Low-Level Radioactive Wastes

Council on Scientific Affairs

Under a federal law, each state by January 1, 1993, must provide for safe disposal of its low-level radioactive wastes. Most of the wastes are from using nuclear power to produce electricity, but 25% to 30% are from medical diagnosis, therapy, and research. Exposures to radioactivity from the wastes are much smaller than those from natural sources, and federal standards limit public exposure. Currently operating disposal facilities are in Beatty, Nev, Barnwell, SC, and Richland, Wash. National policy encourages the development of regional facilities. Planning a regional facility, selecting a site, and building, monitoring, and closing the facility will be a complex project lasting decades that involves legislation, public participation, local and state governments, financing, quality control, and surveillance. The facilities will utilize geological factors, structural designs, packaging, and other approaches to isolate the wastes. Those providing medical care can reduce wastes by storing them until they are less radioactive, substituting nonradioactive compounds, reducing volumes, and incinerating. Physicians have an important role in informing and advising the public and public officials about risks involved with the wastes and about effective methods of dealing with them.

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UNDER a federal law passed in 1980 and amended in 1985, all states by January 1, 1993, must provide for safe disposal of low-level radioactive wastes (LLRW) generated within their borders. Hospitals and physicians generate 25% to 30% of the wastes, and the 50 states produce a total of about 2.7 million cubic feet each year in civilian applications.[1] What are the sources and makeup of the wastes? How are the states planning to comply with the laws while ensuring the safety of their citizens and their participation in the process?[2] What are the environmental and technological factors that must be considered in developing disposal facilities? This report considers such issues, summarizes the progress of 1 state, and makes recommendations about how physicians can help with the problem.

BACKGROUND AND DEFINITIONS

Radioactive wastes may be classified into five categories according to their origin, content of radioactivity, and hazard[3]: spent fuel from nuclear power reactors; high-level wastes, which include materials remaining after the separation of uranium and plutonium from fuel rods for nuclear reactors; transuranic wastes, which consist of elements with atomic numbers higher than that of uranium and extracted during the reprocessing of fuel rods; uranium and thorium mine and mill tailings, which include large amounts of radium and its decay products; and LLRWs.

Low-level radioactive wastes are defined by what they do *not* include[2]: they do not include spent fuel, high-level radioactive wastes, more than 3700 Bq/g (100 nCi/g) of transuranics, or mine or mill tailings. The wastes may be in solid, liquid, or gaseous form. About 57% of LLRWs by volume and 80% by content of radioactivity result from activities and procedures associated with generating nuclear power[4,5]; these wastes include paper, glass, plastic, cloth, filtration materials, resins, sludges, and metal materials. Some wastes result from industrial uses of ionizing radiation such as manufacturing smoke detectors and exit signs, measuring thicknesses and concentrations, and examining the structures of manufactured products. A total of 25% to 30% of the wastes by volume result from medical uses.[3,4] The nation's inventory of LLRWs accumulated to 1984 made up about 84% by volume of all radioactive wastes, and it contained 0.1% of the total radioactivity in the wastes.[5]

In 1985, about 20 000 civilian facilities in the United States produced 2.68 mil-

From the Council on Scientific Affairs, American Medical Association, Chicago

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This report is not intended to be construed or to serve as a standard of medical care. Standards of medical care are determined on the basis of all of the facts and circumstances involved in an individual case and are subject to change as scientific knowledge and technology advance and patterns of practice evolve. This report reflects the views of the scientific literature as of December 1988

Reprint requests to Council on Scientific Affairs, American Medical Association, 535 N Dearborn St, Chicago IL 60610 (William R Hendee, PhD)

lion cubic feet of LLRWs with an activity of 28 × 10^9 MBq (749 100 Ci).[6] The federal government, which has its own facilities for storing wastes, produced a similar volume that had twice as much radioactivity. These volumes represent only a minuscule proportion of all wastes generated in the nation through agriculture, mining, and industry and in homes.

