nagasaki, Japan. |
| 29 Aug 49 | — "Joe I," first Russian atom bomb detonated. |
| 3 Oct 52 | — Britain detonates first atom bomb in Monte Pello Islands, off coast of Northwest Australia. |
| 31 Oct 52 | — U.S. detonates first thermonuclear shot, Eniwetok, 10.4 mt. |
| 13 Feb 60 | — France detonates first atomic bomb south of Reggan in the Sahara Desert. |
| 30 Oct 61 | — Largest announced nuclear shot of all time, USSR, Novaya Zemlya, 58 mt. |
| 16 Oct 64 | — Peoples Republic of China detonates first atomic bomb in the Taklamakan Desert in province of Sinkiang. |

17 May 74 — India detonates first atomic bomb in the Rajasthan desert of western India.

It is noted that the five permanent members of the United Nations Security Council are the same five nations first to achieve a nuclear capability. Thus, a nuclear arsenal has become equated with world-power status. It is possible, even probable, that other nations will join the nuclear club.

3. The Radiological Warfare Threat. A bursting nuclear weapon, in addition to producing blast, heat and light, produces large quantities of radioactive materials. These materials are classified as: fission products, uranium or plutonium which has escaped fission, and substances activated by neutron bombardment. (Note: These could be components of the soil or air, dissolved minerals in water, or materials of construction of the bomb itself. So-called "rigged bombs" or "salted bombs" could conceivably be constructed with a casing, such as cobalt, which would become radioactive.)

In addition to the above, it should be noted that a so-called radiological bomb could be built, in which no nuclear detonation would take place. Dissemination of a radioisotope, or radioisotopes, would be achieved by spraying, high explosive dispersal, etc. It has been suggested that the tremendous stockpile of accumulated fission products occurring as a byproduct of the nuclear reactor industry could be used as material for a radiological bomb. In addition, specific radioisotopes could be produced by irradiation in a nuclear reactor. However, it is believed that this procedure would see little if any use, since it would result in a loss of reactor capacity or would introduce a major handling problem. Other materials considered as RW agents are zirconium-95-niobium-95, protactinium-233, and tantalum-182.

In the case of either a nuclear or a radiological bomb, water to be used for drinking purposes could become sufficiently contaminated to cause physiological damage to the human body. The damage would be due to ionization of the tissues by the bombardment of alpha, beta, or gamma rays. In reality, the human body is exposed at all times to *some* ionizing radiation, notably the cosmic rays and also the rays emitted from naturally occurring radioisotopes such as potassium-40 and carbon-14. Ordinarily, such naturally occurring radiation is not considered harmful. However, some harmful effects could be caused by the ingestion of radioisotopes through the medium of contaminated water. Little, if any, damage might result from radioisotopes with a combination of short half life and high excretion rate. Serious damage could result from radioisotopes with a combination of long half life and selective absorption into certain parts of the body such as the bones or glands.

Figure 1 is a photograph of a nominal atomic detonation at Yucca Flat, Nevada Test Site.

Figure 2 is a photograph of shot Priscilla, Operation Plumbbob. Shot Priscilla was fired at 0630 hours, 24 June 1957, from a 700-foot-high suspended balloon at the Frenchman Flat, Nevada Test Site. The yield was 37 kt.

Figure 3 is a nuclear shot from an artillery piece.

Figure 4 shows the fireball from a Pacific theatre thermonuclear detonation. The downtown skyline of a city has been inserted.

4. Characteristics of Radioactivity. The fission of uranium or plutonium results in the formation of numerous atomic fragments, representing isotopes of 37 different elements. One hour after detonation, approximately 550,000 megacuries, or 125 pounds, of radioactive material exist per megaton of original blast. Most of the radioisotopes decay by the emission of beta particles, frequently accompanied by one or more photons of gamma radiation. The half-lives of the radioisotopes vary from a fraction of a second to many years, and the products of decay are usually also radioactive. The decay products may have longer or shorter half-lives than their parents. Each of the fission products undergoes, on the average, three stages of beta decay, often accompanied by gamma radiation before it is converted into a stable species.

The most critical fission products involved for time intervals up to 1 month include radioisotopes of the following elements (in descending order of importance): tellurium, strontium, iodine, barium, niobium, xenon, cerium, rhodium, praseodymium, and yttrium. For longer periods of time, and for many years following, strontium-90 and cesium-137 are the most critical radioelements.

Individual pure radioisotopes decay according to the radioactive decay law, in which the rate of decay is proportional to the total number of atoms present. A convenient means of expressing the decay of a radioisotope is by means of its half-life. The half-life simply states the period of time required for one-half of the atoms present to disintegrate. Strontium-90 is selected as an example since it is probably the most important of the fission products, with great physiological significance. Strontium-90 is actually part of a chain of radioelements starting with krypton-90 and ending with stable zirconium, i.e.:

Krypton-90
(Primary fission product)

β^- emission
32-second
half-life

Rubidium-90

β^- emission
4.3-minute
half-life

| | |
|--------------|--|
| Strontium-90 | β emission 28.9-year half-life |
| Yttrium-90 | β emission 64-hour half-life |
| Zirconium-90 | Stable |

Selecting pure strontium-90 from the chain, Table 1 illustrates the half-life law in action. It is noted that 10 half-lives reduce the original radioactivity to less than 0.1 percent of the original amount.

Table 1. Decay of Strontium-90
(Half-life 28.9 years)

| Time (years) | Activity (curies) |
|--------------|-------------------|
| 0 | 100 (example) |
| 28.9 | 50 |
| 57.8 | 25 |
| 86.7 | 12.5 |
| 115.6 | 6.25 |
| 144.5 | 3.125 |
| 173.4 | 1.56 |
| 202.3 | 0.78 |
| 231.2 | 0.39 |
| 260.1 | 0.195 |
| 289.0 | 0.0977 |

If the activity of strontium-90 is plotted on the log axis of semi-log paper, and time is plotted on the rectilinear axis, a straight line results. (See Figure 5.)

The decay of pure strontium shown in Figure 5 is complicated by the fact that the immediate daughter formed, yttrium-90, is also a beta emitter, with a half-life of 64 hours. Therefore, if a sample of pure strontium-90 were available, the total count would actually increase to an eventual value twice that of the strontium-90 alone. This final state is called secular equilibrium. This phenomenon is illustrated in Figure 6.

Fission products, being a mixture, do not decay according to the radioactive decay law for a single pure radioisotope. However, when the total gross count of fission

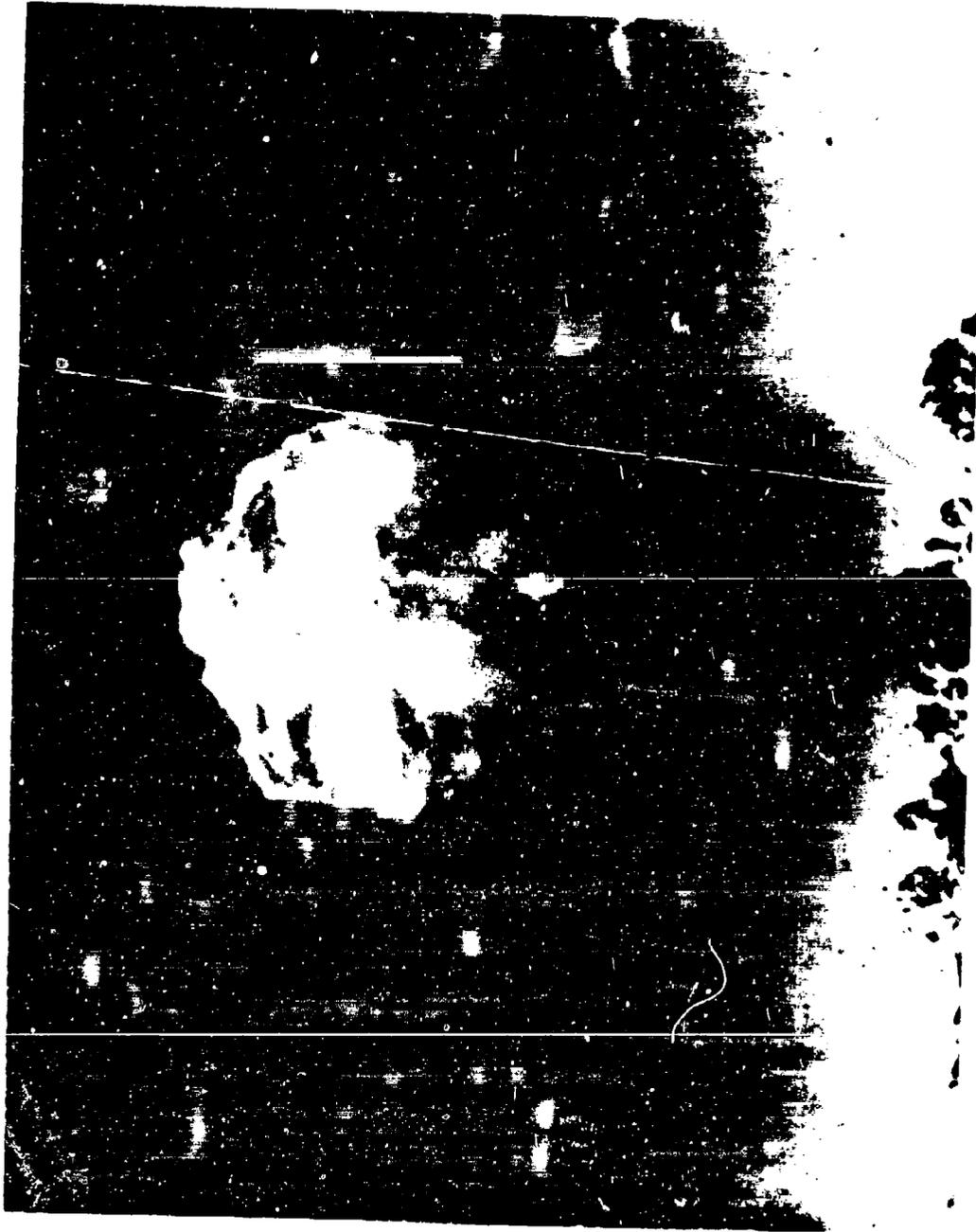


Figure 1. Nominal yield atomic detonation, Nevada Test Site.



Figure 2. Shot Priscilla, Frenchman Flat, Nevada Test Site.

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Figure 3. U.S. Army exercise: artillery-fired atomic bomb.

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Figure 4. Thermonuclear shot, Pacific Proving Ground.

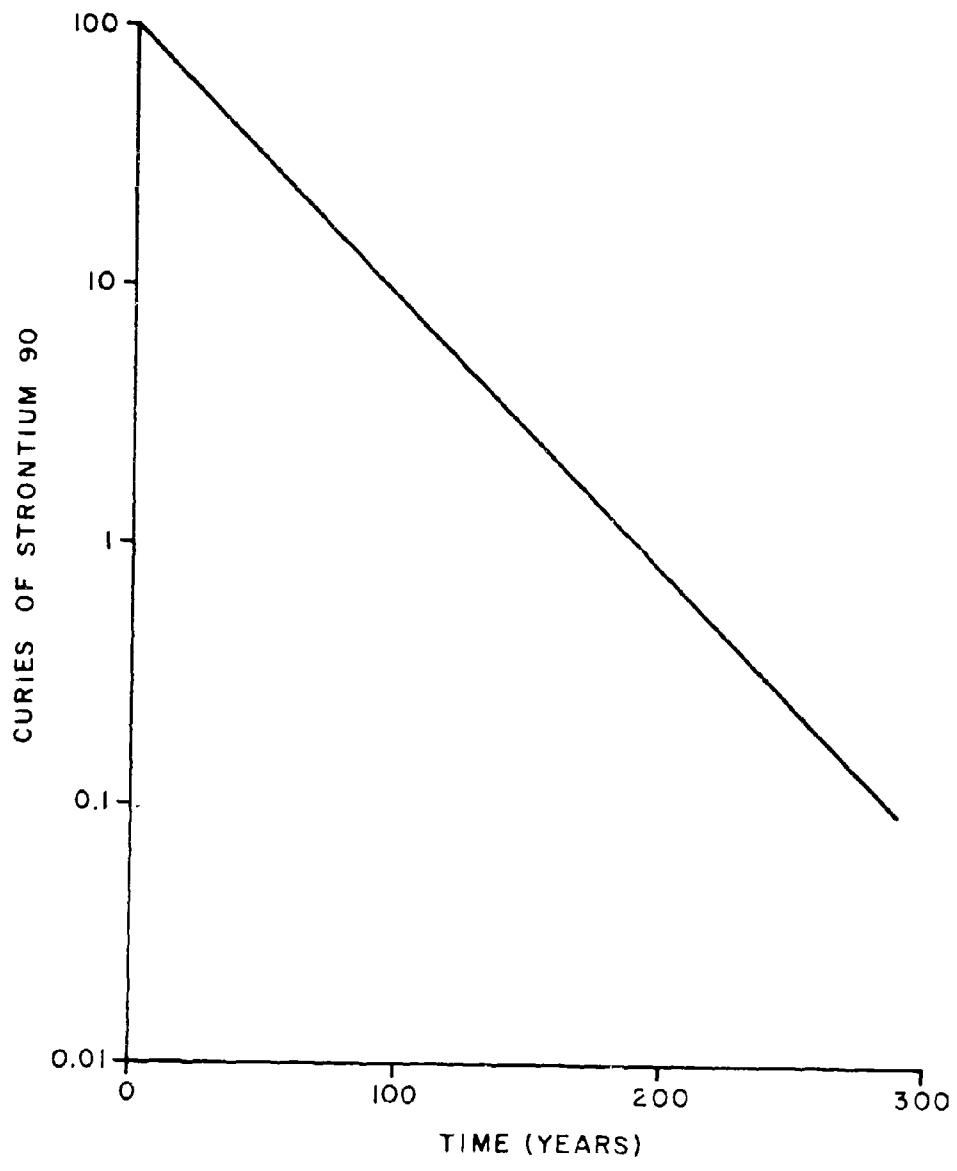


Figure 5. Decay of strontium-90.

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STARTING WITH PURE STRONTIUM 90 AT TIME ZERO
HALF-LIFE ^{90}Sr = 28.9 YEARS
HALF-LIFE ^{90}Y = 64.0 HOURS

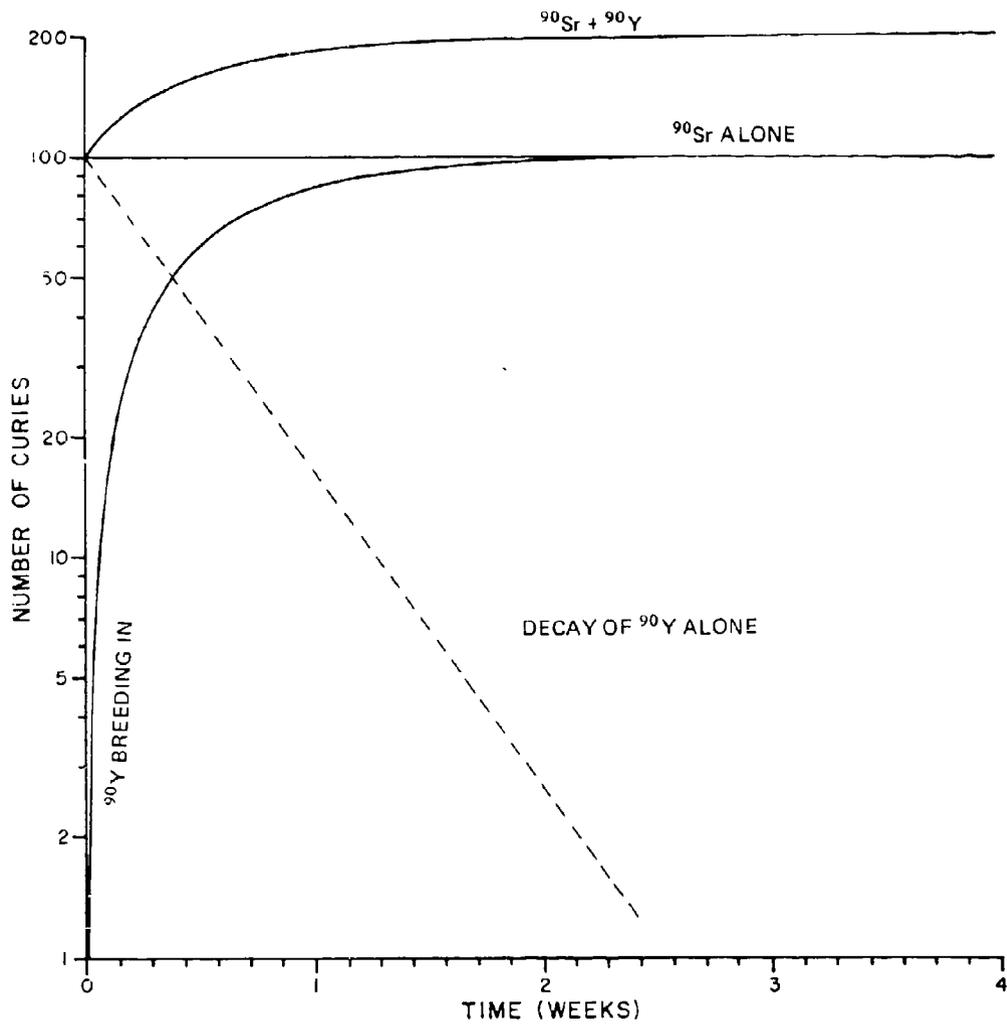


Figure 6. Count pattern.

products is plotted against time on log-log paper, a straight line is obtained with a slope of 1.2. (See Figure 7 for example.) A close approximation to the line is obtained by use of the 7:10 rule. This rule states that for every *seven-fold increase* in-time after detonation, there is a *ten-fold decrease* in radioactivity. This point is illustrated in Table 2. A complicating factor that could occur is "fractionation." "Fractionation" is a term applied to the separation of fission products, once formed, into enriched and lean portions as a result of selected condensation during the cooling of the fallout particles. For instance, certain fallout material could be richer or leaner in strontium-90 than other fallout material, depending upon the condensation behavior of the precursor radioisotope, rubidium-90. Fractionation or not, as time goes on, the shorter half-life portion of the fission product mixture dies out and all that is left is strontium-90 and cesium-137.

Table 2. 7:10 Decay Rule for Fission Products

| Time after Detonation | Curies |
|-----------------------|---------------|
| 1 Hour | 100 (example) |
| 7 Hours | 10 |
| 49 Hours (2 Days) | 1 |
| 14 Days (2 Weeks) | 0.1 |
| 14 Weeks (1 Quarter) | 0.01 |
| 7 Quarters (2 Years) | 0.001 |
| 14 Years | 0.0001 |

5. **Water Contamination.** A certain low-level "background" radioactive contamination already existed in the world's water supplies even before the advent of nuclear fission on 16 July 1945. This level was about as shown in Table 3.

Table 3. Naturally Occurring Radioactivity in Water

| Source | Picocuries/Liter |
|---------------------------|---------------------------------------|
| Routine Fresh Water | 0.1 to 1 |
| "Radioactive" Springs | 10 to 1000 |
| Radioactivity in Seawater | 330 (due principally to potassium-40) |

However, any significant tactical or strategic use of nuclear or thermonuclear weapons could be expected to result in additional contamination of surface water supplies. The amount of contamination would depend on numerous factors including: size and type of weapon, method of employment, weather conditions, and topography

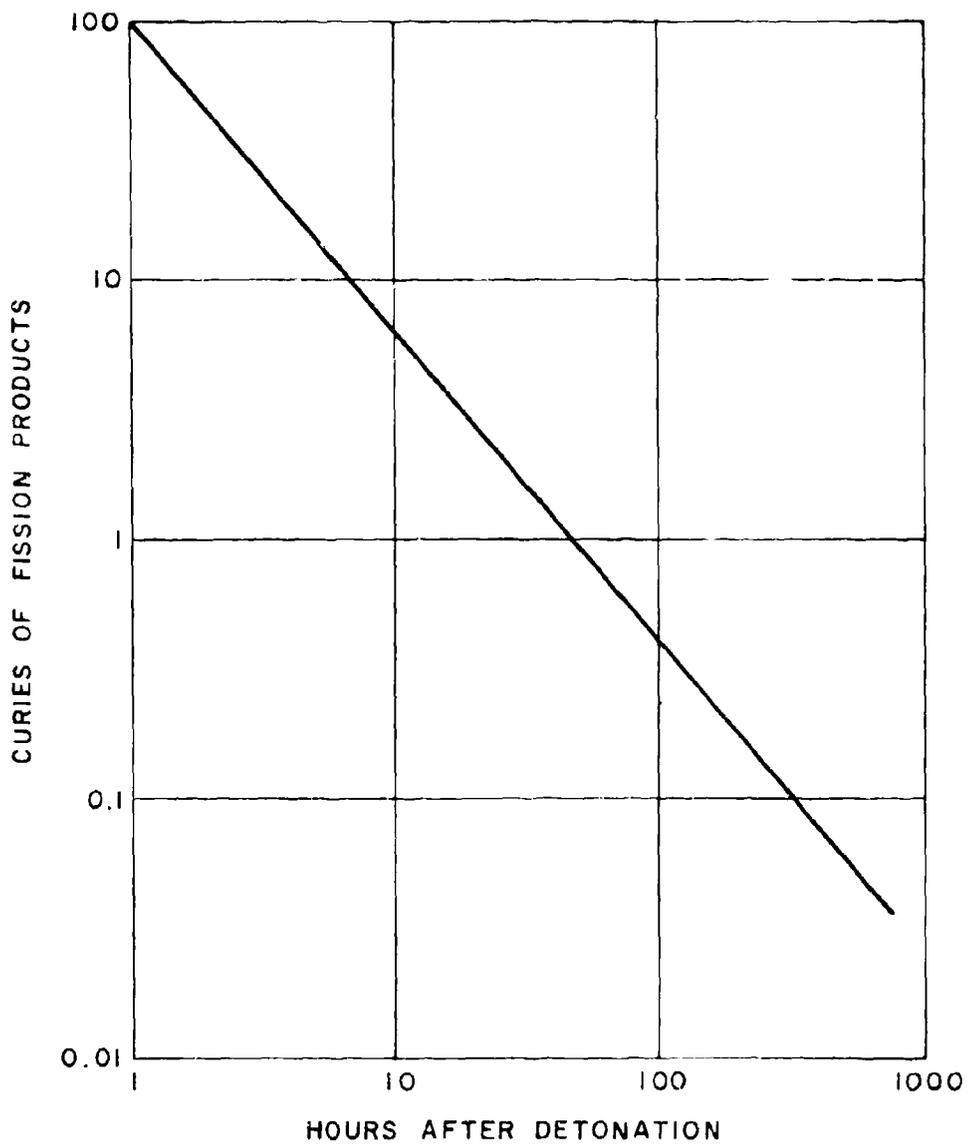


Figure 7. Decay of fission products from ^{235}U , ^{233}U , or ^{239}Pu .

and geology of the region. Even a low-yield weapon detonated on or immediately under the surface of the ground may result in heavy contamination in the immediate area of the target. On the other hand, when detonated at heights exceeding the fire-ball radius, atomic weapons in the kiloton range do not heavily contaminate the target area. So-called "dirty" weapons in the megaton range have the capability of heavily contaminating large areas.