In medicine, LLRWs may be related to diagnosis, treatment, or research.[7] Diagnostic procedures may involve virtually any body system and may yield wastes of short-lived gamma ray emitters such as technetium Tc 99m, indium 111, and thallium 201. Wastes from treatment often include longer-lived beta or gamma ray emitters such as iodine 131 and phosphorus 32, and they may include those from sealed sources of iodine 125 and iridium 192, which have half-lives of 60 and 74 days. Wastes from nuclear power reactors and other nonmedical uses include iridium 192, cesium 137 (half-life, 30 years), and cobalt 60 (half-life, 5 years).[6] In terms of radioactivity, cesium 137 makes up almost all LLRW from nuclear power reactors; strontium 90 (half-life, 29 years) and iodine 129 make up much smaller proportions of the wastes.[8]

Biomedical research may involve the use of radioisotopes in such diverse projects as exploring enzyme kinetics, determining the distribution of drugs in body fluids, or studying the structure of nucleic acids. Wastes from research and teaching applications may include hydrogen 3 (tritium), carbon 14, phosphorus 32, and sulfur 35, with half-lives that range from 14 days for phosphorus 32 to 5730 years for carbon 14. Technetium Tc 99m, with a half-life of about 6 hours, and hydrogen 3, with a half-life of about 12 years, are two of the most widely used radionuclides.

RISKS

Low-level radioactive wastes may emit alpha, beta, or gamma radiation and in some cases neutrons or combinations of these forms. Alpha radiation is the least penetrating type and can be stopped by the skin.[7] However, it can damage lung tissues if substances emitting it, such as radon gas, are inhaled. Beta radiation can penetrate the skin and also can present a hazard to internal tissues. Gamma radiation, which is similar to x-rays, can be attenuated effectively by dense materials such as concrete or lead. Any ingested source of ionizing radiation may damage tissues; the adverse effects would depend on the dose the source delivered and the sensitivity of the tissues.

Although the volumes of LLRWs generated by power companies, other industries, and medical institutions may be large, volumes can be diminished and their handling made easier by compaction, incineration, or evaporation.[7] Many radionuclides used in clinical medicine have relatively short half-lives and may be stored until they have decayed to background levels, then disposed of through the institution's trash disposal system. Also, scintillation fluids and animal carcasses containing less than 1850 Bq (0.05 μCi)/g of hydrogen 3 or carbon 14 may be disposed of without regard to their radioactivity.[9] However, any other hazard related to these materials needs to be considered.

Under national standards set by the US Nuclear Regulatory Commission (NRC) in the Code of Federal Regulations (10 CFR 61), which apply to LLRW disposal facilities, releases of radioactivity from the nuclear fuel cycle affecting any member of the public must not exceed 0.25 mSv (25 mrem)/y to the whole body or 0.75 mSv (75 mrem)/y to the thyroid. A dose of 0.25 mSv approximates the amount received annually by the average person because of natural exposure to cosmic rays[10] and is much less than the average annual exposure per person, 3 mSv (300 mrem), received from all natural sources.[11]

The toxicity of all LLRWs, if combined, is relatively low per unit of volume, and after 100 years it would approximate that of soil if the content of naturally occurring radium and heavy metals in the soil were considered.[12] Eisenbud[13] estimated that LLRWs from uses in biology and medicine contribute less than 0.01 mSv (1 mrem) to each person's annual radiation exposure; the latter is about 3.6 mSv (360 mrem) per person.[11] Fallout from atmospheric testing of nuclear weapons also may be responsible for exposure of 0.01 mSv (1 mrem) per year.[11]

The US Environmental Protection Agency (EPA) estimates that annual exposures of persons living near a disposal facility would be almost 0 to 0.1 mSv (10 mrem) per person, depending on the method of construction, geological characteristics of the area, rainfall, and other factors. The EPA intends to develop environmental standards for the disposal of LLRWs covering exposures to the public from managing and processing the wastes; exposures to the public from disposing of the wastes; groundwater protection; wastes that are "below regulatory concern"; and higher-activity, naturally occurring, and accelerator-produced radioactive wastes (F. L. Galpin and W. F. Holcomb, presentation before American Institute of Chemical Engineers, Minneapolis, Minn, August 16-19, 1987). In some instances the groundwater standards will be those of drinking water. The EPA agrees with the NRC standard, which is that exposures of the public should not exceed 0.25 mSv (25 mrem) per person per year.