An important consideration in the water contamination problem is the fate of fission products and other radioactive contaminants that have fallen to the earth.

Research indicates that 99 percent of alpha-emitting substances (i.e., uranium and plutonium) deposited on the ground will be retained, whereas 50 to 90 percent of beta-emitting substances will be removed in surface runoff.¹ Thus, retention of alpha activity in the ground is reasonably sure, while that of beta contamination is not. However, of the beta activity reaching the surface drainage system, a relatively small amount will be dissolved in the water, the larger fraction being present as suspended solids. Much of the suspended contaminant will be associated with clay and other materials having some ion exchange or adsorptive capacity. However, some of the contaminant may exist in colloidal form. The importance of the radioactivity in solution must be evaluated in terms of the amount present, its age (time since detonation), length of time it will be consumed, and acceptable limits of human tolerance. It appears reasonable to assume that water will not be used in or from an area that is so contaminated that the direct radiation level precludes the employment of personnel in the area.

Certainly an important factor in water contaminant considerations is the solubility of fallout in water. Some basic information on water solubility is shown in Table 4. It is interesting to note that, in many instances, the solution of the radioactive component of fallout and bomb debris takes place quickly. Apparently there is a surface coating of radioactivity on the particles which dissolves rapidly, essentially independent of pH, temperature, and time of contact. The radioactive material on the inside of the particle is much less soluble, or not soluble at all, due to encapsulation by inert fused earth.

In regard to induced activity, and illustrative of what might be expected, some data were obtained on 11 May 1951 under Operation Buster, Shot Easy (air drop, 31 kt, 1314 feet high). A sample of seawater contained in a tin can was placed 500 feet from ground zero. After the detonation, radioactivity of the water was found to be 4.3×10^5 picocuries per liter, an appreciable level of radioactivity. The level was due principally to sodium-24 induced from the large amount of sodium-23 in seawater.

¹ Thomas R. Ostrom, MAJ, MSC, *Provision of Potable Water During Employment of Nuclear Weapons*, Department of Preventive Medicine, Army Medical Service School, M709-1-1, January 1959.

Table 4. Solubility of Nuclear Bomb Debris in Water

| Sample Source | Shot | Particle Size (microns) | Solubility (%-Gross Beta Activity) | | Information Source (See Footnotes) |
|------------------------|--------------------------------|---|------------------------------------|--------------------------------------|---------------------------------------|
| | | | H ₂ O | 0.1 N HCl | |
| Nevada Test Site | Unspecified | 300-900 | 0.3-1.2 | 2-10 | 1 |
| Nevada Test Site | Tesla, 7KT | 3-151 | 0.1-7.6 | 1.5-30 | 1 |
| | Apple I, 14KT | 3-325 | 0.2-44 | 0.7-56 | 1 |
| | MET, 22 KT | 3-214 | 0.2-3 | 4.4-19 | 1 |
| | Apple II, 29 KT | 3-670 | 0.5-4.2 | 2.4-28 | 1 |
| Nevada Test Site | Underground | 0-44 | 5.4 | 25 | 2 |
| | Tower-Mounted | 0-44 | 2 | 14-36 | 2 |
| | Balloon | 0-44 | 14 | 60 | 2 |
| Nevada Test Site | Tower-Mounted | No data | No data | 56-89 (⁹⁰ Sr in 1 N HCl) | 3 |
| | Balloon and Air | No data | No data | 41-99 (⁹⁰ Sr in 1 N HCl) | 3 |
| Pacific Proving Ground | Coral Island | No data | No data | 100 (⁹⁰ Sr in 1 N HCl) | 3 |
| Nevada Test Site | Priscilla | No data | 1.63 | No data | USAMERDC |
| Nevada Test Site | Underground (1 year old) | Glassy globs ground to 3μ | 0.5 | No data | USMAERDC |
| | | Above material fused with NaOH neutralized with HCl | 2.8 | No data | USAMERDC |
| Nevada Test Site | Small Yield Nuclear Weapons | No data | 2.6-14 | No data | USAMERDC |

1. Hidro Nishita and K. H. Larson, *Summary of Certain Trends in Soil-Plant Relationship Studies of the Biological Availability of Fallout Debris* UCLA - 401 (1957).

2. K. H. Larson and J. W. Neel et al, *Summary of Findings to the Distribution, Characteristics, and Biological Availability of Fallout Debris Originating from Testing Programs at the Nevada Test Site*, UCLA - 438, (1960).

3. E. A. Bryant, G. A. Cowan, W. R. Heald, R. G. Menzel, R. F. Reitemeyer, J. E. Sattizahn, and B. Warren, *Biological Availability of Strontium-90 from Atomic Tests*, SCIENCE, 5 August 1960.

As a sidelight, it is interesting to note that a standard 3000-gallon Army field water storage tank constructed of GRS-coated nylon fabric was filled with water and exposed to the blast from Shot Easy. Surprisingly, the tank was still standing after the blast. The side of the tank facing ground zero was blistered, and a few straws and twigs were actually driven through the sidewall. Nevertheless, the tank still held most of the original water.

Additional research on the possible contamination of water with radioactive fallout and bomb debris was conducted under Project Snowball. Open tanks of water were exposed to a 500-ton TNT explosion² at varying distances from ground zero. The greatest water contamination occurred in a 1500-gallon tank at 23.0 psi, where the turbidity rose from 0.9 to 260 units. The tank also lost half of its water volume, leaving only about 750 gallons. The figure of 260 units was obtained by measuring a sample of the supernatant liquid taken from the tank, without stirring, at Z plus 25 minutes (the turbidity would have been much higher had the bottom residue been stirred before sampling). The rise in the level of turbidity to 260 units can be used to estimate the possible level of radioactive concentration if the detonation had been nuclear. In the actual case of fission products, it should be noted that they do not spread evenly but form a circular or cigar-shaped pattern around ground zero with the heaviest deposition close to ground zero and diminishing at farther distances out. The exact shape and size of the fallout pattern depends on many conditions, but usually the height of burst, with particular reference as to whether or not the fireball touches the ground, and the wind are the major controlling factors. Surface bursts give smaller but more highly radioactive patterns than air bursts.

Accurate, detailed fallout pattern information from the detonation of nuclear devices, particularly the detonation of large nuclear devices, is quite limited in its availability. The megaton range information originating at the Eniwetok Proving Grounds must be inferred from relatively few samples taken over the ocean. Furthermore, the presence of seawater in the fallout affects the results. Nuclear tests at the Nevada Test Site have been confined to yields of 100 kt and less, and the results have been influenced by such factors as the presence of towers. However, some idea of an actual fallout pattern can be obtained from the TURK shot³ at the Nevada Test Site. The TURK shot was detonated with a yield of 43 kt on 7 March 1955 from a 500-foot tower. The fallout pattern from this shot was very irregular, not at all typical of the idealized cigar-like patterns. At 12 hours after detonation, the dose rate in the direction of the heaviest fallout was as shown in Table 6.

² This was the largest deliberate, man-made, surface, nonnuclear shot of all time. It is interesting to compare this shot with other famous detonations, see Table 5.

³ U.S. Department of Defense and U.S. Atomic Energy Commission, *The Effects of Nuclear Weapons*, Revised Edition, reprinted February 1964, Samuel Glasstone, Editor; for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25 D.C., Price \$3.00 (paper bound).

Table 5. Significant High Explosive and Nuclear Detonations

| Location | Explosive Detonated | Weight Detonated (yield) | Calculated Distance from Ground Zero if Surface Burst; 10 psi Overpressure (feet) | Remarks |
|------------------------|----------------------|--------------------------|---|--|
| Climax, Colorado | HE | 208 tons | 750 | Mining. |
| Suffield, Canada | TNT | 500 tons | 984 (measured at 9.8 psi) | Operation SNOWBALL |
| Ripple Rock, Canada | Nitramex 2H (Dupont) | 1400 tons | 1,400 | Removal of navigational hazard. |
| Texas City, Texas | Ammonium Nitrate | 2300 tons | 1,300 | Accident; ship explosion. |
| Heligoland Island | HE | 4476 tons | - | Demolition, U-boat pens |
| Hiroshima, Japan | Nuclear | 13 kt | 2,400 | Wartime. |
| Alamagordo, New Mexico | Nuclear | 19 kt | 2,700 | 15 July 1945 - start of nuclear age. |
| Nevada Test Site | Nuclear | 100 kt | 4,700 | Shot Sedan - largest continental shot. |
| Novaya Zemlya (USSR) | Nuclear | 58 mt | 39,000 | Largest shot ever announced. |

Table 6. Fallout Intensity (Shot TURK)

| Dose Rate (mr/hr) | Distance from Ground Zero (ft) |
|-------------------|--------------------------------|
| 1000 | 150,000 |
| 100 | 190,000 |
| 10 | 360,000 |
| 1 | 400,000 |

These dose rates would be several orders of magnitude higher if a large megaton weapon were employed. As noted previously, the largest single nuclear detonation ever reported in the open literature was the Russian shot of 30 October 1961 (58 mt). If this were a so-called "dirty" weapon (i.e., principally fission), very severe contamination of thousands of square miles may have resulted.

Although samples of contaminated soil resulting from heavy fallout are relatively difficult to obtain, samples have been obtained upon occasion in connection with water decontamination studies. For example, a sample of surface soil was obtained from the LITTLE FELLER I nuclear event. This detonation occurred on 17 July 1962 at the Nevada Test Site. The sample was taken 2 days after detonation at the 10-r/hr line and analyzed a week later when it measured 45 microcuries per gram. A specific activity of 45 microcuries per gram translated into a water contamination of 259 turbidity units

(260 to 0.9) gives a figure of 11,700,000 picocuries per liter. Other pertinent water level contaminations are shown in Table 7. All of these waters would require decontamination before use.

Table 7. Calculated Radiological Water Contamination

| Tank | Overpressure (psi) | Turbidity (units) | | Calculated Contamination (picocuries per liter) |
|--|-----------------------|----------------------|---------------|--|
| | | Before Shot | After Shot | |
| 1500-Gallon Upright Cylinder | 23.0 | 0.9 | 260 | 11,700,000 |
| 36-Gallon Lyster Bag (behind berm) | 9.8 | 1.8 | 135 | 6,000,000 |
| 1500-Gallon Upright Cylinder (behind berm) | 9.8 | 0.7 | 36 | 1,600,000 |
| 36-Gallon Lyster Bag | 9.8 | 1.5 | 14 | 560,000 |
| 1500-Gallon Upright Cylinder | 9.8 | 0.7 | 10 | 420,000 |

In view of the contamination that can occur to water stored in rubberized-fabric, upright cylinders, consideration should be given to the utilization of the pillow tank which provides very good protection from contamination. The pillow tank also has other advantages; it is lighter in weight and takes less volume in shipping. Basically, it is simpler in construction and has few appurtenances. It is easier and faster to erect and install. Its silhouette is lower and it is therefore less subject to damage from flying debris. However, on the debit side, the present pillow tank is difficult to drain completely, is almost impossible to clean thoroughly on the inside, and cannot be used effectively for purposes other than water storage (e.g., for chemical pretreatment). In addition, the water in a pillow tank cannot be observed conveniently.

II. RADIOLOGICAL WARFARE DETERMINATION

6. **Maximum Permissible Concentration.** All available evidence appears to indicate that ingestion of any quantity of radioactive materials is harmful. However, complete abstinence is not possible since small amounts of radioactivity exist everywhere. The answer is to establish realistic standards, "tolerances," or MPCs to control the amount of radioactive substances taken into the body via drinking water.

During normal peacetime, the U.S. Army abides by so-called "peacetime standards." The American Water Works Association recommends the following:⁴

- Gross Beta Activity – 100 picocuries per liter (in the known absence of strontium-90 and alpha emitters)
- Alpha Activity – 0.5 picocuries per liter *or* 5 picocuries per liter (when radium-226 is less than 0.5 picocuries per liter)

In addition to "peacetime" considerations, the U.S. Army is directly concerned with emergency levels of radioactivity in water. At one time the Army considered using the Civil Defense emergency figures, which are stated in Table 8.

Table 8. Civil Defense Maximum Permissible Concentration

| Acceptable Beta-Gamma Activity | |
|--------------------------------|------------------|
| Estimated Consumption Period | Picocuries/liter |
| 10 days | 90,000,000 |
| 30 days | 30,000,000 |

NOTE: These values are applicable only during the month immediately following a nuclear detonation.

| Acceptable Alpha Activity | |
|------------------------------|------------------|
| Estimated Consumption Period | Picocuries/liter |
| 10 days | 5,000,000 |
| 30 days | 1,700,000 |

NOTE: These values are not limited to the month immediately following a nuclear detonation, but apply to *any* 10- or 30-day period.

The earliest direct guidance as to MPC for Army field water supplies was given by the Surgeon General on 18 August 1958; and is quoted directly as follows:

Beta-gamma radioactivity in treated drinking water should not exceed 3.0×10^{-4} microcuries per milliliter, provided the distribution of fission products is in accord with normal decay processes. Water of the quality specified may be consumed by combat troops daily for a total period of one year. For greater or lesser periods of consumption the figures may be adjusted proportionally.⁵

⁴ Elwood L. Bean, *Potable Water-Quality Goals*, AWWA Journal, April 1974, p. 221.

⁵ Determination of Acceptable Limits of Radioactive Materials Consumed in Water, DF, MEDCE-CH, 18 August 1958, From: TSG, To: DCSLOG, S. B. Hays, Major General, The Surgeon General.

The figure of 300,000 picocuries per liter (3×10^{-4} microcuries per milliliter) was used as the product water goal for much of the field research done on decontaminating water containing radiological materials.

In 1966, a quadripartite radiological water standard was issued, quoted directly as follows:

Radiological Standards (Gross Fission Products): (a) For short term consumption, no absolute numerical standard is recommended or considered necessary. This is based on the conclusion that, if the external radiation hazard permits occupancy of the water point, the water is suitable for consumption during occupancy not exceeding the one-week period. (b) For long term consumption, available information does not permit the establishment of a practical standard.⁶

For the record another MPC approach was taken by Morgan and Straub.⁷ Morgan and Straub recognized that fresh fission products are much less hazardous than old fission products, microcurie for microcurie. Therefore, they established an MPC that is a function of time. The older the fission product mixture, the lower is the MPC. Morgan and Straub also recognized the logic in establishing the rate at which the MPC decreases as the same rate at which fission products decay; i.e., the "1.2 law." Accordingly, they established the following MPC equation for the emergency drinking of water following a nuclear explosion:

$$\text{MPC} = 10^6 t^{-1.2}$$

where:

MPC = Maximum permissible concentration in picocuries per liter.
t = Time after detonation in days.

The above equation applies only to the time interval from 30 minutes to 3 years following detonation. The complete MPC curve is plotted in Figure 8. Only the straight portion of the curve conforms to the equation. The MPC value at low time periods after detonation (under 15 minutes) is set at 10^9 picocuries per liter. The MPC value at long time periods after detonation (over 10^4 days) is set at 10 picocuries per liter.

⁶ Title of Agreement, Minimum Potability Standards for Field Water Supply, SOLOG Agreement 125; United States, United Kingdom, Canadian, Australian Armies, 9 September 1966, p. 6.

⁷ K. Z. Morgan and C. P. Straub, *External and Internal Exposure to Ionizing Radiation and Maximum Permissible Concentration (MPC) of Radioactive Contamination in Air and Water Following an Atomic Explosion*, Oak Ridge National Laboratory. Speech presented at a meeting of the Southeastern Section of the American Physical Society in Raleigh, North Carolina, April 10, 11, and 12, 1952.

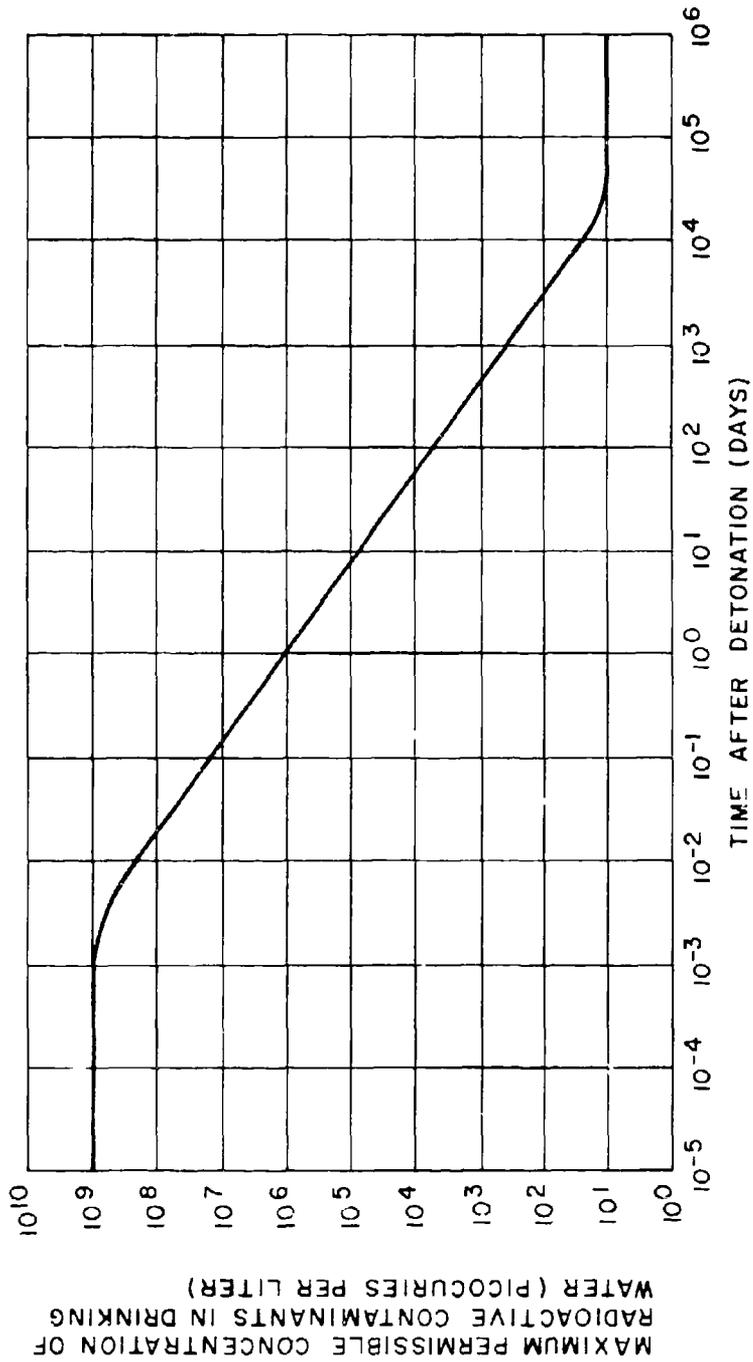


Figure 8. Emergency values of maximum permissible concentration (MPC) of radioactive materials in water following a nuclear detonation.

Effective 19 May 1972, Quadripartite Standardization Agreement-245 (QSTAG-245) established the following RW MPC policy:

For short term consumption (one through seven days), no absolute maximum tolerance is recommended or considered necessary. This is based on the conclusion that if the risk of external radiation is such as to allow the source to be used, then the water will be suitable for drinking during occupancy not exceeding one week. Water which has been deliberately contaminated with radioactive substance must, in no case, be used for consumption. For long term consumption, available information does not permit the establishment of a practical requirement.