DISPOSAL FACILITIES PAST, PRESENT, AND FUTURE

Prior to 1963, federally owned and supervised sites and facilities received all LLRWs generated in the nation.[4] In that year, this disposal service was discontinued, and the US Atomic Energy Commission began to license commercial facilities to receive the wastes. By 1971, licensed facilities existed in Illinois, Kentucky, Nevada, New York, South Carolina, and Washington. During the 1970s, however, reports began to circulate that improper packaging and insufficient compacting of the wastes, theft of contaminated tools, and contamination of groundwater were occurring at the facilities. Although no adverse public health effects were shown,[4] opposition to the facilities by the public and state governments mounted; by 1979, facilities in Illinois, Kentucky, and New York had closed, and the remaining ones were threatening to close.

Reacting to the threat, Congress in 1980 passed the Low Level Radioactive Wastes Policy Act (Public Law 96-573), under which each state eventually would become responsible for ensuring proper disposal of LLRWs generated within its borders through civilian activities.[2] In the act Congress stated that disposal facilities could best be provided through compacts, or agreements, among regional groupings of states, but it did not designate the groupings. Also, it stated that after January 1, 1986, any regional facility would be allowed to exclude wastes from states outside of the region.

After passage of this legislation, most action in the states concerned discussions about whether to join a compact and, if so, which one.[2] Once a compact was formed, negotiations were needed among the member states and formal agreements had to be signed. All of the states wanted to protect the interests of their citizens, and an overriding issue was which state would have the first disposal facility for the region. Another issue was the sharing of liability in the event of an inadvertent escape of radioactivity.

Progress toward the 1986 deadline was slow despite pressure from the three states with operating disposal facilities. In 1985, Congress intervened and passed amendments to Public Law

96-573. These set a series of deadlines for states in planning and licensing disposal facilities; outlined financial penalties if the states did not develop sites; and specified that after December 31, 1992, parties generating LLRWs in states without facilities could ask their states to take possession of the wastes, and the states would assume legal liability if they did not do so.

At present, facilities for LLRWs remain open at Beatty, Nev, Richland, Wash, and Barnwell, SC; the latter receives about half of the LLRWs generated in the United States[2] but is scheduled to close on January 1, 1993. Table 1 shows the status of regional compacts and the states that have not joined compacts as of March 1989. "Host states" are those in which the first disposal facilities will be located.

SELECTING DISPOSAL SITES

The NRC is responsible for rules and regulations pertaining to the disposal of radioactive by-products, and it may allow states with appropriate enabling legislation and approved radiation protection agencies and programs, called "Agreement States," to assume this responsibility. At present about half of the 50 states, including Illinois, are Agreement States, and others are preparing to apply for this status. Illinois and Pennsylvania are "host states" for their respective compacts and are making progress in preparing the regional disposal facilities that they will regulate Information and materials are available from the Illinois Department of Nuclear Safety (Thomas A. Kerr, [217] 524-6417) and the Pennsylvania Department of Environmental Resources (William P. Dornsife, [717] 787-2163) that describe the many issues and processes involved in planning the facilities.

Selecting a disposal site and preparing and operating a facility in a manner that will ensure public safety and maintain environmental quality are complex undertakings that involve legislation, government oversight, public participation, financing, engineering and technology, supervision, surveillance, and quality control over a period of decades. Table 2 lists some steps in the process.

Illinois, the host state for the Central Midwest Compact, is making progress in managing its LLRWs, and the procedures it has followed are informative. Through a state law passed in 1983, the Illinois Department of Nuclear Safety (IDNS) received authority to develop a program and select a site for a disposal facility, and Illinois became an Agreement State in 1986. The Illinois facility will be financed completely by fees paid by the generators of LLRWs.

Table 1 —Status and Makeup of Regional Compacts

Compacts Approved by Congress and President	
Northeast	**Central Midwest**
Connecticut (host state)	Illinois (host state)
New Jersey (host state)	Kentucky
Southeast	**Central**
North Carolina (future host state)	Nebraska (host state)
Alabama	Arkansas
Florida	Kansas
Georgia	Louisiana
Mississippi	Oklahoma
South Carolina (host state)	
Tennessee	**Rocky Mountain**
Virginia	Nevada (host state)
	Colorado
Midwest	New Mexico
Michigan (host state)	Wyoming
Indiana	
Iowa	**Northwest**
Minnesota	Washington (host state)
Missouri	Alaska
Ohio	Hawaii
Wisconsin	Idaho
	Montana
Appalachian	Oregon
Delaware	Utah
Maryland	
Pennsylvania (host state)	
West Virginia	
Compact Pending Approval of Congress	
Southwestern	
Arizona	
California	
North Dakota	
South Dakota	
States Not in a Compact	
Maine	Puerto Rico
Massachusetts	Rhode Island
New Hampshire	Texas
New York	Vermont
	Washington, DC