The latest guidance for MPC is given in TB MED 229,⁸ quoted as follows:

| Constituent | Field supplies | | Fixed installations | |
|---------------------|----------------------------------|------------------------------------|--------------------------------------|---|
| | Short term (less than 7 days) | Long term (more than 7 days) | 1962 PHS drinking water standards | EPA 1975 interim primary drinking water standards |
| RADIOLOGICAL: | See Note | Same as for fixed installations | | |
| Gross beta activity | - | - | 1000 pc/l | - |
| Strontium 90 | - | - | 10 pc/l | - |
| Radium 226 | - | - | 3 pc/l | - |

Note: For short term consumption, no absolute numerical standard is recommended or considered necessary. This is based on the conclusion that if the external radiation hazard permits occupancy of the water point, the water is suitable for consumption during occupancy not exceeding the one-week period.

7. **Detection.** Although water quality assessment in the field is the primary responsibility of the field medical officer, the water supply operator at the Engineer field water point requires certain basic radiation detection equipment. Specifically, the operator needs an instrument to measure total activity in water semi-quantitatively. The instrument should be simple, quick and easy to use, and reasonably accurate. Since most of the water contaminants of sanitary significance are beta emitters, a survey meter measuring only beta particles would be adequate. However, as a practical matter, a beta-gamma survey meter standardized against fission products would be the instrument of choice. The monitoring operation would be used to check the raw water supply to determine its relation to the MPC and also the quality of the finished product. These measurements would establish the basic water purification equipment required, the need for changes in water treatment procedure, whether supplemental equipment might be required, or whether the source must be abandoned.

In addition to measuring the contaminants in the water, the operator needs an instrument capable of determining the level of area contamination. In addition, it

⁸ Department of the Army Technical Bulletin, TB MED 229, "Sanitary Control and Surveillance of Water Supplies at Fixed and Field Installations," 29 August 1975.

is noted that all water decontamination procedures concentrate the radioactive materials in such devices as sludge collectors, filter beds, ion exchange columns, etc. These "hot spots," or zones of activity buildup, must be monitored to protect the operator from over-exposure. It would be desirable for one meter to accomplish all these objectives.

In regard to monitoring radioactive materials in water, it must be noted that we are dealing with small quantities of matter. This point is brought out in Table 9, which expresses the concentration of four significant radioisotopes in milligrams per liter at the MPC level. It is observed that the mass concentration is as low as 1.15×10^{-13} milligrams per liter (in the case of sodium-24). In consideration of these low values of mass concentration, it is obvious that "wet chemistry" methods of determination are out of the question. Resort must be made to radiological methods. The accuracy of radiological methods is remarkable. It is recognized that a single beta count on a beta-gamma survey meter represents the decay of a single atom.

Table 9. Relationship- Radioactive Concentration Versus Mass Concentration

| Radioisotope Contaminant | Half-Life | Radioactive Concentration (MPC) (picocuries/liter) | Expressed as Milligrams/liter* |
|--------------------------|-----------------------|--|--------------------------------|
| Plutonium-239 | 2.41×10^4 yr | 3 | 4.84×10^{-8} |
| Cesium-137 | 30.2 yr | 1000 | 1.16×10^{-8} |
| Strontium-90 | 28.9 yr | 10 | 7.28×10^{-11} |
| Sodium-24 | 15.0 hr | 1000 | 1.15×10^{-13} |

* Calculated from equation:

$$\text{milligrams/liter} = (\text{picocuries/liter}) (7.67) (10^{14}) (\text{mass no.}) (\text{half life in days})$$

A basic procedure has been developed for field water monitoring, using a standard military beta-gamma service meter. According to this method, the probe of the meter is protected with a rubber sheath and inserted into the water in a storage tank, or even directly into a stream. The meter reading is then taken. The reading in milliroentgens per hour is proportional to the concentration of radioactive material in the water in picocuries per liter and gives a straight line on log-log paper. The water in the tank, being present in considerable bulk, shields out most extraneous radiation. However, in an area of high background, the method would have limitations.

The radiation instrument of choice is the IM-111/PDR-27J Radiameter (see Figure 9). This instrument is issued by the U.S. Signal Corps and is a portable, water-tight, battery-operated, partially transistorized meter designed for field use. It is actually part of Radiac Set AN/PDR-27J, which also consists of case, headset, harness, and spare parts.

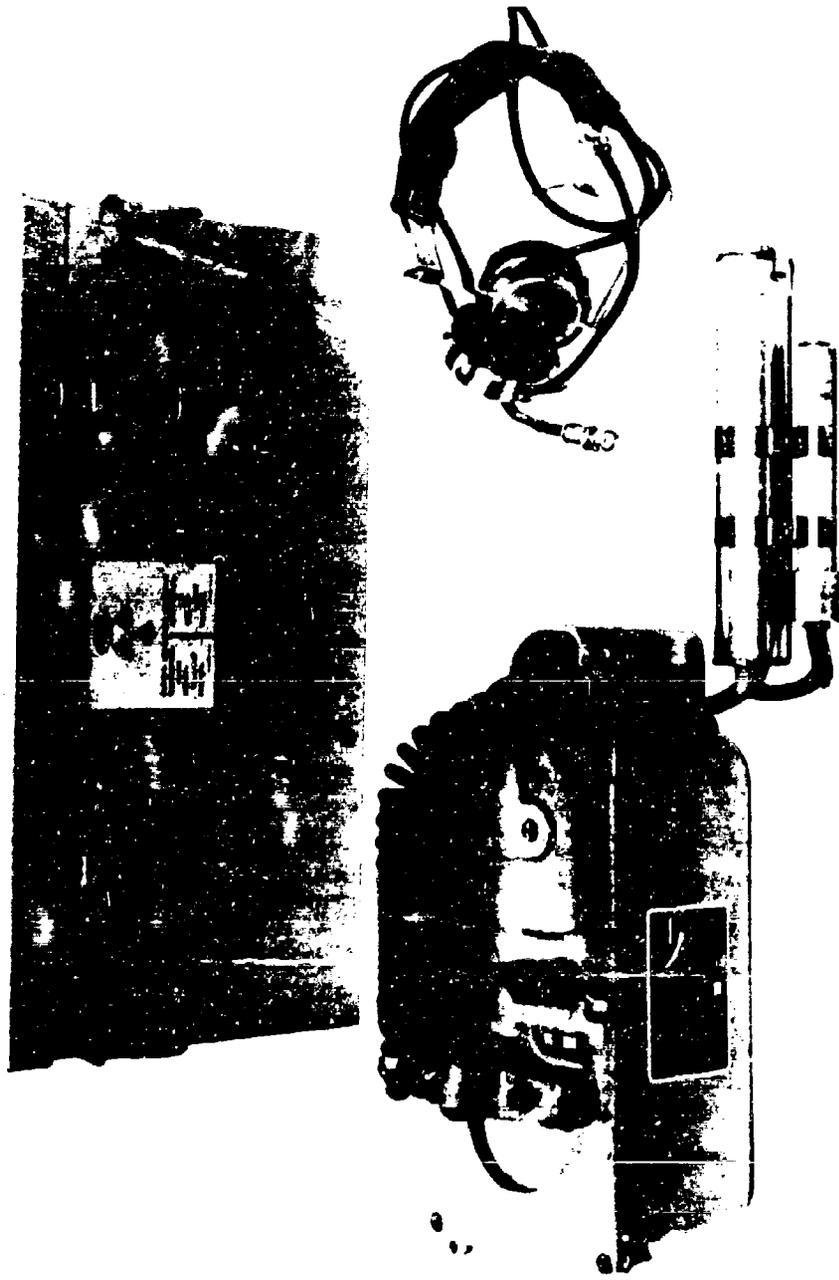


Figure 9. IM-141/PDR-27J Radiacmeter.

The procedure to be used is as follows:

- a. Remove the Radiacmeter from the carrying case.
- b. Turn the range switch to BATT. COND. The meter should read to the right of the halfway mark indicated on meter. If not, replace the batteries.
- c. Cover the entire probe assembly with a thin wall rubber glove or other thin rubber sheath.
- d. Insert protected probe into water to be measured (raw water, product water, or concentrated waste). If possible, insert probe into a bulk of water, at arm's length, in order to minimize the possibility of recording extraneous radiation.
- e. Read meter in milliroentgens per hour.
- f. Refer to conversion chart to convert from milliroentgens per hour to picocuries per liter.

Figure 10 shows a commercial instrument in use on a contaminated pond. Figure 11 shows the same commercial unit in use on water in a tank. Figure 12 shows the PDR/27J in use on contaminated water contained in a drum.

Some data in regard to this method of field monitoring were obtained at the Nevada Test Site under Operation Sunbeam. These data are presented in Table 10 and 11. The data shown in Table 11, beta shield closed, are plotted in Figure 13. It is seen from Figure 13 that the meter was near the limit of sensitivity at the tentative MPC value of 300,000 picocuries per liter for 1-year consumption (used at that time). However, since proportional adjustments were permitted in MPC for greater or lesser periods of consumption, a 2-week consumption MPC, for instance, at 8,000,000 picocuries per liter was readily determinable.

It is noted that the field water radiological detection method was developed with the AN/PDR-27J meter. However, it is believed that it also would be operational with the AN/PDR-27L, AN/PDR-27P, AN/PDR-27Q, and the AN/PDR-27R meters.

Table 10. Monitoring Radioactively Contaminated Water with IM-141/PDR-27J Survey Meter

- PROCEDURE:
1. Add 1,000, 100, 1, and 0.1-gm of bomb debris (13 days old, specific activity 22 $\mu\text{c}/\text{gm}$) to each of four 20-gallon plastic drums containing 50 liters of tap water.
 2. Agitate.
 3. Leave beta shield of IM-141/PDR-27J Radiacmeter intact and cover the entire probe assembly with a surgeon's rubber glove. Wrap and tape the loose fingers of the glove around the probe to give a neat appearance. Insert sheathed probe vertically into water. Take reading in milliroentgens per hour.

| Time after Detonation (days) | IM-141/PDR-27J Reading (mr/hr) | Concentration of Radioactivity (pc/l) |
|------------------------------|--------------------------------|---------------------------------------|
| 13 | 0.2 | 440,000 |
| 13 | 1.0 | 4,400,000 |
| 13 | 15 | 44,000,000 |
| 13 | 72 | 440,000,000 |
| 17 | 0.15 | 320,000 |
| 17 | 0.6 | 3,200,000 |
| 17 | 9 | 32,000,000 |
| 17 | 40 | 320,000,000 |

Table 11. Monitoring Radioactively Contaminated Water with IM-141/PDR-27J and CDV-700 Survey Meters

- PROCEDURE:
1. Add 1.3, 4.2, 12.6, 42, 126, and 416 gm of nuclear shot soil (specific activity 11 $\mu\text{c}/\text{gm}$) to each of six 20-gallon plastic drums containing 50 liters of tap water.
 2. Agitate.
 3. Take reading with meters as indicated.

| Tank | Concentration of Radioactivity (pc/l) | IM-141/PDR-27J Meter | | CDV-700 |
|------|---------------------------------------|---|--|---|
| | | Surgeon's Glove Around Probe Assembly. Beta Shield Closed (mr/hr) | Rubber Sheath on Each Probe (Separated) Beta Shield Open (mr/hr) | Rubber Sheath on Probe Beta Shield Open (mr/hr) |
| 1 | 290,000 | 0.10 | 0.14 | 0.13 |
| 2 | 920,000 | 0.23 | 0.23 | 0.18 |
| 3 | 2,800,000 | 0.55 | 0.65 | 0.45 |
| 4 | 9,200,000 | 1.65 | 1.85 | 1.60 |
| 5 | 28,000,000 | 4.8 | 6.0 | 4.7 |
| 6 | 92,000,000 | 14.5 | 19.0 | 18.0 |

NOTE: General area background 0.07 mr/hr.



Figure 10. Monitoring raw water supply with commercial beta-gamma survey meter.



Figure 11. Monitoring finished water supply with commercial beta-gamma survey meter.

III. WATER DECONTAMINATION

ARISTON MED HYDOR
(Good water is the best of all)
Pindar The Greek, 2000 BC

8. **ERDLator Unit.** The current, standard U.S. Army Mobile Water Purification Units (ERDLator Units) were designed subsequent to World War II to provide an answer to the projected water supply needs of the modern mobile field Army. The equipment is produced in several sizes varying in capacity from 420 gallons per hour (gph) to 3000 gph. Figure 14 is a photograph of a 420-gph unit being transported on an Army Mule. Figure 15 is a photograph of a truck-mounted 3000-gph unit in operation on Accotink Creek, Virginia. For illustrative purposes, reference is made to the Truck-Mounted Water Purification Unit, 1500 gph, typical of the general line. In essence, the unit is a water purification plant on wheels. Three basic processes take place in the unit: coagulation, disinfection, and filtration. Two major pieces of equipment are involved: the ERDLator (a conical-shaped solids contact clarifier) and a pressure diatomite filter. Coagulation takes place in the ERDLator, and the coagulated effluent from the ERDLator is filtered through the diatomite filter. Disinfection takes place concurrently with coagulation, and a positive chlorine residual of 5 milligrams per liter is carried through into the final filtrate. The rest of the equipment is essentially supporting in nature (i.e., plumbing, feeders, etc.).

The largest component, which determines the water production rate of the unit, is the coagulation basin, which will now be described in greater detail (see Figure 16). The raw water enters the unit through an aeration assembly, the purpose of which is to release supersaturated air and gases which might cause difficulty by later release, with resulting floating floc. The aerated water spills in a thin sheet into a mixing compartment where ferric chloride solution, limestone suspension, and calcium hypochlorite solution are added concurrently at a controlled rate. The water, plus developing floc, pass down through a central downcomer. The central downcomer is equipped with an agitating device comprising flat metal disks mounted on a central hollow shaft rotating at a relatively high speed, imparting a maximum peripheral velocity of 24 feet per second. The agitation provides additional aeration and promotes separation of solids from attached gases. Air, which may be separated during mixing, is vented through holes in the disks near the hub or through the perforated hollow shaft. Rotation of the water leaving the downcomer is reversed by the fins at the bottom of the ERDLator, and the water then proceeds upward with a counter-revolving motion through a contact and separation zone. The separation of floc from clear water occurs in the section of maximum area or at a minimum upward flow of 1.14 gpm per square foot. With cold water (or water temperatures less than 40°F) this rise velocity generally is reduced to 1.0 gpm per square foot. The upward revolving action, which is at a greatly reduced rate of 3 to 10



Figure 12. Monitoring water in a drum with 1M-141/PDR-27J Radiacmeter.

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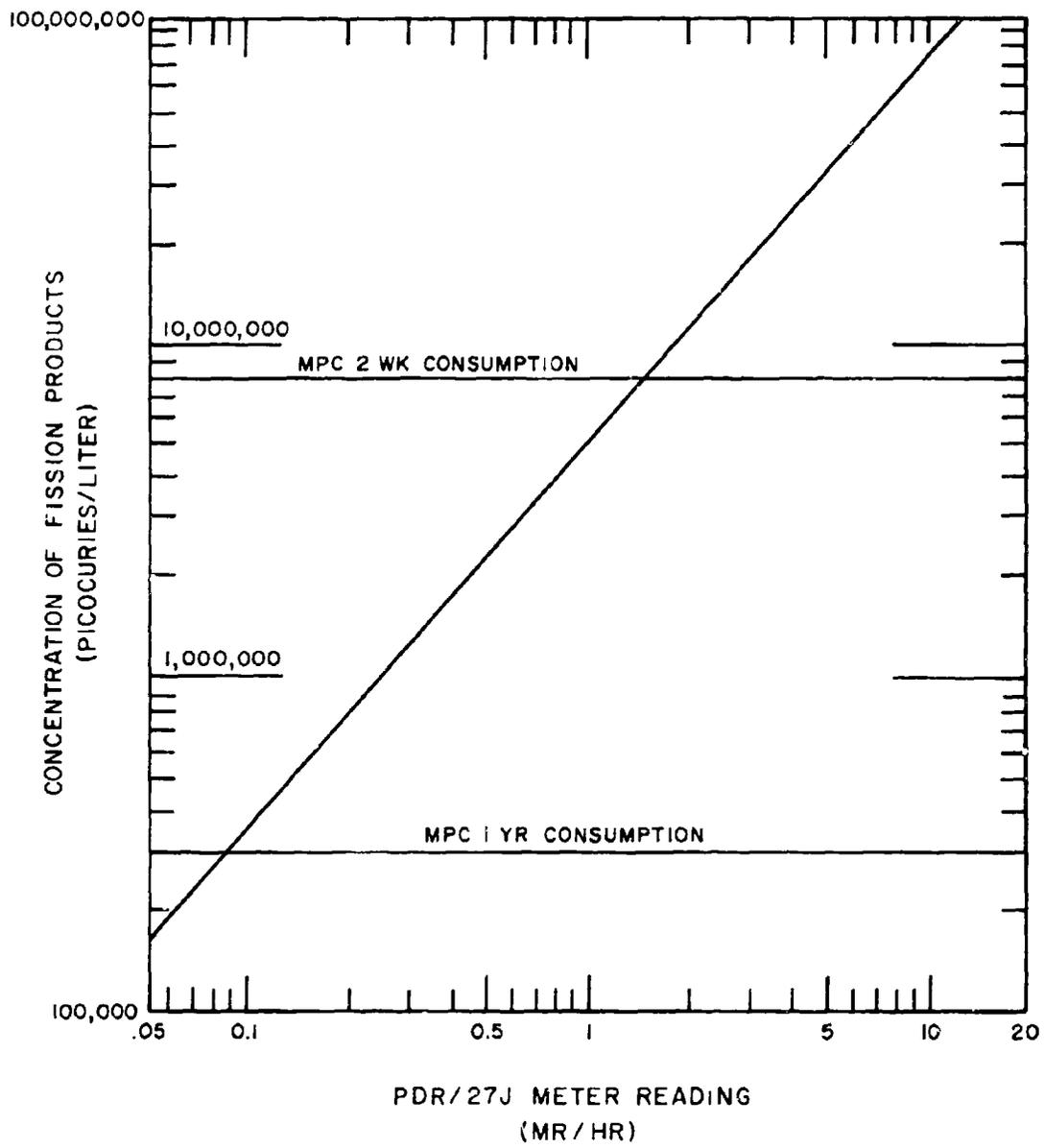


Figure 13. Conversion of milliroentgens per hour to picocuries per liter.

feet per minute, prevents short-circuiting and promotes effective contact between the water, chemicals, developing floc, and previously formed floc. The upper part of the contact and separation zone is characterized by a well-defined horizontal plane, below which is a heavy concentration of orange-colored iron hydroxide and above which is clear coagulated water containing only 0.5 to 2.0 turbidity units. The residence time in the unit is about 20 minutes. The clear coagulated water is discharged over a weir and pumped to the diatomite filter. Control of the slurry level in the clarification zone is accomplished by continuous withdrawal of a small amount of floc from the upper portion of the slurry pool. The unit is designed to hydraulically keep all slurry in suspension with sludge concentration or sedimentation occurring only in a small external concentrator.

The primary coagulant of choice is ferric chloride. Ferric chloride has certain advantages, of importance to the Army, over other conventional coagulants. Ferric chloride is effective over a wide range of pH, readily soluble in water (dissolves rapidly in even cold water), stable (has a long shelf life), and characterized by a high degree of coagulating power per unit of weight.

The coagulant aid, pulverized limestone, has the following roles to play: adds alkalinity to raw water with depressed pH, raising the pH to near 7, and as a dispersed powdered material, becomes enmeshed with the forming floc and lends weight to the floc particles.

The calcium hypochlorite disinfects the raw water and also assists as a coagulant aid in effective floc formation.

It is noted that a fourth chemical, activated carbon, is sometimes added to control excessive tastes and odors.

Although the exact dosages of the four chemicals involved are dependent upon the specific nature of the raw water in question, the following table shows the usual order-of-magnitude for average and typical waters:

| <u>Chemical</u> | <u>Parts per Million (ppm)</u> |
|-----------------------------------|--------------------------------|
| Ferric Chloride | 25-75 |
| Limestone | 50-150 |
| Calcium Hypochlorite (70 percent) | 8-12 |
| Activated Carbon | 2-10 |

In regard to the diatomite filter, the coagulated water passes through the filter cake to the interior of each filter element. The filtrate collects in the bottom of

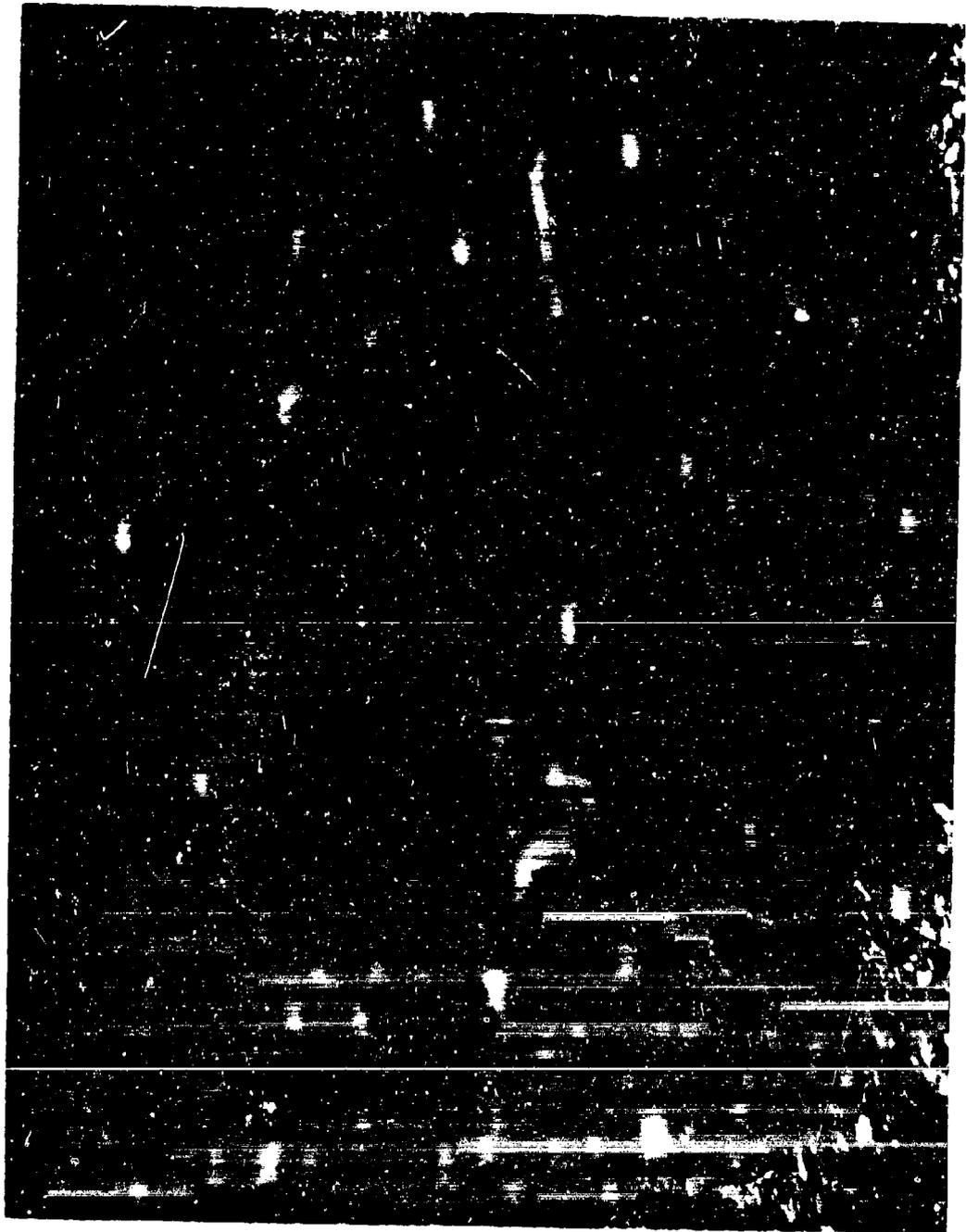


Figure 14. 420-gph ERDLator unit.



Figure 15. 3000-gph ERD Lator unit in operation on Accotink Creek, Virginia.

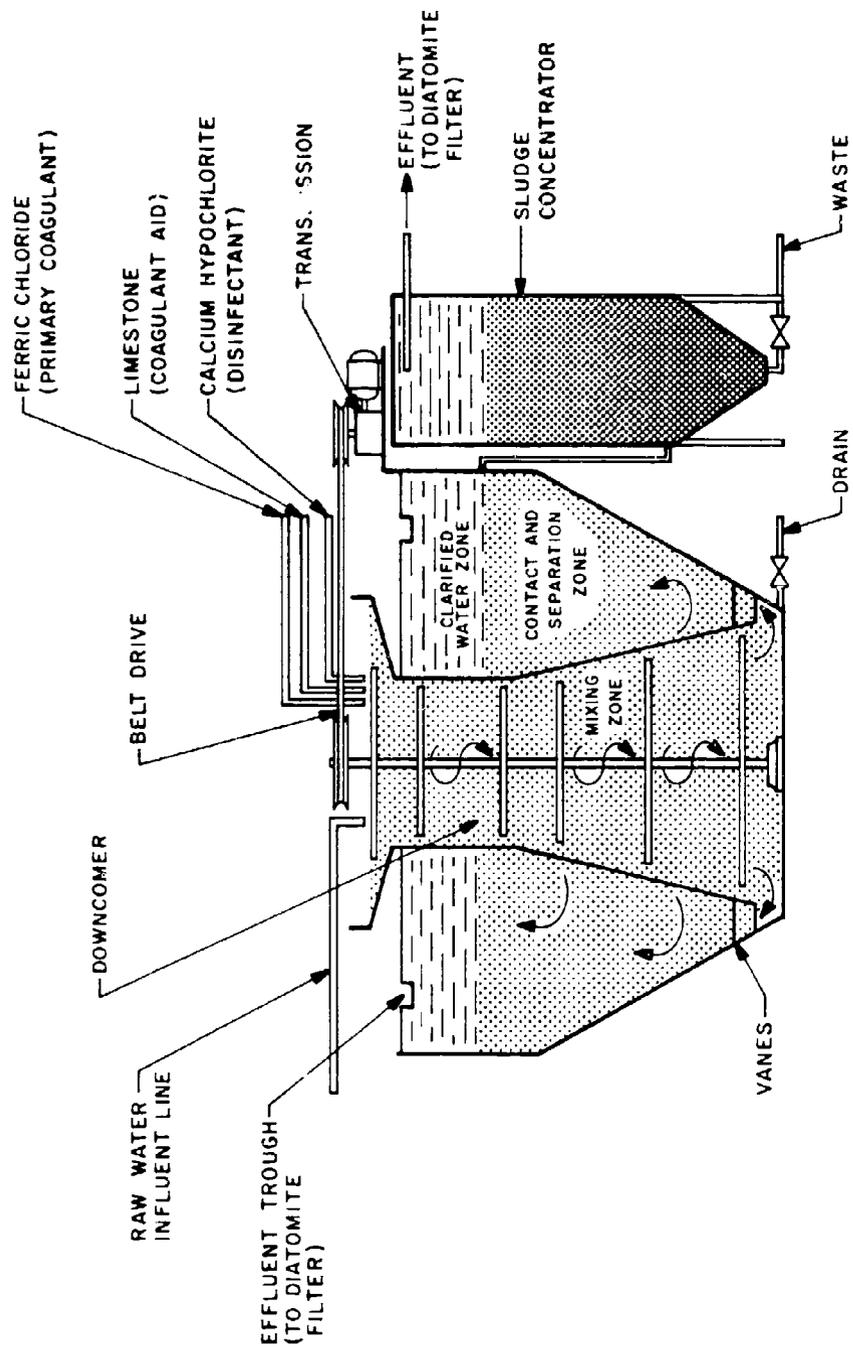


Figure 16. Diagrammatic sketch of ERD Lator solids-contact clarifier, component part of Mobile Water Purification Unit.

the filter and is carried to the clear well for distribution. The continuous addition of filter aid to the cake (body feed) results in a slow pressure rise and longer filter cycles. Eventually, however, the cake must be replaced. Removal of the old cake is accomplished by using the impounded air in the upper portion of the filter on the air bump principle; i.e., a quick reduction of the external pressure to literally blast the cake from the external face of the elements. The expended filter aid is washed to waste. By a reversal of the process, a new cake is precoated and a new cycle of filtering begun. The proper time for backwashing is arbitrarily established.

The purpose of the entire process is six-fold: clarification, removal of microorganisms, removal of tastes, removal of odors, removal of toxic materials, and removal of color. Accomplishment of these six objectives is imperative if the finished water is to be used for drinking, cooking, and dehydrated-food-reconstitution purposes. The objectives are also highly desirable if the water were to be used for laundry or bathing purposes.

The removal of turbidity is important since turbidity can cause digestive disturbances. It can also harbor dangerous germs or radioactive substances. Finally, it detracts materially from the appearance and palatability. The removal of tastes and odors is important from the standpoint of making the water appealing to the senses. The removal of microorganisms is imperative in order to prevent the contraction of disease by ingestion.

The removal of toxic substances is obviously of major importance and will remain the subject of much continued study. Such toxic substances could include the heavy metals, insecticides, fire fighting chemicals, rocket fuels, POL products, and other military chemicals. They could also include decaying animal matter and industrial pollutants.

The effectiveness of the ERDLator units in removing radioactive contaminants from water is dependent on two primary factors: first, whether the contaminant is present in the form of turbidity or in the form of true solution, and second, exactly which radioisotope or radioisotopes are present.

As mentioned previously, coagulation and filtration is the normal treatment given to raw surface waters and is the process inherent in the ERDLator Units. Removal of suspended matter is high; therefore, if radioactive substances are present in the form of turbidity, the removal is essentially complete.

A much greater problem is encountered when the radioactive contaminant is in true solution. The removal in this instance is dependent upon the exact radioisotope present. In general, dissolved radioisotopes are difficult to remove from water

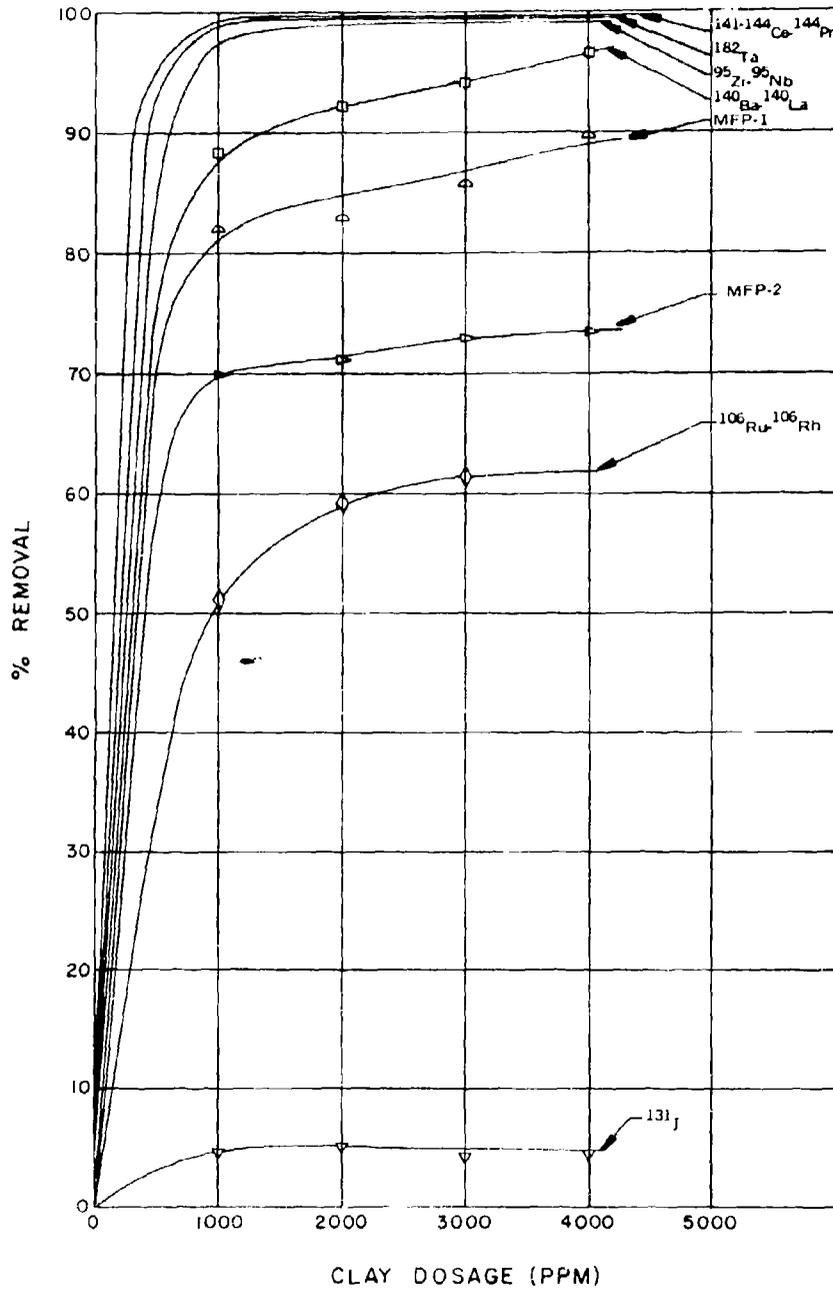


Figure 17. Decontamination of radioactively contaminated water by slurring with clay.

by coagulation and filtration. There are certain exceptions. Yttrium, for example, is readily adsorbed on surfaces and is removed from water in high percentage by coagulation. On the other hand, strontium-90 and cesium-137, two dangerous radioactive materials of fission product origin, are difficult to remove, even in small percentages, by coagulation and filtration. Although it is not generally recommended for field use, dissolved radioisotopes can be removed from water in fairly high percentages by pre-treating the contaminated water with a selected material having adsorptive and ion exchange capacity. An excellent material of choice is clay, preferably of the kaolinite-montmorillonite type. The water is slurried with 1000-ppm clay for 30 minutes or more. The water is then settled, coagulated, clarified, and filtered. Figure 17 shows what can be expected of clay under equilibrium conditions with selected radioisotopes and a mixed fission product contaminant containing 41 percent trivalent rare earths, 27 percent cerium, and 17 percent strontium. The curves were obtained after 90 minutes contact time in Oak Ridge tap water with a kaolinite-montmorillonite clay.

Table 12 shows summary data obtained at the Oak Ridge National Laboratory with an 1800-gph prototype ERDLator Unit and an experimental Ion Exchange Unit in use for decontaminating water contaminated with 2-month-old, reactor-produced fission products. It is observed that the presence of clay appreciably improved the removal of radioactivity by coagulation and filtration. The use of ion exchange following filtration improved the overall removal by an order of magnitude.

Table 12. Removal of 2-Month-Old, Reactor-Produced Fission Products from Water at Oak Ridge National Laboratory by Prototype ERDLator Unit (1800-gph) and Experimental Ion Exchange Unit

| Run | Process | Percent Removal |
|-----|--|-----------------|
| 1 | Pretreatment with clay and coagulation. | 91.2 |
| 2 | Pretreatment with clay, coagulation, and filtration. | 92.8 |
| 3 | Coagulation. | 80.2 |
| 4 | Coagulation and filtration. | 83.9 |
| 5 | Coagulation, filtration, and cation exchange (Na cycle). | 99.4 |

Table 13 shows summary data obtained at the AEC Nevada Test Site with the standard ERDLator Unit, 1500-gph truck-mounted, and the 1500-gph prototype mobile Ion Exchange Unit in use for decontaminating water contaminated with radioactive substances. The data indicate the following:

- a. Nuclear bomb debris from a silicious soil, being essentially insoluble in water, is easily removed by coagulation and filtration.

Table 13. Removal of Radioactive Materials from Water at Atomic Energy Commission's Nevada Test Site by the Standard ERDLator Unit (1500 gph) and Mobile Ion Exchange Unit (1500 gph)

| Run | Contaminant | Process | Contamination (Picoeuries/liter) | | Percent Removal (cumulative) |
|-----|---|----------------------------|-------------------------------------|---|------------------------------------|
| | | | Influent | Effluent | |
| 1 | Nuclear bomb debris, 1-yr old, 3 microns | Coagulation and filtration | 667,000 | 5,400 | 99.2 |
| 2 | Bomb debris, fused w/NaOH | Coagulation and filtration | 1,550,000 | 44,500 | 97.2 |
| | | Cation exchange (H) | 44,500 | 7,100 | 99.5 |
| 3 | Strontium-90-Yttrium-90 | Coagulation and filtration | 1,010,000 | 876,000 | 13.3 |
| | | Strontium-90 | 769,000 | 25,000 | 96.7 |
| | | Yttrium-90 | | | |
| | | Cation exchange (H) | 876,000 | 700 (⁹⁰ Sr + ⁹⁰ Y) | >99.9 |
| 4 | Cesium-137-Barium-137 | Coagulation and filtration | 12,700,000 | 12,400,000 | 2.4 |
| | | Cation exchange (H) | 12,400,000 | 3,500 | >99.9 |
| 5 | Strontium-90-Yttrium-90 | Cation exchange (Na) | 1,107,000 | 50,000 | 95.5 |
| | | Yttrium-90 | 903,000 | 229,000 | 74.6 |

b. Strontium-90 and cesium-137-barium-137, being water soluble and resistant to adsorption, are ineffectively removed from water by coagulation and filtration.

c. Yttrium-90, water soluble but readily adsorbable, is effectively removed from water by coagulation and filtration.

Table 14 shows summary data obtained at the Los Alamos Scientific Laboratory with the standard ERDLator unit, 1500-gph, truck-mounted, for decontaminating water contaminated with plutonium-239.

Table 14. Removal of Plutonium-239 from Water at Los Alamos Scientific Laboratory by the Standard ERDLator Unit (1500-gph)

| Run | Process | Percent Removal |
|-----|--|-----------------|
| 1 | Coagulation and filtration | 72 |
| 2 | Activated carbon, coagulation, and filtration | 89 |
| 3 | Clay plus caustic soda to pH 11.4, coagulation, and filtration | 97.5 |

9. Distillation Unit.

"Water water everywhere, nor any drop to drink."

Rhyme of the Ancient Mariner
Samuel Taylor Coleridge

It is interesting to note that 75% of the earth's surface is covered with sea water; unfortunately, unfit to drink, as noted by the Ancient Mariner. Sea water contains approximately 35,000 ppm of total dissolved solids. If ingested, it dehydrates the human body, and thus the drinker is worse off than drinking no water at all.

In order to cope with sea water, the U.S. Army maintains as standard a skid-mounted vapor compression distillation plant mounted on a 2½-ton two-wheel trailer. The plant is designed to produce potable water (distillate) from seawater at a rate of 150 gph. The key components of the plant are trailer; 4-cylinder, 4-stroke, liquid-cooled gasoline engine; aluminum evaporator-condenser; vapor compressor; water pumps; heat exchanger; engine water cooler; exhaust gas cooler; engine lubricating oil cooler; acid pot; and feedwater strainer. Figure 18 is a flow chart of the process. Figure 19 is a photograph of the unit.

The use of distillation for the decontamination of radioactively contaminated water is predicated upon the same principle used to produce potable water from seawater; namely, boiling the water and condensing the steam and leaving the nonvolatile

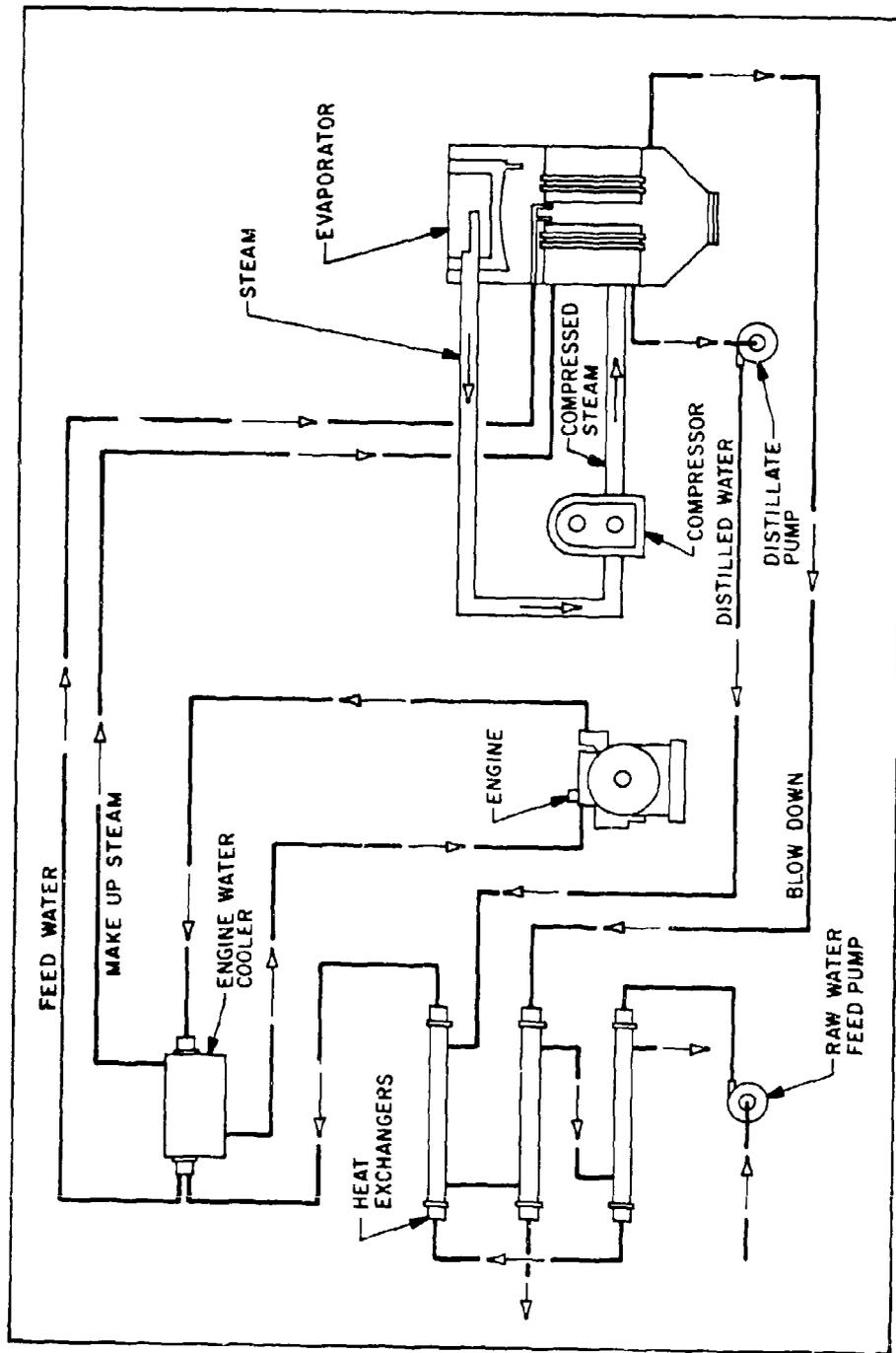


Figure 18. Flow diagram of vapor compression distillation unit (150 gph).