Table 2 —Processes, Procedures, and Factors in Developing Disposal Facilities for Low-Level Radioactive Waste

- Enabling legislation, decision about agency or group to have responsibility for construction and operation
- Selection of favorable and unfavorable site factors, survey of state for possible sites, selection of site, selection of contractor
- Public participation in site selection process, open meetings and active public relations programs, provision for continuing oversight by public board or committee involvement of knowledgeable professionals
- Determination of financial benefits that will accrue to municipality and county hosting facility
- Development of facility's design and specifications, specification of forms for receiving and storing wastes
- Financing of construction and operation, determination of rate and fee structure and costs to be met
- Ensuring quality control during construction, ensuring quality control during operation, including receiving, transporting, record-keeping, and checking integrity of waste containers
- Monitoring of air, water, and ground in and around facility, monitoring health of population around facility; monitoring health of workers at facility
- Preparing for emergencies and emergency closures, planning for closure and monitoring of facility after useful life
- Funding for contingencies and legal costs
- Maintaining good relations with other states in the compact; deciding on use of facility by other states

Officials selecting the site for the Illinois facility considered it essential that the facility be located where there would be no opposition by a county or municipal government. Beginning the process, the IDNS identified counties in Illinois with an interest in having the facility, and it also identified counties having favorable geological characteristics. Twenty-three counties met these criteria. Using the state's computer-based Geographic Information System and considering "exclusionary" and "favorability" factors, the IDNS identified 72 possible sites, each at least 4 square miles in area.

Under the Illinois approach, "exclusionary factors" consisted of the presence of a floodplain or standing water, earthquake history, designated and protected lands, and the possibility of landslides "Favorability factors" related to absence of shallow aquifers, low soil permeability, lack of sand and gravel, lack of high-yield groundwater aquifers, simple geological structure, low erosion potential, and not being in a watershed for surface water supplies. Other important factors related to population concentrations, presence of prime farmland, existing industry and projected industrial development, presence of endangered species, and presence of archeological, cultural, or historical sites.

Aridity and lack of precipitation simplify the management of radioactive and other types of wastes.[14] Stabilizing the wastes and selecting a site with hydrological and geological features that minimize movement of contaminants are other key factors.[15] While it is known that radioactive substances can be stable in geological strata over thousands of years, the episode at Maxey Flats, Kentucky, in which radiation-containing materials moved through soil and contaminated water and milk, and other episodes in which water infiltrated disposal sites[4] illustrate the hazards that must be prevented.

In 1988 the IDNS designated two sites for detailed geological and environmental studies. The first site is located near Martinsville, a city in central Illinois near the eastern border. The Martinsville City Council and surrounding townships expressed strong support for the LLRW program, and the IDNS began detailed studies of this site in June 1988. The second site is near the town of Geff, in Wayne County in southeastern Illinois. Members of the Wayne County Board unanimously supported location of the LLRW disposal facility in that county. After completion of studies in both places and with the approval of the local government, the IDNS in late 1989 will make a final decision about location of the disposal facility.