Figure 19. Vapor Compression Distillation Unit (150 gph), Fort Stovr, Virginia.

contaminants in the concentrate or blowdown. In the case of radioactively contaminated water, the contaminant is radioactive ions, while in normal seawater distillation the material to be removed is sodium chloride and other dissolved salts. Of interest is the fact that the concentration of radioactive materials in the expected order of magnitude of contamination is appreciably lower than the concentration of salt in seawater; i.e., radioisotopes are usually present in concentrations much less than 1 ppm, whereas the salts in seawater, as noted, are present in the neighborhood of 35,000 ppm.

A standard 60-gph Vapor Compression Distillation Unit was evaluated at the Oak Ridge National Laboratory for decontaminating water containing radioactive materials. The results are shown in Table 15. The results show that vapor compression distillation is a very effective method of decontaminating radioactively contaminated water. It is considered significant that practically no difficulty was experienced because of volatility of the contaminants. Even with potentially volatile iodine-131 (if present in the elemental state) as the sole contaminant, a 99.96 percent removal was obtained. Other radioactive materials characterized by some volatility, such as xenon, krypton, and ruthenium, and presumably present in the fission product mixtures, caused no difficulty.

Table 15. Radiological Warfare Water Decontamination
U.S. Army Vapor Compression Distillation Unit
(Oak Ridge National Laboratory)

| Contaminant | Picocuries per Liter | | Percent Removal |
|---------------------------|----------------------|------------|-----------------|
| | Feedwater | Distillate | |
| Fission Products (2-week) | 44,000,000 | 8,900 | 99.98 |
| Fission Products (3-year) | 9,900,000 | 2,400 | 99.98 |
| Iodine-131 | 27,000,000 | 39,000 | 99.96 |
| Protactinium-233 | 19,000,000 | 8,000 | 99.96 |

10. Field Expedient. Equipment for providing water for the individual or squad is intended primarily for emergency treatment of raw fresh water supplies when it is impossible to obtain water from Corps of Engineers water production units. If raw water sources are contaminated with CBR agents, however, the first alternative is to attempt to find an uncontaminated source. This may be difficult in view of certain military situations, especially where large areas may be contaminated. In this case, contaminated water must be subjected to decontamination procedures.

As normal practice, raw water from a fresh water source is disinfected in the service canteen with a Globaline tablet. In the event of CBR contamination, an extra dose could be used, and some chemical agents would be partially detoxified by this

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procedure. Most biological agents could be killed, although those protected by turbidity and those resistant to disinfection might not. The additional oxidizing power as a result of the extra dosage would have to be given consideration, however, as no means are now provided to accomplish a deiodification step. Too much oxidizing agent would render the water unfit to drink due to excessive taste and odor. The Globaline-canteen procedure would be of no value in removing radiological material from water.

Sustained boiling of water by the individual soldier would kill all microorganisms but would probably be of little value in removing or destroying chemical agents and of no value in destroying radiological agents in water. In fact, boiling could actually concentrate radiological agents in water.

Water Purification Unit, Hand-Operated, Knapsack-Pack, Filter-Pad-Type, ¼ gpm (Set No. 1) is a direct-filtration device consisting essentially of a hand-operated diaphragm pump in combination with a housing used to support two cellulose filter pads. This device would be of limited value in removing chemical agents from water. It would be reasonably effective in removing most microorganisms from water, especially when used with globaline disinfection tablets. The device would be effective in removing suspended radioactive particles from water but would be ineffective for removing dissolved radioactive materials.

Because of the inadequacies of existing equipment and procedures, a universal multipurpose method was developed for the individual or squad to decontaminate water containing CBR agents. The method utilizes existing chemicals and equipment, with the exception of the mixed bed demineralization column, which would have to be procured separately. The procedure is as follows:

- a. Put 36 gallons contaminated water in Lyster bag.
- b. Add 20 gram, 70-percent strength calcium hypochlorite (100 ppm available chlorine), stir, and let stand for ½ hour. Destroys G-agents, V-agents, blood gases, and BW-agents.
- c. Add 82 grams (600 ppm) activated carbon. Stir occasionally for ½ hour. Removes Lister gases and arsenicals.
- d. Add 7 grams (50 ppm) FeCl_3 and 14 grams (100 ppm) limestone, stir, and let settle for ½ hour. Removes particulate radioactivity.
- e. Pump supernatant through Set No. 1.
- f. Pump effluent through mixed-bed demineralization column. Removes

soluble radioactivity.

g. Post chlorinate to 5-ppm residual.

See Figure 20 for photograph of equipment.

The Squad Method of purifying CBR-contaminated water was tried at the AEC's Nevada Test Site for decontaminating water containing radioactive material. Bomb debris from a small surface-detonated nuclear shot was used as the contaminant. The results obtained are shown in Table 16.

Table 16. Squad Method of Purifying Water Contaminated with Radioactive Material (Bomb Debris)

| Radiological Data | |
|---|------------------------------------|
| Sample | Radioactivity Concentration (pc/l) |
| Raw contaminated water | 46,000,000 |
| (Soluble portion of raw contaminated water) | 4,400,000 |
| After coagulation | 3,200,000 |
| (Soluble portion after coagulation) | 2,100,000 |
| After filtration | 1,900,000 |
| After mixed-bed ion exchange | 0 |

| Process Removal | |
|---|-------------|
| Process | Removal (%) |
| Coagulation | 93 |
| Coagulation plus filtration | 96 |
| Coagulation plus filtration plus mixed-bed ion exchange | 100 |

The method proved to be effective for reducing radioactivity to an undetectable level, indicating essentially complete removal. Coagulation and filtration removed 96 percent of the activity. Passage of the filtrate through a mixed-bed ion exchange cartridge removed the remaining 4 percent of activity. Even though 96 percent of the activity was removed by coagulation and filtration, the remaining 4 percent represented a soluble radioactivity concentration of 1,900,000 picocuries per liter. The removal of this soluble activity by a mixed-bed ion exchange resin column demonstrates the usefulness of ion exchange resins for removing soluble radioactivity from water.

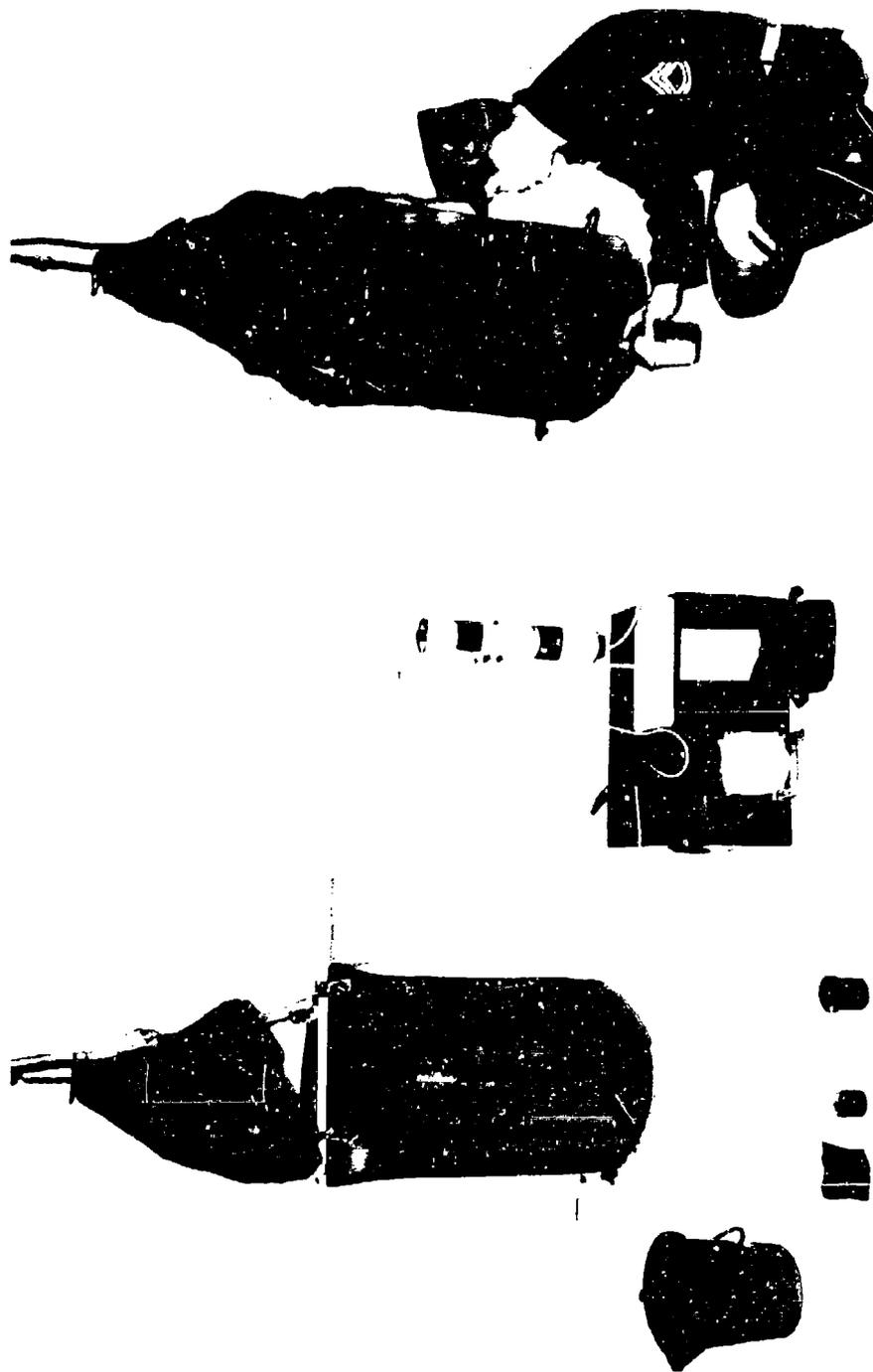


Figure 20. Field expedient method of decontaminating water containing CBR agents.

The squad method was also tried on water contaminated with plutonium-239, where an overall removal of greater than 99.9 percent was obtained.

11. Ion Exchange Unit. Ion Exchange Unit, 420-3000 gph is a mobile, self-contained, field demineralization plant. The equipment assembled in the unit's shelter consists principally of a cation exchange column and an anion exchange column operable in series. The columns are 35 inches ID. Each column contains 21 cu ft of macroreticular resin, characterized as follows:

| Item | Cation Resin | | Anion Resin | |
|--|-------------------|------|----------------|------|
| | (Strongly Acidic) | | (Weakly Basic) | |
| | Min | Max | Min | Max |
| Effective size (mm) | 0.40 | 0.55 | 0.40 | 0.55 |
| Wet density (lb/cu ft) | 46.0 | 52.0 | 37.0 | 42.0 |
| Moisture content (%) | 55.0 | — | 60.0 | — |
| Exchange capacity (milliequivalents/dry gram) | 4.30 | — | 4.20 | — |

When saturated, the beds are backwashed and regenerated. Hydrochloric acid is used for regenerating the cation resin, and sodium carbonate for the anion resin. Auxiliary equipment includes electrical control panel, conductivity meter, flow indicator, and necessary piping and valves for flow control. Support equipment in the field consists of a 10-kw gasoline-engine-driven generator and three electric-motor-driven pumps. See Figure 21 for a photograph of the cation and anion columns and the essential piping.

The Ion Exchange Unit is used as a post-treatment apparatus in series with the standard ERDLator-type Mobile Water Purification Unit. This point is illustrated in Figures 22 and 23. The Mobile Water Purification Unit is primarily a clarification and disinfection device utilizing the processes of coagulation, hypochlorination, and diatomite filtration. The contemplated use of the Ion Exchange Unit is in the following areas:

- a. Primary use — decontamination of water containing dissolved radioisotopes present as a result of nuclear warfare.
- b. Demineralization of brackish waters to 1500 ppm total dissolved solids (by blending) for emergency drinking purposes.
- c. Softening of hard water (cation exchanger only on sodium cycle).
- d. Desalination of fresh or saline sources to produce a high purity deionized water for special purpose use such as boiler feedwater, jet aircraft, batteries, photographic

requirements.

e. Decontamination of waters containing chemical agents.

It is recognized that most of the fission products are cationic in nature. Therefore the cation exchanger plays the dominant role in the removal of dissolved radioactive substances from water. The cation exchanger is more effective on the hydrogen cycle than the sodium cycle. As illustrative of the action of a cation exchanger on the hydrogen cycle, data are plotted in Figure 24 from a test run conducted at the Oak Ridge National Laboratory using mixed fission products as the contaminant and cation exchanger Amberlite IR-120. It is noted that cationic activity is removed effectively until the resin is exhausted and breakthrough occurs. At this time, it is imperative that the resin be regenerated with hydrochloric or other acid. The quality of the effluent can be monitored by counting the activity or, if more convenient, by monitoring the pH or hardness. Breakthrough of pH, hardness, and activity occur at the same time.

In addition to this information, it is noted that further information on the removal of radioactive materials by ion exchange was presented in a joint survey made by the Oak Ridge National Laboratory and the U.S. Public Health Service.⁹ A summary of their findings is shown in Table 17.

Table 17. Removal of Individual Radioisotopes by Ion Exchange Materials
(Report of the Joint Program of Studies on the Decontamination of
Radioactive Waters - ORNL, R ATSEC)

| Isotope | Amount of Isotope Removed (%) by | | | |
|--------------------------------------|----------------------------------|----------------------|------------------|-----------|
| | Cation Exchange Resin | Anion Exchange Resin | Mixed-Bed Resins | Greensand |
| ¹⁸⁵ W | 12-16 | 97.2-99.2 | 98.9 | 9 |
| ⁹¹ Y | 86-93.1 | 94.2-98.5 | 97.6-98.7 | 75 |
| ⁴⁶ Sc | 95.7-97.2 | 98.8-99.0 | 98.5-98.7 | 96.4 |
| ⁸⁹ Sr | 99.1-99.8 | 5-7 | 99.95-99.97 | 99.8 |
| ¹⁴⁰ Ba- ¹⁴⁰ La | 98.3-99.0 | 36-42 | 99.5-99.6 | 96.3 |
| ¹³⁷ Cs | 99.8 | 9 | 99.8 | |
| ¹¹⁵ Cd | 98.5 | 0 | 99.2 | |
| ⁹⁵ Zr- ⁹⁵ Nb | 58-75 | 96.4-99.9 | 90.9-99.4 | |

⁹ U.S. Public Health Service, *Report of the Joint Program of Studies on the Decontamination of Radioactive Waters*, Health Physics Division, Oak Ridge National Laboratory & Robert A. Taft Sanitary Engineering Center, ORNL-2557, February, 1959.

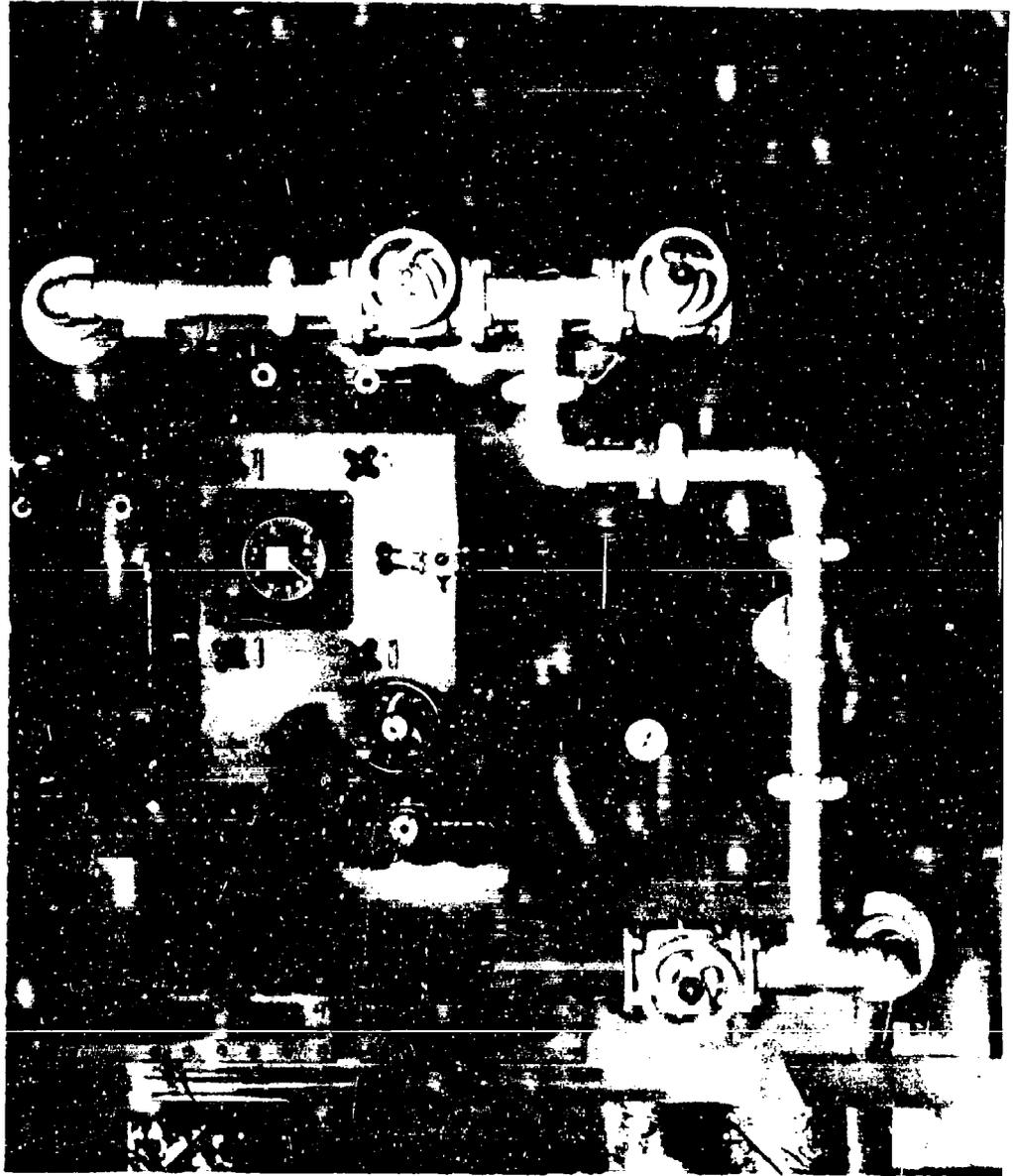


Figure 21. Ion Exchange Unit (420 to 3000 gph).

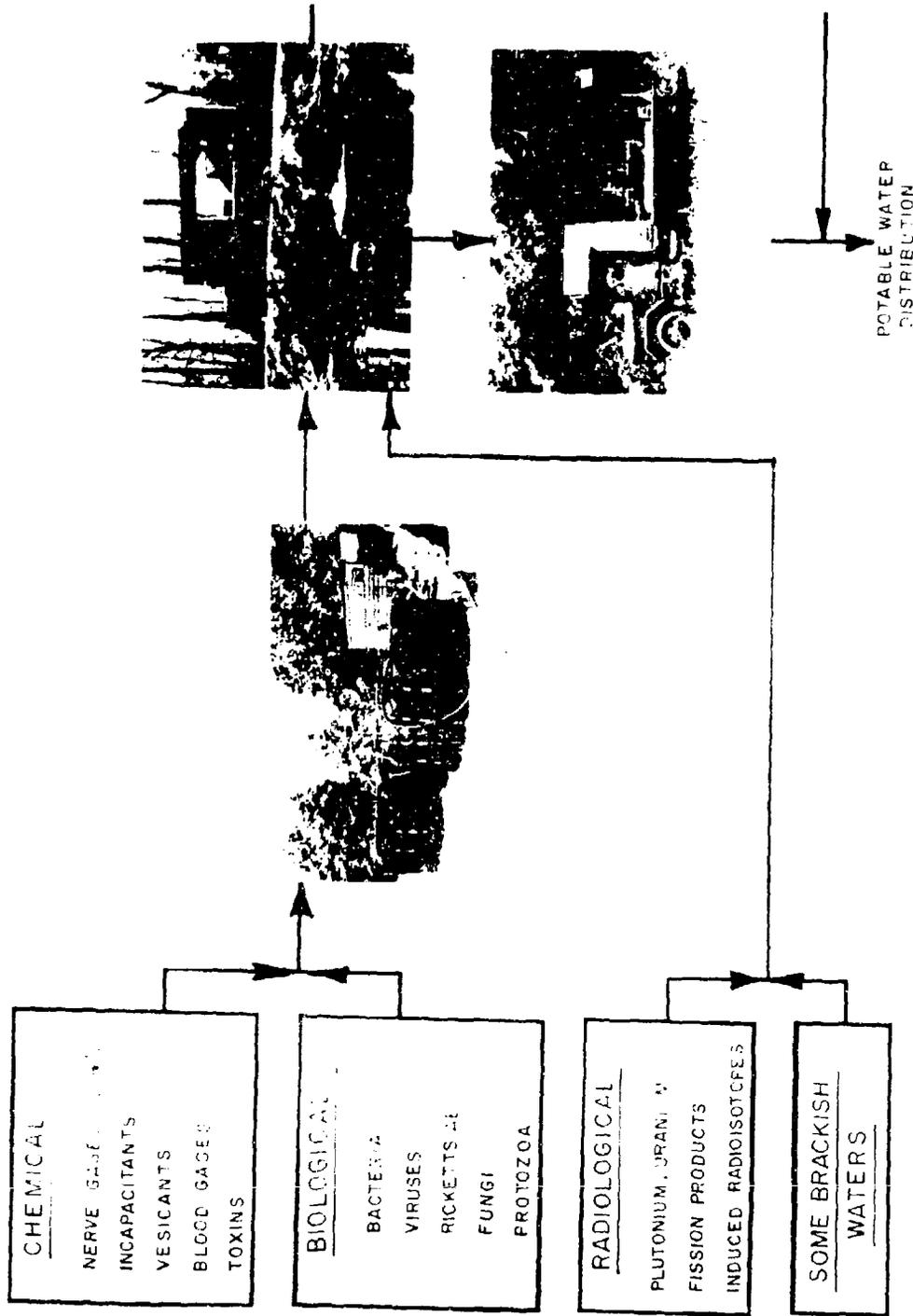


Figure 22. Application of Mobile Ion Exchange Unit for removing contaminants.

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USAMERDC conducted water decontamination studies involving ion exchange at the Newtown Test Site of the U.S. Public Health Service on a joint basis. One study was made on a seminatural pond deliberately inoculated with four radioisotopes, and the results were presented in the Health Physics Journal.¹⁰ Summarized information is shown in Table 18. It is noted from the results of Table 18, Step 1 that the cation exchange process was most effective when challenged by strontium-85, where it removed 99.3 percent. It was least effective for cesium-137, where the removal was zero. The anion exchange process was most effective in the removal of cesium-137, where a removal of 62 percent was recorded. The strange behavior of cesium-137 in this study is attributed to the theory that cesium-137 is sorbed essentially irreversibly on illite, a predominant clay in the Cincinnati area. Much of this clay is a very fine colloid, and could appear as a filterable material in an analytical analysis. In processing, much of this colloid might pass through the coagulation, filtration, and cation exchange processes. However, in the high pH environment existing in the anion exchanger, this silicate would carry a strong negative charge and be susceptible to removal by the anionic resin. Results of a rainwater run are shown in Table 19.

Table 18. Radioactivity Water Decontamination Data, USAMERDC-USPHS Joint Project

| Process | Cesium-137 | Cobalt-60 | Strontium-85 | Zinc-65 |
|---------------------------------------|-------------|-----------|--------------|---------|
| | Removal (%) | | | |
| <u>Step 1 - 10 hr - low turbidity</u> | | | | |
| Coagulation | 59 | 38 | 5 | 82 |
| Diatomite Filtration | 0 | 0 | 0 | 0 |
| Cation Exchange | 0 | 60 | 99.3 | 50 |
| Anion Exchange | 62 | 40 | 33 | 0 |
| Overall | 84 | 85 | 99.6 | 91 |
| <u>Step 2 - 9 hr - high turbidity</u> | | | | |
| Coagulation | 96 | 78 | 23 | 82 |
| Diatomite Filtration | 0 | 4 | 1 | 0 |
| Cation Exchange | 31 | 89 | 99 | 94 |
| Anion Exchange | 36 | 46 | 25 | 33 |
| Overall | 98 | 99 | 99.5 | 99.6 |

Pertinent Information

Natural water containing biota with 5 months equilibration.
 Flow rate 25 GPM.
 Coagulation, 50 ppm FeCl₃, 100 ppm CaCO₃.
 Cation exchanger, Duolite C-25 (hydrogen cycle).
 Anion exchanger, Duolite A-30G (hydroxide cycle).

¹⁰ D. C. Lindsten, S. K. Hasuike, A. G. Friend, "Removal of Radioactive Contaminants from a Semi-natural Water Source with U.S. Army Water Purification Equipment," Reprinted from Health Physics, Official Journal of the Health Physics Society, Vol II, pp. 723-729, by PERGAMON PRESS (Oxford, London, New York, Paris), 1965 (Printed in Northern Ireland).

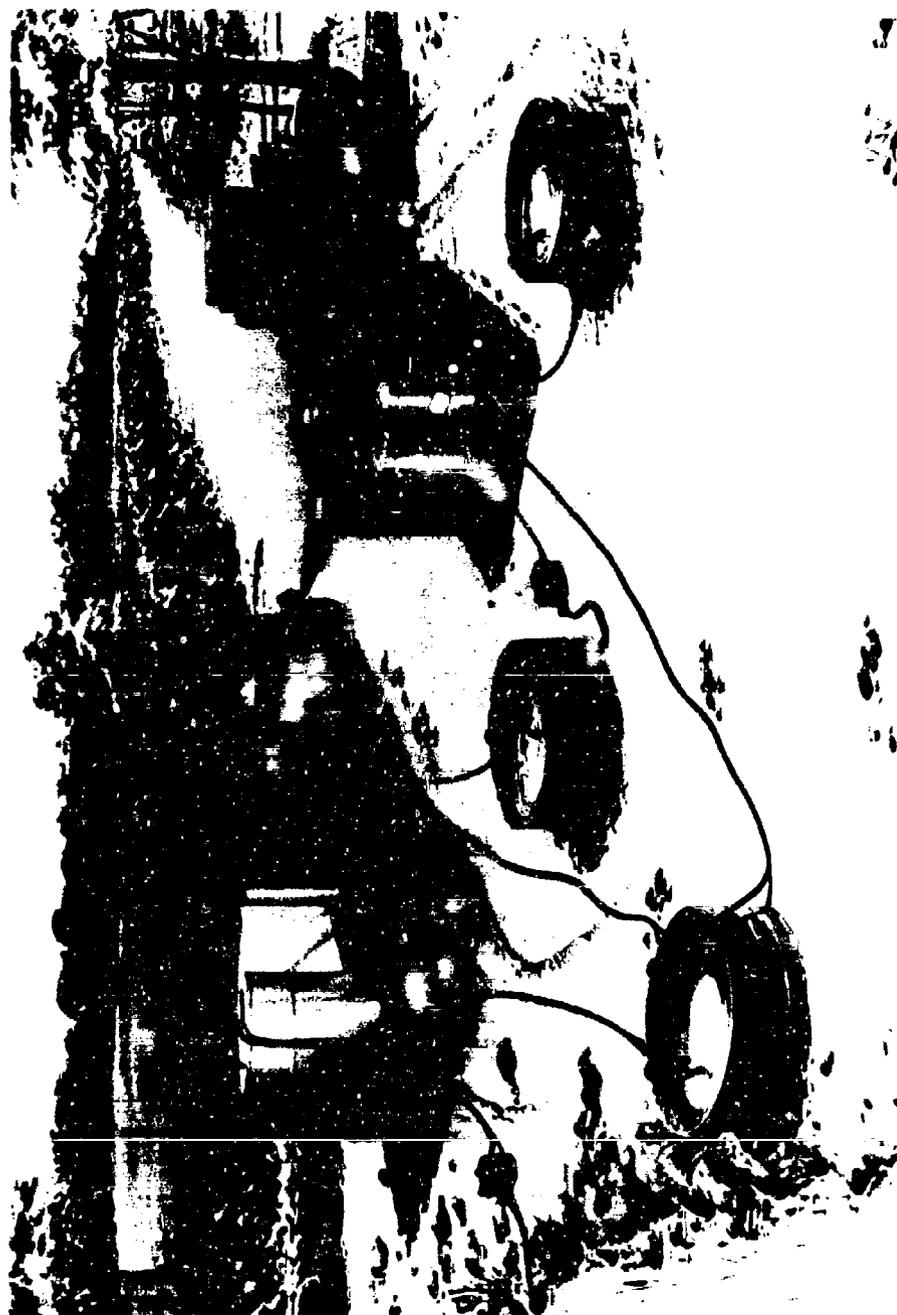


Figure 23. Decontamination of water containing radiological warfare agents.

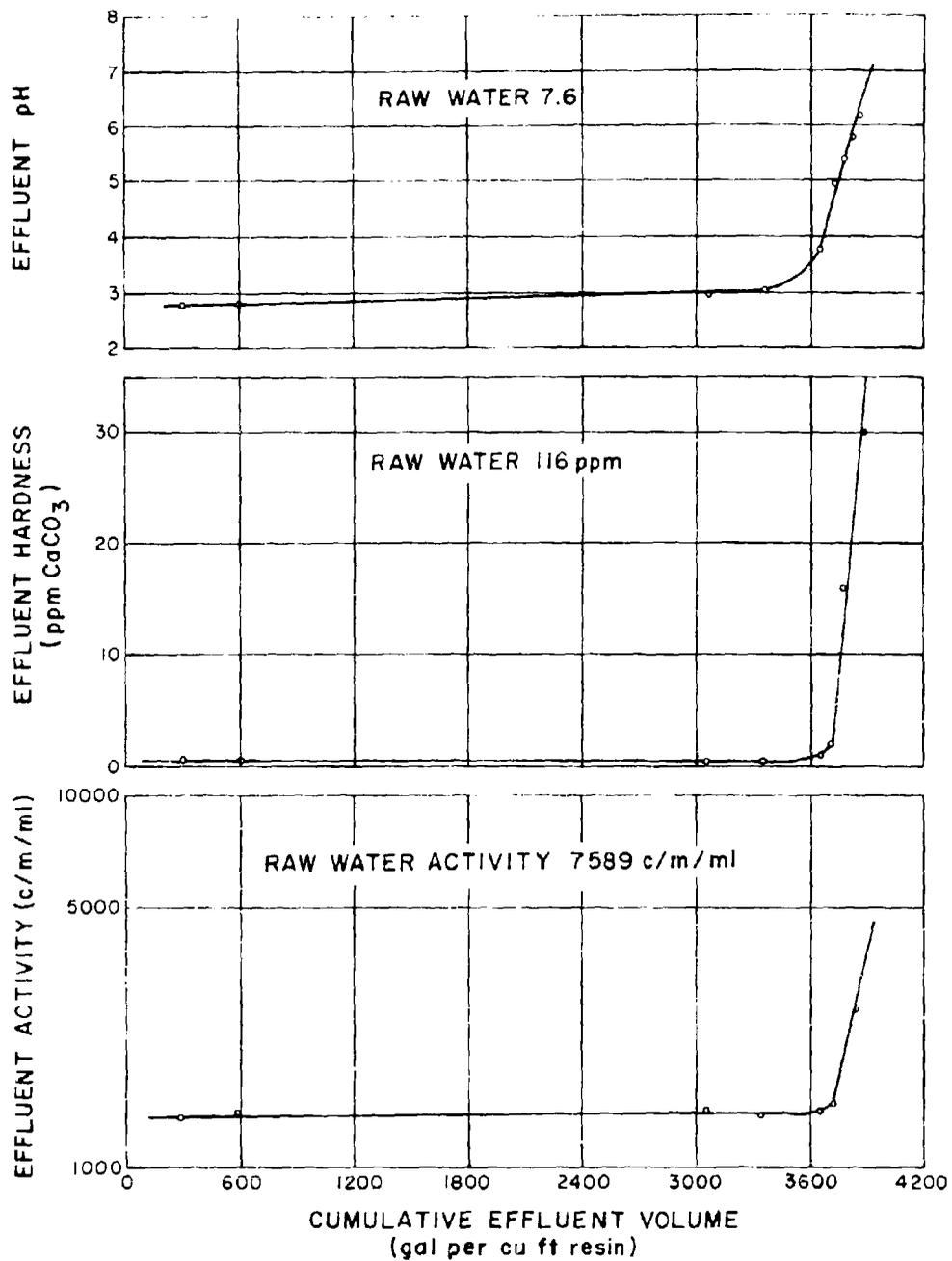


Figure 24. Effluent characteristics, Cation Ion Exchange Resin Column (hydrogen cycle) operated on water contaminated with mixed fission products (Oak Ridge National Laboratory).

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Table 19. Radioactive Rainwater Decontamination Data,
USAMERDC-USPHS Joint Project

| Process | Antimony- | Cerium- | Cesium- | Manganese- | Ruthenium- | Zirconium-95- |
|----------------------|-----------|---------|---------|------------|------------|---------------|
| | 125 | 144 | 137 | 54 | 106 | Niobium-95 |
| Removal (%) | | | | | | |
| Coagulation | 64 | 40 | 83 | 57 | 73 | 76 |
| Diatomite Filtration | 0 | 9 | 5 | 4 | 44 | 47 |
| Cation Exchange | 63 | 35 | 26 | 96 | 86 | 73 |
| Anion Exchange | 33 | 0 | 0 | 0 | 13 | 25 |
| Overall | 91 | 65 | 88 | 98.4 | 98.1 | 97.5 |

Pertinent Information

Rainwater collected off roofs at Newtown, Ohio.
Flow rate 25 GPH.
Coagulation, 22 ppm FeCl_3 , 57 ppm CaCO_3 .
Cation exchanger, Duolite C-25 (hydrogen cycle).
Anion exchanger, Duolite A-30G (hydroxide cycle).

USAMERDC also conducted water decontamination studies involving ion exchange on a full-scale basis at the AEC Nevada Test Site in 1959. The results, using nuclear bomb debris, strontium-90-yttrium-90, and cesium-137-barium 137, are shown in Table 20. It is noted that strontium-90-yttrium-90 and cesium-137-barium-137 were removed effectively by the cation exchanger on the hydrogen cycle.

Table 20. Ion Exchange for Decontamination of Water Containing Radioactive Materials
(Nevada Test Site - 1959)

| Contaminant | Cation Exchanger Amberlite IR 120 (cycle) | Radioactivity (Picocuries/Liter) | | Removal (%) |
|----------------------------|---|-------------------------------------|--|----------------|
| | | Influent | Effluent | |
| Fission Products | Hydrogen | 44,500 | 7,100 | 85.1 |
| Strontium-90 Yttrium-90 | " | 876,000 25,000 | 700 (^{90}Sr - ^{90}Y) | >99.9 |
| Cesium-137-Barium-137 | " | 12,400,000 | | |
| Strontium-90 | Sodium | 1,107,000 | 50,000 | 95.5 |
| Yttrium-90 | " | 903,000 | 229,000 | 74.6 |

12. Reverse Osmosis. It is essential that the U.S. field Army be provided with potable drinking water for culinary, washing, bathing, laundering, and food preparation purposes. Water treatment equipment currently available in the Army supply system has the capability of producing potable water from polluted fresh water, sea water, certain brackish water, and water contaminated with chemical, biological, and radiological

agents. Purification of all these raw waters requires essentially four different processes and many different pieces of equipment. In view of this inherent complexity, and in pursuit of improved reliability and efficiency, the U.S. Army has established a requirement¹¹ to develop a single multipurpose unit capable of producing potable drinking water from whatever raw water source may be available.

The reverse osmosis (RO) process holds promise of satisfying this requirement and is the primary approach to meeting the stated goal. Figure 25 is an artist's concept of a single, multipurpose unit for handling all manner of surface water.

RO is a membrane process in which the raw water is pressurized to a value above the osmotic pressure. Pure water passes through the membrane, leaving most of the soluble salts behind (see Figure 26). At the same time, essentially all particulate matter, including microorganisms and suspended colloids, is removed.

Passage of water through the membrane is governed by diffusive transport according to the following equation, which relates to permeate *quantity*.

$$F = K_1(P_a - P_o) \quad (1)$$

where:

- F = Product (permeate) water flux in gal/sq ft of membrane area/day
- P_a = Applied pressure in psi
- P_o = Osmotic pressure in psi
- K₁ = Proportionality constant

An examination of the above equation indicates that no product water is produced when the applied pressure is *less* than the osmotic pressure. *Above* the osmotic pressure, the more the pressure, the more the water. Seawater, for example, has an osmotic pressure of 350 psi. The flux obtained at 550 psi would be doubled by going to 750 psi.

Permeate *quality* is governed by the following:

$$S = K_2(C_r - C_p) \quad (2)$$

where:

- S = Salt flux in grams/sq ft of membrane area/day
- C_r = Concentration of salt in raw water
- C_p = Concentration of salt in product (permeate) water
- K₂ = Proportionality constant

¹¹ ROC, "Family of Water Supply Equipment," U. S. Department of the Army approved 4 Mar 74.

When a tight, high rejection membrane is used, the C_p term becomes negligible and can be dropped. Under this condition, the amount of salt migrating through the membrane is directly proportional to the salt concentration in the raw water. It is interesting to note that the salt migration is independent of pressure. Hence, the quality of the product water is best at high applied pressure, where a constant salt migration is diluted with a large volume of pure water.

At the present time, cellulose acetate (C/A) is the principal material used for membrane fabrication. Other materials are used to a lesser degree, such as cellulose acetate butyrate, modified sulfonated polyphenylene oxide, and aromatic polyamide. Continuing research could well develop materials superior to C/A. The usual employment of C/A is as an anisotropic asymmetric membrane. A typical membrane is about 3 mils (75 microns) thick. The surface is a thin, dense skin of tightly packed C/A. This skin is only 0.1 to 0.25 micron thick. The rest of the membrane is porous substructure (see Figure 27). The membrane is produced wet and must be stored wet, as a water-laden, heavily hydrated amorphous plastic.

It is noted that experiments are currently underway investigating the possibility of producing a dry C/A membrane. The dry membrane is produced dry, stored dry, shipped dry, and it does not encounter water until it is put to use. The dry membrane is composed of tiny dry crystals. The thin skin consists of unusually small crystals. Water passes through narrow passages (interstices) between these crystals. The supporting substructure underneath consists of larger crystals. With the dry membrane, the life-span should be increased and handling and replacement costs decreased. It should be noted that significant progress has already been made in the development of a dry cellulose acetate membrane — for use in the spiral wound configuration. Specifically, a 4-inch-diameter module containing 65 square feet of dry cellulose acetate membrane has been produced. The module is intended primarily for brackish water desalination. In addition, work is progressing satisfactorily on the development of a dry sea water membrane, which, when configured into a spiral wound module with suitable support material, will permit operation at 1000 psi and provide greater than 99% salt rejection. This dry sea water membrane module would be interchangeable with the currently available dry spiral wound cellulose acetate brackish water module. In addition, work is being accomplished on the development of a thin-film composite membrane system in the spiral wound configuration to operate in a single-stage sea water unit. The membranes are constructed from a polyamine cross-linked with an acid chloride to produce a sea water membrane with a projected flux rate of 28 gallons per square foot per day and salt rejections of 98.5% on a single-pass operation. The major potential advantage of this new membrane over other polyamide membranes is that it may be more stable to chlorinated feed water used in military field operations.

The basic flow pattern of water through an RO system is illustrated in Figure

28. Sample figures are shown illustrating the relationships that exist for 80 percent water recovery and 98 percent salt rejection.

Three basic configurations may be used for employing the RO principle: tubular, hollow fiber, and spiral-wound.

The tubular configuration (Figure 29) has several assets: (a) it utilizes a well-known technology—pumping water through a pipe; (b) the tube itself serves as the pressure vessel and, thus, an outside pressure container is not needed; (c) turbulent flow is easily maintainable, reducing the probability of fouling; and (d) it is more easily cleanable. On the debit side, the tubular configuration has a poor packing density and requires troublesome return bends. Data using the tubular configuration (and other configurations) indicate that a drop in flux as a function of time is a serious problem. It is believed that this phenomenon is a direct result of increased flow resistance due to any or all of the following reasons: (a) compaction of the porous membrane substructure; (b) release of tiny pinpoints of air or dissolved gas on and in the membrane; (c) electrical charge build-up due to streaming potential; (d) deposition of raw water turbidity (including microorganisms, clay organic turbidity, suspended iron and manganese, and colloidal color particles); (e) deposition of scale due to the precipitation of sparingly soluble dissolved salts; and (f) accumulation of ions adjacent to the membrane surface, which is responsible for "concentration polarization." Three operational approaches to the fouling problem are as follows: (a) preclarification of the feed, (b) accept the fouling phenomenon, but clean the membrane occasionally, or (c) accept the fouling phenomenon, but practice modular replacement.

Salt rejections above 90 percent are easily achievable. With current projections of research and development, it is anticipated that 99 percent rejection membranes will be available in the near future. In any event, it must be remembered that salt migration through the membrane is a function of the salt concentration in the feed [Equation (2)]. This becomes important when it is realized that the pressurized feedwater passing through a tubular system is continuously being "dewatered." Therefore, the feed becomes more concentrated and the quality of the product continually deteriorates through the system as more salt migrates through the membrane and less water migrates through the membrane to dilute it. At the end of the system, the concentrated feed is discharged as the waste stream. Alleviation of the concentration problem is achievable by operating at a low "water recovery": i.e., maintaining a high feed rate so that the product output is a small fraction of the feed. However, when a highly concentrated waste stream is desired, such as when processing wastewater, low "water recovery" is undesirable. Also, low "water recovery" results in a comparatively high energy requirement.

The hollow fiber configuration is illustrated in Figure 30. A typical module is a 4-foot-long, 4½-inch-diameter aluminum tube containing about 900,000 nylon fibers,

each fiber measuring 85 microns outside diameter and 42 microns inside diameter: total area 1900 square feet. It is noted that the packing density of a typical hollow fiber module is sensationally high. Much of the effect of tremendous area per cubic foot of equipment is lost, however, due to low flux. Also, the hollow fiber configuration is particularly subject to the common problem of membrane fouling.

The spiral-wound configuration is illustrated in Figure 31. This configuration, by tradeoff analysis, is probably the most suitable for use by the modern mobile Army.

In regard to field usage of RO, in addition to purifying polluted fresh water, seawater and brackish water, it is imperative that the RO unit be effective in decontaminating water containing CBR agents.

Very little data are available on the removal of radiological agents from water by reverse osmosis.

In analyzing the situation, it is recognized that radioactive substances resulting from the detonation of nuclear weapons will probably be partially soluble in water. In regard to the insoluble portion, the RO membrane is capable of 100 percent rejection. This is in line with its general capability of rejecting all forms of turbidity including clay, color particles, and microorganisms. In regard to the soluble portion, the dissolved radioactive ions are governed by the same permeation laws as stable, non-radioactive ions. Therefore, a rejection on the order of 99 percent can be expected with modern membrane material. However, further data should be obtained. In a preliminary study at Fort Belvoir about a decade ago with a now-obsolete plate and frame RO unit, 94 percent of strontium-85 was removed from tap water to which this radioisotope was deliberately added. It is noted that strontium-85 was used as a "simulant" for the very-dangerous fission product strontium-90, a long-lived bone-seeker. Strontium-85 is a gamma emitter (0.51 MEV) of short half-life (64 days).

Hindin and Bennett¹² reported a removal of 98.9% of chromium-51 (existing as the chromate) by Merana on a noxious liquid waste.

Based on results obtained, it is concluded that:

- a. RO is capable of removing up to 99 percent of dissolved salts from water.
- b. RO is capable of removing essentially all turbidity from water.
- c. In line with a and b above, RO should be capable of removing a high

¹² *Water Reclamation by Reverse Osmosis*, E. Hindin and P. J. Bennett, Water and Sewage Works, February 1969.



Figure 25. Army field water supply.

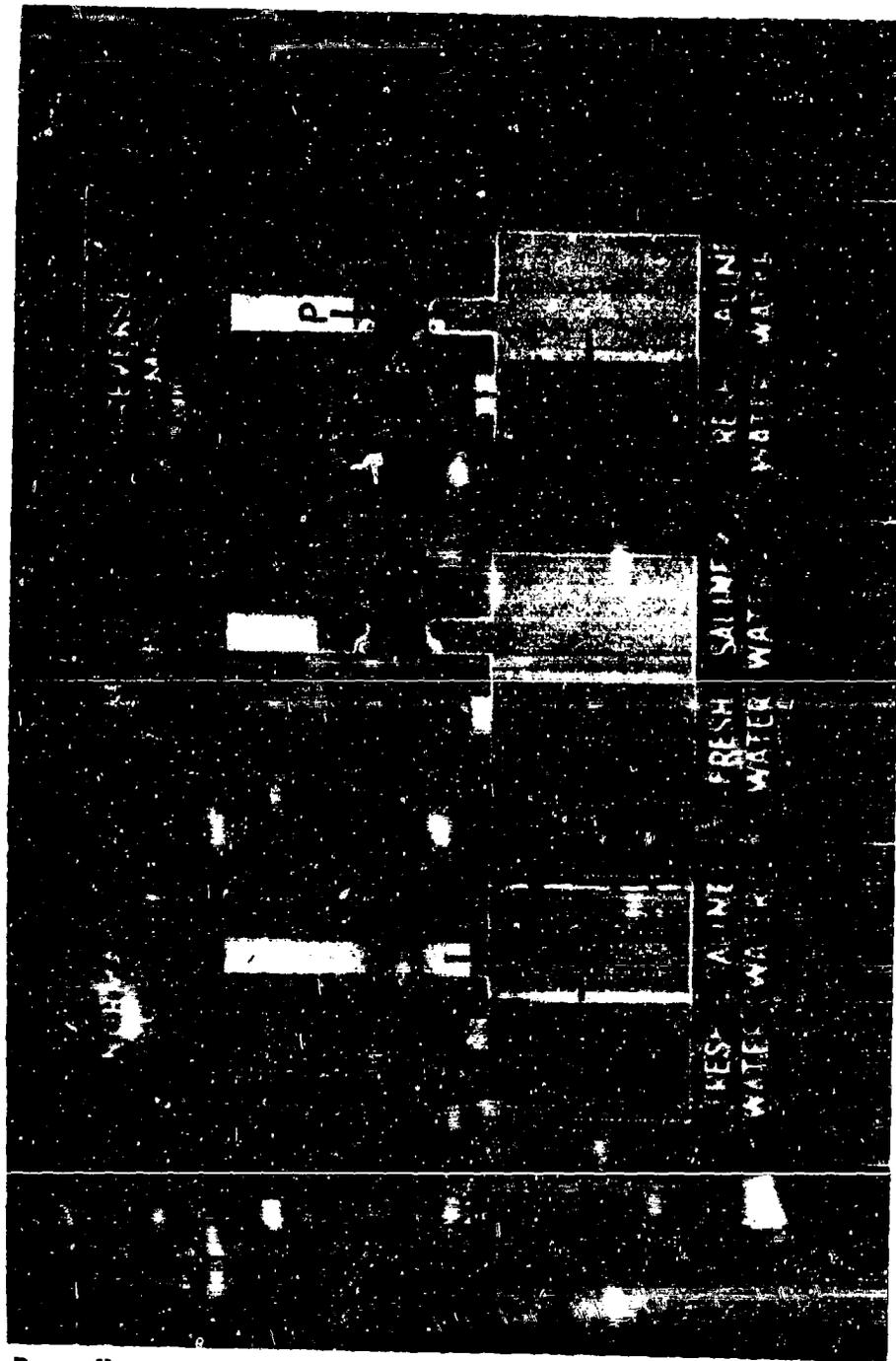


Figure 26. Reverse osmosis.



Figure 27. Cellulose acetate anisotropic membrane, cross-section.

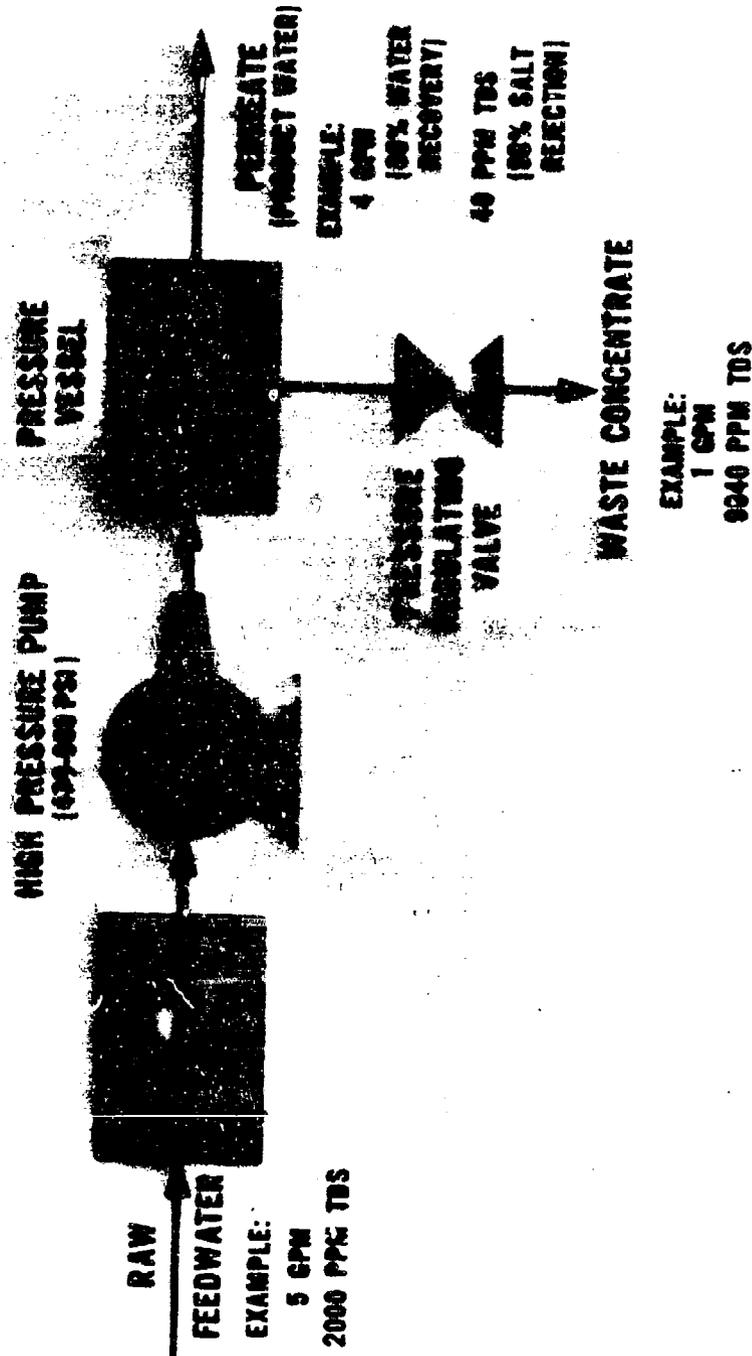


Figure 28. Basic flow chart, Reverse Osmosis Unit operation.

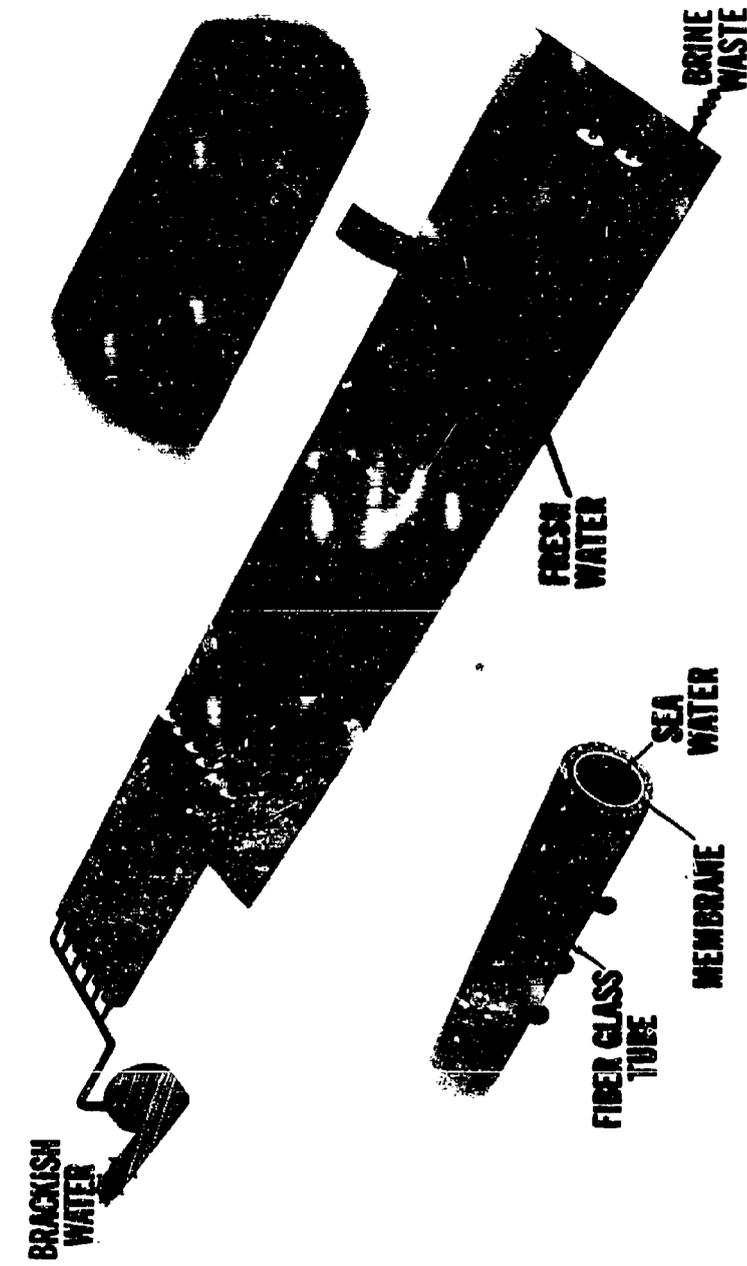


Figure 29. Tubular type reverse osmosis.

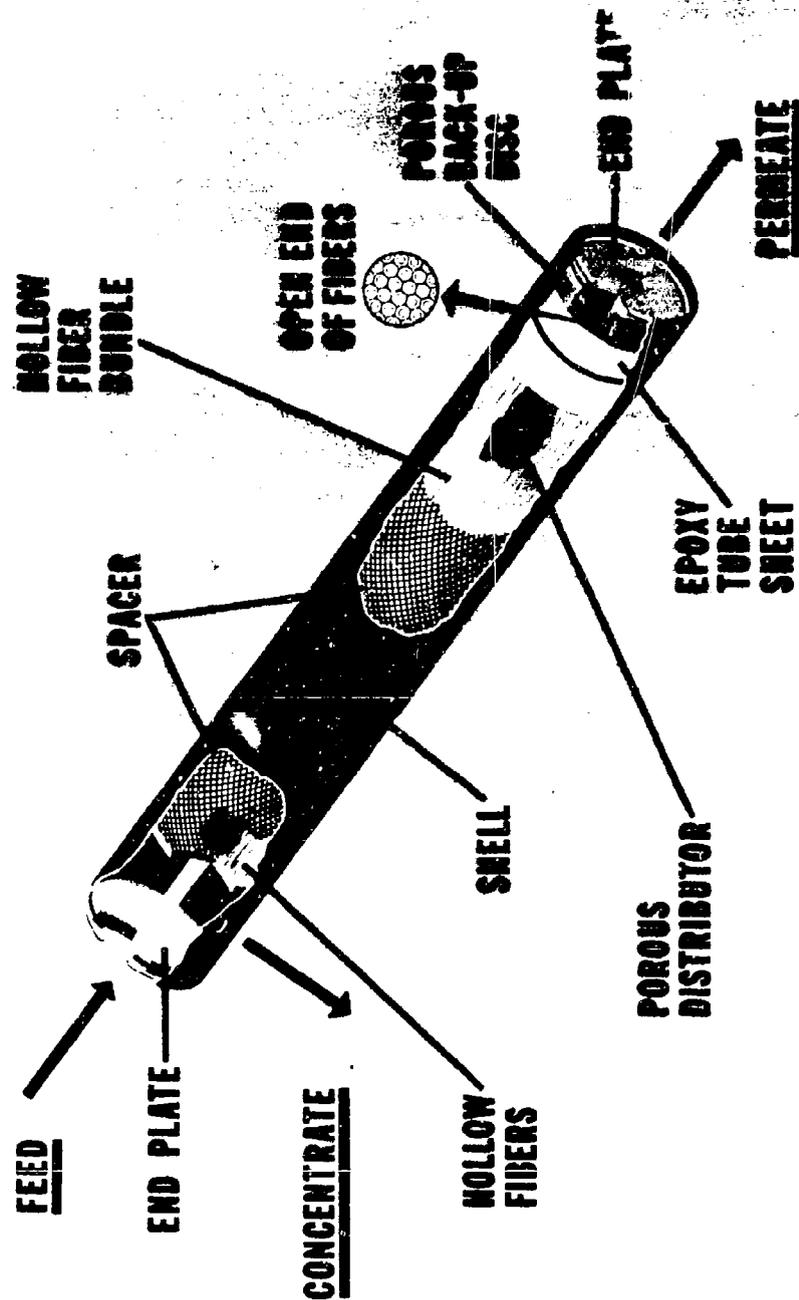
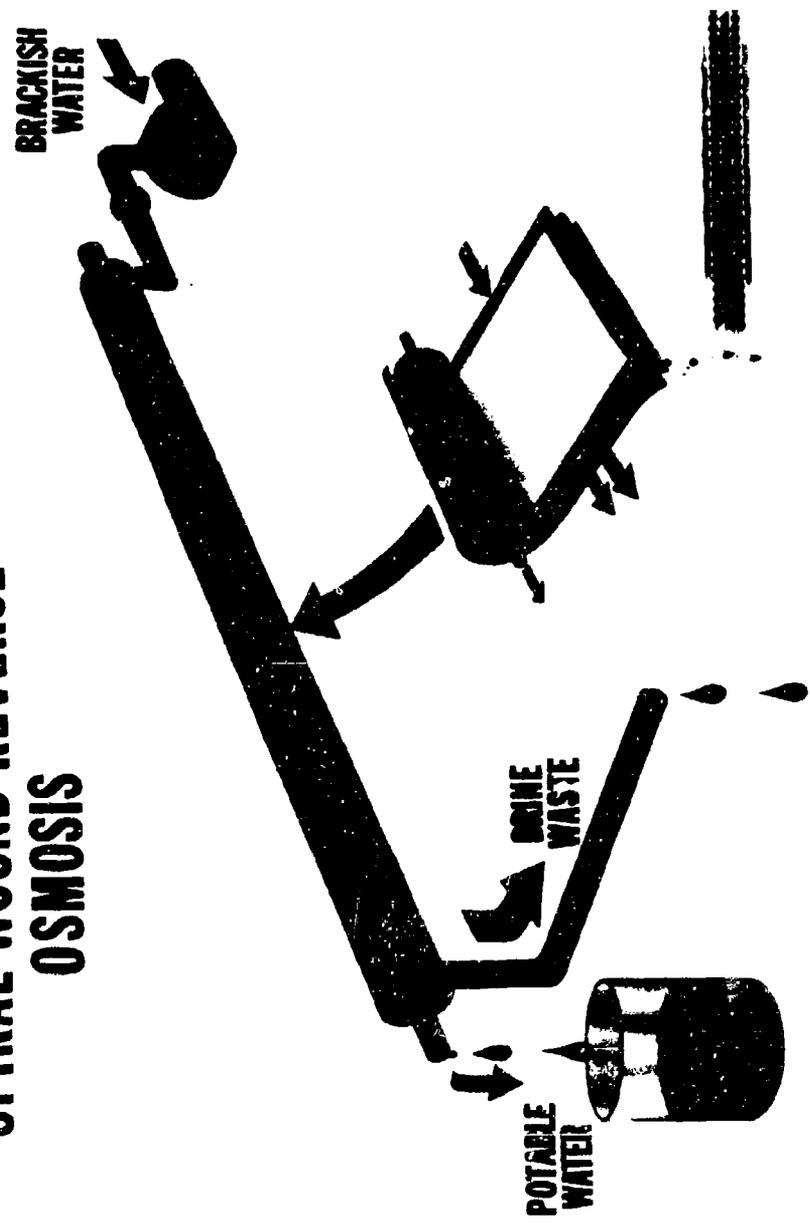


Figure 30. Hollow fiber reverse osmosis.

SPIRAL WOUND REVERSE OSMOSIS



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Figure 31.

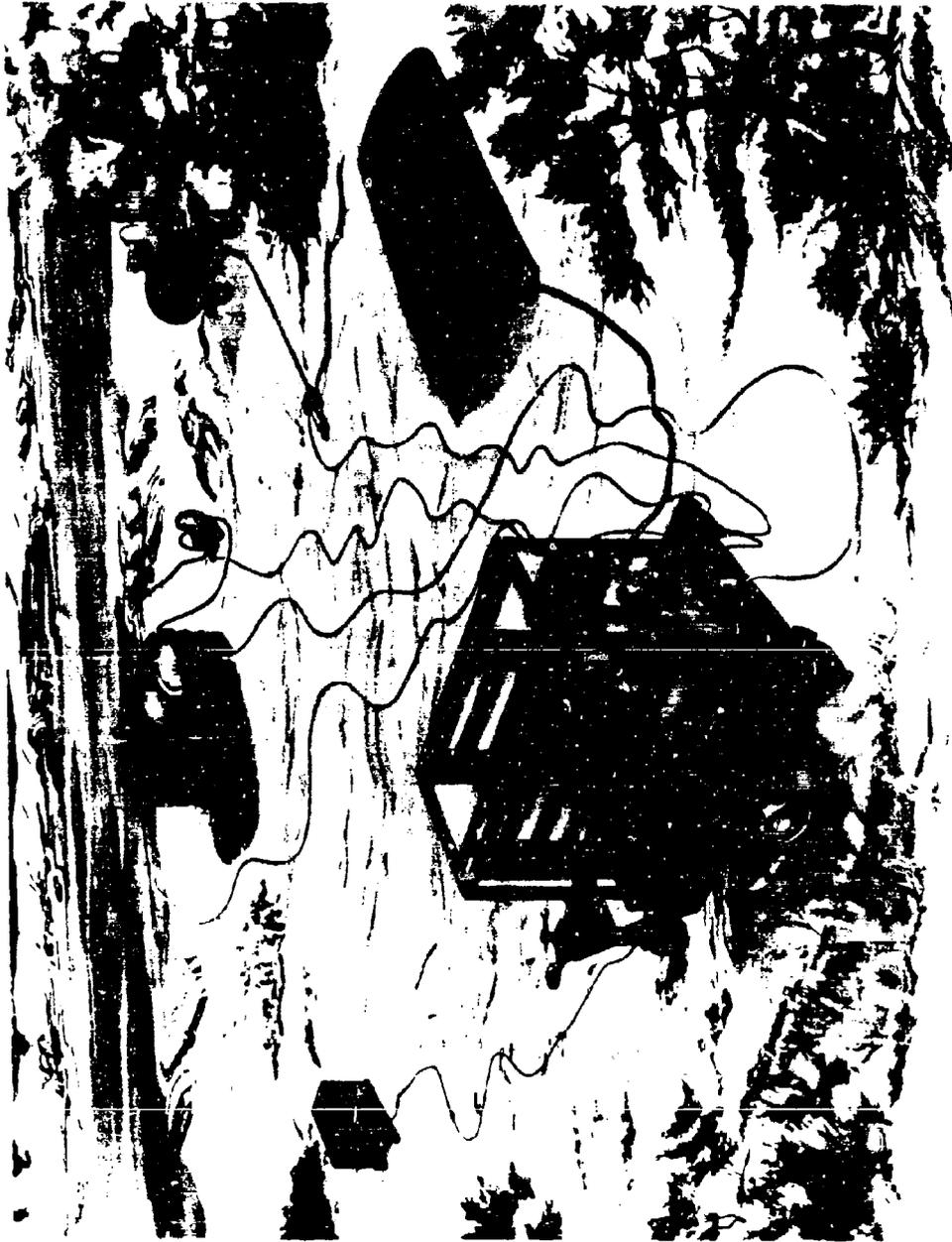


Figure 32. Artist's Concept 600-gph Reverse Osmosis Unit.

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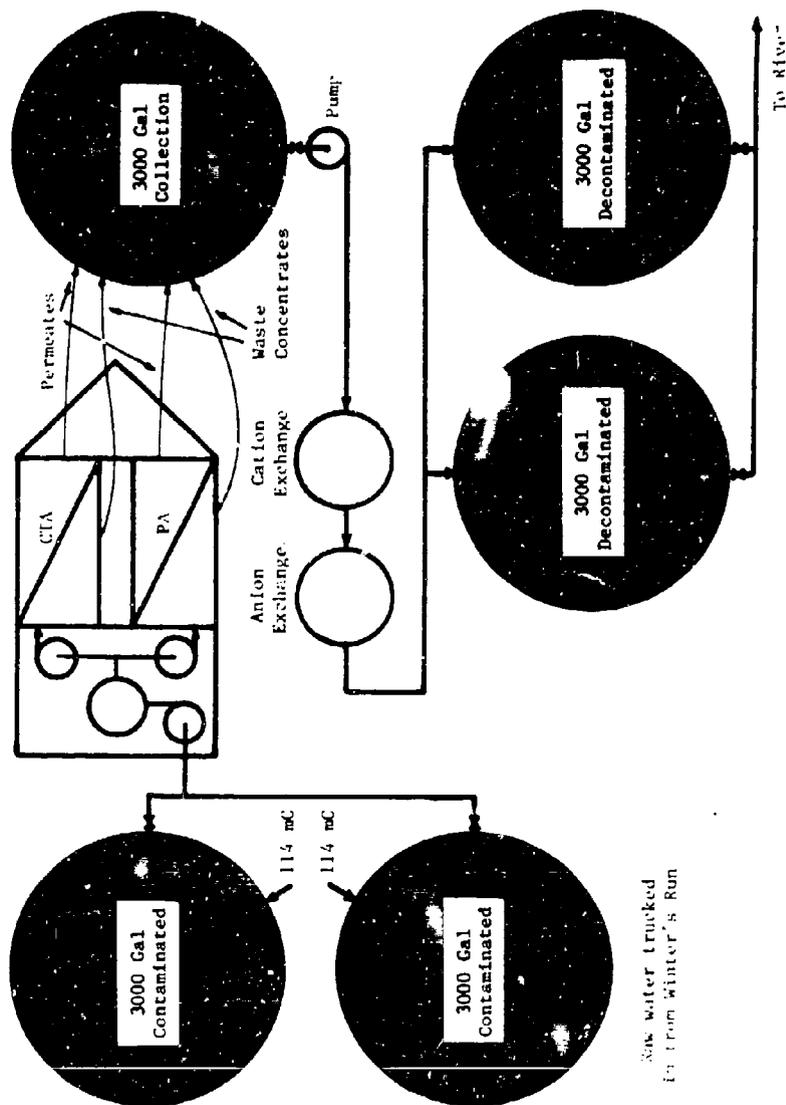


Figure 33. Equipment Layout, RO vs RW.

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percentage of the radioactivity that could be present in water as the result of fallout from the use of nuclear weapons.

d. RO is subject to membrane fouling, which seriously curtails its output and efficiency. The problem may be solvable by feedwater pretreatment, intermittent cleaning, or modular replacement.

e. RO is an inherently effective and simple process which lends itself to a single multipurpose Army water purification unit for purifying polluted fresh water, seawater, brackish water, and CBR contaminated water.

In recent developments, a 600-gph prototype unit has been produced (see Artist's Concept, Figure 32). This is the first of three types to be developed for the U. S. Army, with varying capacities. The 600-gph unit consists of ten pressure vessels, each containing two spiral wound RO modules. The incoming raw water is pretreated by additions of calcium hypochlorite for disinfection and a cationic polyelectrolyte, with subsequent filtration through a dual media (coal-sand) filter.

Future Research. It is planned to evaluate the reverse osmosis unit in the foreseeable future for decontaminating water containing radioactive materials.

Radioisotopes for Study
(RO vs RW)

| Agent of Concern (Fission Product) | |
|---------------------------------------|------------|
| Symbol | Half-Life |
| ⁹⁰ Sr (bone seeker) | 28.9 years |
| ¹³⁷ Cs (muscle-seeker) | 30.2 years |
| ¹³¹ I (thyroid-seeker) | 8 days |

It is proposed to contaminate the raw water to 10,000,000 picocuries per liter. This level of contamination is considered realistic in the event of a nuclear war. The equipment layout for planned tests is shown in Figure 33.

13. **Ground Water.** The Field Army has the capability to obtain ground water by developing dug, bored, jet-driven, and drilled wells. Of particular interest in defensive operations is the fact that properly located and constructed wells would not become contaminated by RW surface contaminants under average conditions. This is not to imply

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that ground water would be completely immune to contamination. Recent studies on the transport of synthetic detergents and other domestic and industrial waste products by ground water strongly suggest that ground water can bear its proportionate burden of contaminants falling on the ground surface. Nevertheless, ground water is considered a first line of RW defense and should be exploited whenever possible. In addition, ground water has many advantages other than freedom from contamination: e.g., (a) it is usually available during dry periods when surface water supplies may be depleted, (b) it is usually available at a near constant cool temperature, and (c) it might permit location of a water source within immediate proximity of the consumer. Ordinarily, however, ground water cannot be used as effectively in a mobile situation as in a static one because of the time required to locate and develop the wells. Well drilling equipment is heavy and bulky, and special skills are required to locate subsurface aquifers, drill wells, and deliver the water to the surface. In RW contaminated areas, tests would have to be performed to determine its presence (or absence) in ground water supplies. If RW were present, it would be necessary to treat the water by the developed technique: i.e., coagulation, filtration, and demineralization by ion exchange.

14. Hazards Consideration. Normally, when processing radioactively contaminated water, the water point operator requires no special protective clothing. Standard fatigues suffice, with the understanding that the fatigues are to be sent to the laundry after every shift. The point would be to avoid carrying radioactivity into the living quarter area, as it is recognized that splashing of radioactively contaminated water onto the fatigue uniform will probably occur in the normal operation of the equipment. Also, the operator should take a thorough shower after each shift to completely wash away any radioactivity which might have reached his skin. In the case of any airborne activity, such as dust or mist in the area, the M-17 standard CBR service mask should be used to avoid taking any activity into the lungs. Also, no water or food that has not been checked and cleared for radioactivity should be consumed.

The peculiar hazard of radioactivity, in contrast to chemical and biological warfare agents, is the penetrating power of beta and gamma radiation. Gamma radiation, in particular, has no trouble penetrating ordinary clothing or rubber suits. Therefore, the greatest hazards to personnel operating the ERDLator Unit and the Mobile Ion Exchange Unit lie in excessive exposure time and nearness to zones of concentrated gamma activity. These zones would normally be the outside of the ERDLator opposite the slurry pool, the outside of the bottom section of the Judge concentrator, and the outside surface of the cation exchange column. Based on data obtained at the Nevada Test Site in the fall of 1959, the personnel hazard is not great. During a 6-week test period in which several runs were made with contaminated water, the ERDLator Unit operator received only 210 milliroentgen-equivalent-man total body exposure and the Mobile Ion Exchange Unit operator only 30 milliroentgen-equivalent-man. This dosage is well below the 3000 milliroentgen-equivalent-man permitted by the AEC for any given 13-week period.

Some care should be exercised in disposing of concentrated wastes such as ERDLator floe, cation exchange regeneration fluid, etc. Three basic schemes are applicable:

- a. "Di and Di" - Dilute and disperse.
- b. "Co and Co" - Concentrate and confine.
- c. "De and De" - Delay and decay.

Reducing these principles to practice, it would appear that one of the following disposal practices could be invoked:

- a. **Downstream Discharge.** No addition of radioisotopes to the stream that were not there to start with.
- b. **Lagooning.** Could contaminate ground water.
- c. **Containerize and Ship Away to Nuclear Graveyard.** May be the best way, but is expensive, and may appear ridiculous in comparison with other problems associated with a nuclear war.

Consideration must be given to the decontamination of equipment that has been used for processing water that has been contaminated with radioactive materials. Two types of decontamination are involved. Gross decontamination involves the quick, reasonably effective methods that can be applied in the field to remove the bulk of the contamination. Detailed decontamination, in contrast, refers to the lengthy, thorough process carried out in a rear area and intended to restore the equipment to its original clean condition.

Equipment decontamination should proceed with awareness of certain fundamental facts, as follows:

- a. Equipment contamination with radioactive substance does not occur evenly. It favors rough or porous surfaces and those surfaces subject to scaling or encrustation.
- b. Some radioisotopes are more readily adsorbed on surfaces than others.
- c. Radiological contaminants, unlike chemical or biological contaminants, cannot actually be inactivated, neutralized, or destroyed. No degree of heat or cold or chemical reaction can speed up or slow down the rate of decay. Time is the only factor capable of destroying radioactivity. Therefore, the only way of decontaminating equipment is to remove the radioactive substance and transfer it elsewhere.

d. Determination of the degree of contamination may be difficult. Most of the contamination will be inside pipes, pumps, etc. In fact, positive radiation readings outside the plumbing can be obtained only when the contaminating material is a gamma emitter. When the contaminating material is an alpha or beta emitter, the radiation particles will usually be shielded by the wall thickness and will not be detectable on the outside. In this instance, the equipment will have to be opened, such as by loosening a union and, perhaps, a section of pipe removed. The probe of a beta-gamma survey meter, such as the IM-141/PDR-27J Radiacometer, may then be inserted directly into the pipe.

e. Decontamination should always proceed using "mild" methods, first, and then proceeding to so-called "harsh" methods.

The standard Army procedure for decontaminating water contaminated with radioactive substances calls for series processing in an ERDLator Unit and a Mobile Ion Exchange Unit.

The ERDLator Unit would remove all radioactive substances in suspension, and the Mobile Ion Exchange Unit would remove all radioactive substances in solution. Radioactive substances could be adsorbed on surfaces of the up-flow basin, pipes, pumps, etc, and in the scale and oxide films that normally form on metallic surfaces. Since most of the water passages of the Mobile Ion Exchange Unit are rubber lined, the contamination should be of a low order of magnitude. Before any equipment decontamination procedure is attempted, the first consideration should be the degree of contamination acceptable. For equipment to be transported to unrestricted areas, it would be desirable to maintain a radiation level essentially that of background, with the probe of a survey meter held directly on or close to the surfaces. For emergency wartime conditions, a much higher level of contamination would be acceptable, perhaps 20 milliroentgen-absorbed dose per hour or more. Radioactive substances inside the pipe would not then be harmful, as long as they were not leached out into the process water by a change in pH or other factors. Also, if the equipment were contaminated with fresh fission products, considerable decontamination could be accomplished by means of simple decay. The equipment should be allowed to stand idle for a week or more. This is effective if replacement equipment is available or if the equipment is not required immediately. If the radioactivity were of a long half-life or if the equipment were needed immediately, gross decontamination procedures would be initiated employing materials at hand, if possible. The water circuits should be flushed (or recirculated) with the following, in turn, as needed: clean uncontaminated water and clean uncontaminated water plus detergent. In many instances, this procedure would leave the equipment at a low enough level of contamination to be transferred to other areas.

When a more extensive decontamination is required, a detailed decontamination procedure, conducted in a rear area, is necessary. The procedure is as follows.

conducted in the exact order shown to achieve best results:

a. Conduct a preliminary flush to remove easily dislodged surface contamination.

b. Conduct a citric acid-disodium EDTA solution treatment by circulating the solution through the equipment. One-hour contact time is suggested, preferably at a temperature of 160°F to 200°F. Continue until a check of the residual activity indicates that the desired degree of decontamination has been achieved, or until it is apparent that a continuation of the treatment would result in no further decontamination. The citric acid-disodium EDTA solution is prepared by dissolving the following ingredients in hot water in the order shown: Disodium EDTA - 1 ounce/gallon; citric acid - 1 ounce/gallon; synthetic nonionic detergent - 0.1 to 1 ounce/gallon (Military Specification MIL-D-1679).

If further decontamination is necessary, conduct a sodium hydroxide-potassium permanganate ammonium citrate treatment. This treatment facilitates the removal of adherent oxide films with their associated contamination. The sodium hydroxide-potassium permanganate rinse is used first. One-hour contact time is suggested, preferably at a temperature of 190°F to 200°F. The solution is prepared by dissolving the following ingredients in water: Sodium hydroxide - 13.5 ounces/gallon; potassium permanganate - 4.9 ounces/gallon.

After the sodium hydroxide-potassium permanganate treatment, the equipment is given a water rinse and then subjected to an ammonium citrate treatment. One-hour contact time is suggested, preferably at a temperature of 190°F to 200°F. The solution is prepared by dissolving diammonium monohydrogen citrate in water as shown: Diammonium monohydrogen citrate - 13.5 ounces/gallon.

IV. CONCLUSIONS

15. Conclusions. It is concluded that:

a. The use of nuclear weapons poses a severe threat to water supplies as a result of contamination with fission products, unfissioned plutonium or uranium, or neutron-activated radioisotopes.

b. Fallout from a nuclear weapon varies widely in its water solubility, depending primarily upon the nature of the soil in the vicinity of ground zero.

c. For evaluation of water decontamination processes, a provisional MPC of 300,000 picocuries per liter of beta-gamma activity served as an adequate guide.

d. A semiquantitative check of the level of activity in raw or finished water can be made with a standard PDR-27J beta-gamma radiation meter. The probe is protected with a rubber sheath, inserted into the water, and a conversion made from the meter reading in milliroentgen per hour to picocuries per liter.

e. The standard Army ERDLator Water Purification Unit is effective for removing radioactive substances from water when present as suspended insoluble turbidity. The ERDLator will not remove radioactive contaminants present as soluble radioisotopes.

f. The efficiency of the standard ERDLator Water Purification Unit in removing soluble radioisotopes can be improved substantially by pretreating the contaminated water with clay or some other radioisotope adsorbent.

g. The standard Army Vapor Compression Distillation Unit is effective in decontaminating water containing radioactive material.

h. A field expedient method consisting of the following steps is effective in removing CBR contaminants from water: superhypo-chlorination and activated carbon adsorption in series in a Lister bag, coagulation, filtration, mixed-bed ion exchange demineralization, and post chlorination.

i. The standard Army Ion Exchange Unit, when used as a post treatment device after the standard ERDLator Unit, is effective for removing soluble radioactive substances from water.

j. The reverse osmosis water purification process is promising for decontaminating water containing radioactivity in both the soluble and insoluble state.

k. Ground water may reasonably be assumed to be free of radioactive substances and should be used whenever the tactical situation permits.

l. Radioactive waste slurries developed as a result of using Army field water purification equipment should be disposed of properly by burial or other appropriate means.

APPENDIX A

USAMERDC REPORTS

DECONTAMINATION OF WATER CONTAINING RADIOLOGICAL AGENTS

| USAMERDC Report No. | Title of Report with Date & Brief Description |
|------------------------|---|
| 1275 | "Purification of Water Contaminated with Radioactive Material," 24 December 1952. Describes jar test studies at the Oak Ridge National Laboratory using powdered metals, clay, coagulants and ion exchange resins for the removal of reactor-produced fission products and selected radioisotopes from water. |
| 1313 | "Removal of Radioactive Materials from Contaminated Water by Thermocompression Distillation," 28 August 1953. Describes the use of a 60-GPH vapor compression distillation unit for removing fission products and significant individual radioisotopes from water at the Oak Ridge National Laboratory. |
| 1357 | "Removal of Radioactive Substance from Water by Ion Exchange Processes," 11 June 1954. Describes laboratory ion exchange studies and a pilot-size ion exchange column for removing fission products and significant radioisotopes from a water. |
| 1396 | "Removal of Radiological Warfare Agents from Water," 22 April 1955. Describes the removal of aged fission products and selected radioisotopes of radiological warfare significance from water by coagulation, clay adsorption and ion exchange. Equipment evaluated includes 60-GPH vapor compression distillation unit, Water Purification Set No. 1 and a field expedient. |
| 1404 | "Removal of Radioactive Materials from Water by the Water Purification Unit, Hand-Operated, Knapsack-Pack, Filter-Pad-Type, ¼-GPM and by a Field Expedient," 19 May 1955. Describes evaluation of Water Purification Set No. 1 for removing radioactive substances from water. Removals of 85 to 95 percent of fission products indicated with clay pretreatment. Also describes a field expedient consisting of a column packed with clay, humus, and vegetation which removed 85 to 95 percent of fission product activity. |

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- 1406 "Removal of Radioactive Contaminants from Water with the Corps of Engineers Mobile Water Purification Unit," 27 May 1955. Describes field operation of 1800-GPH Mobile Water Purification Unit at the Oak Ridge National Laboratory for removing fission product activity from water by conventional processing, pretreatment with clay, and post treatment with ion exchange resins.
- 1451-RR "The Removal of Radioactive Material from Water by Serial Coagulation, by Ion Exchange and by Charcoal Adsorption," 22 June 1956. Describes laboratory studies at the Oak Ridge National Laboratory for removing radioactive substances from water by serial coagulation with various coagulant combinations, ion exchange, and adsorption on activated bone charcoal.
- 1492-RR "Ion Exchange for the Removal of Radionuclides from Water," 7 August 1957. Describes the use of ion exchange equipment for removing fission product activity from water.
- 1569-TR "Solubility Characteristics of Radioactive Bomb Debris in Water and Evaluation of Selected Decontamination Procedures," 12 February 1959. Describes work conducted at the Nevada Test Site under Operation Plumbbob using bomb debris obtained from shot Priscilla. Debris was subjected to a laboratory study of its solubility characteristics in water, followed by an evaluation of coagulation, adsorption, ion exchange, and other processes for removing the debris from water.
- 1613-RR "Decontamination of Water Contaminated with Plutonium," 12 January 1960. Describes experiments conducted at the Los Alamos Scientific Laboratory evaluating the 1500-gph Mobile Water Purification Unit for removing plutonium from water. Also describes pilot scale work on the decontamination efficiency of softening, carbon adsorption and ion exchange processes.
- 1673-RR "Removal of Nuclear Bomb Debris, Strontium-90, Yttrium-90, and Cesium-137, Barium-137 from Water with Corps of Engineers Mobile Water Treating Equipment Covers experiments conducted at the Nevada Test Site studying the 1500-gph Mobile Water Purification Unit and 1500-gph Mobile Ion Exchange Unit for removing from water 1-year-old nuclear bomb debris ground to 3 microns average particle size. Also covers the removal of soluble strontium-90 - yttrium-90, and cesium-137 - barium-137.

- 1702-RR "Removal of Chemical, Biological, and Radiological Contaminants from Water with Corps of Engineers Field Water Supply Equipment," December 1961. Summarizes and applies to field use research data obtained on the removal of chemical, biological, and radiological agents from water. Discusses the problem and covers maximum permissible concentrations, detection, water decontamination equipment and methods, protective clothing and equipment decontamination.
- 1832 "Blast Effects on U.S. Army Water-Storage Containers," October 1965. Describes a study made at the Suffield Experimental Station, Canada, investigating the blast vulnerability of current military water-storage containers relative to: shock damage and water contamination resulting from airborne dust. Tanks filled with water were exposed to the effects of a 500-ton TNT detonation.
- 1904 "Field Expedients for Decontaminating Water Containing Nuclear Bomb Debris," July 1967. Covers the results obtained at the Nevada Test Site during the summer of 1962 investigating: the solubility of radioactive debris in water, field methods of determining the concentration of radioactive materials in water, field expedient methods for removing radioactive materials from water, and a squad-type universal method for the removal of CBR agents from water.

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| 1613-RR | PB 147816 |
| 1673-RR | PBAD 265585 |
| 1702-RR | PBAD 274300 |
| 1832 | AD 625396 |
| 1904 | AD 656930 |

APPENDIX B

ADDITIONAL REPORTS

Sanitary Sciences Division Participation (Non-USAMERDC Reports)

1. "Effects on Selected Water Supply Equipment," Operation Buster Project 3.9, 24 April 1952, Lindsten and Hansen, Defense Atomic Support Agency, Unclassified. Available from Sanitary Sciences Division, USAMERDC, Fort Belvoir, Virginia.

Describes the effects of a nuclear air burst on water stored in 3000-gallon GRS coated nylon fabric tanks. Study conducted at the AEC Nevada Test Site in 1951.

2. "Evaluation of U.S. Army Field Water Supply Equipment and Operations," Operation Jangle 6.8, 15 May 1952, Lindsten and Lowe, Defense Atomic Support Agency, Unclassified. Available from Sanitary Sciences Division, USAMERDC, Fort Belvoir, Virginia.

Describes the effects of a nuclear ground-surface blast on water stored in 3000-gallon GRS coated nylon fabric tanks. Also describes an evaluation of a U.S. Army 15-gpm Diatomite Water Purification Unit for removing radioactive contamination from water. Study conducted at the AEC Nevada Test Site in 1951.