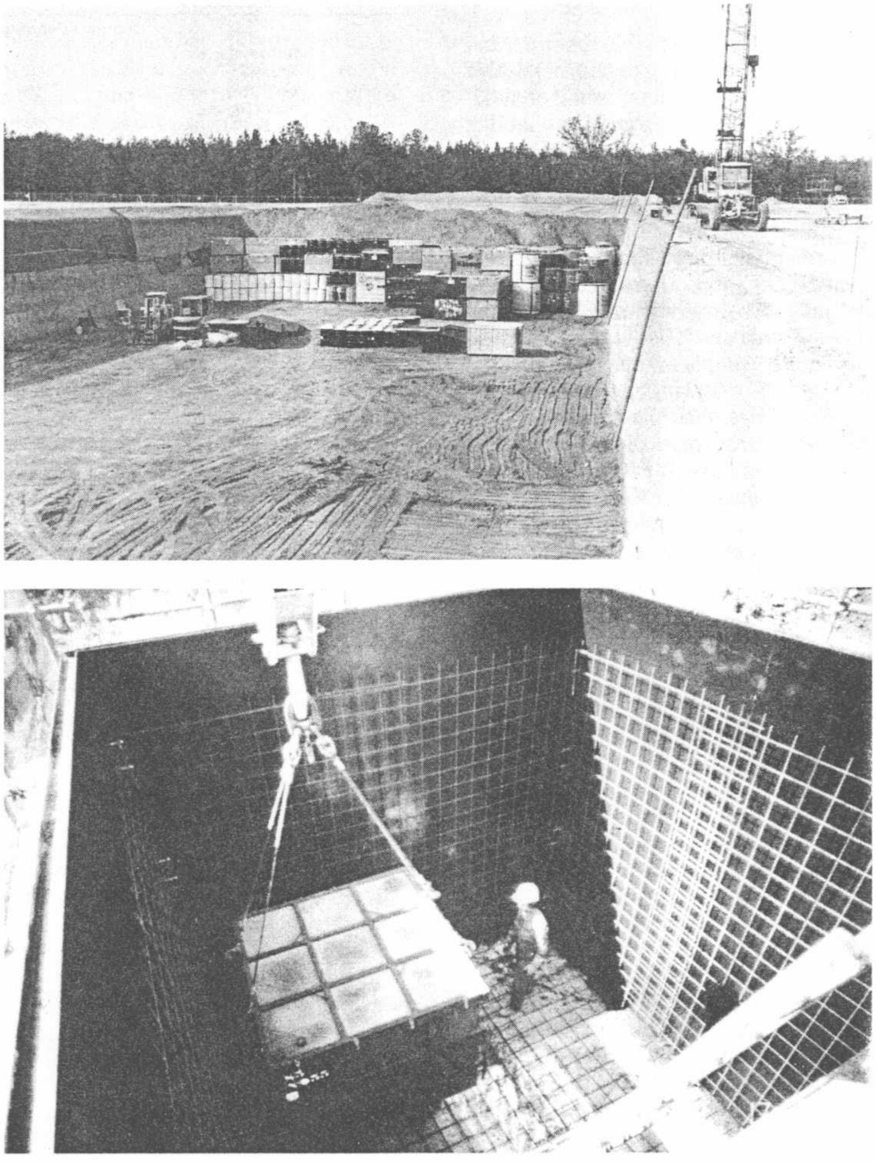
BUILDING AND FINANCING FACILITIES

Future disposal facilities for LLRWs probably will make use of multiple-engineered safeguards to isolate the wastes, concentrating and stabilizing them, placing them in strong-walled containers that will maintain their integrity, preparing a type of facility above or below ground that will minimize any escape of radioactivity or radiation that might affect people or the environment, and controlling access.[6] The Central, Central Midwest, Midwest, and Northeast compacts, and some states such as Pennsylvania, have specified that the facilities must be aboveground; other states will allow shallow land burial.

Protection against disruption of the facility by people or natural forces will be sought. Monitoring of the containers and of groundwater and air will be basic features, as will protection of workers at the facility and of persons living nearby. Some of these activities will continue long after the disposal facility is closed.

In the past, facilities built for LLRWs utilized "shallow land burial," the wastes being placed in wide trenches 25 ft deep (Figure). Sand, gravel, and crushed stone cover the bottom of the trenches to a depth of several feet. Containers are inspected and then placed into the trenches by crane, and the wastes with high levels of radioactivity are segregated. Sand is forced into the spaces among the circular containers. When the facility reaches its capacity, clay, gravel, topsoil, and grass are used to cover and restore the area. Other approaches have utilized underground cells with walls of reinforced concrete or boreholes that have steel liners and wide caps of concrete. In all cases, records are maintained of the locations of wastes.

In general, it is expected that those who generate the LLRWs will pay the costs of transporting and storing them. Costs for medical institutions probably will be variable: at Children's Memorial Hospital in Chicago, Ill, the costs per year are negligible; at a medium-sized hospital in LaGrange, a suburb near Chicago, and at a hospital in Princeton, a town in rural Illinois, costs per year also are low. In contrast, the Mayo Clinic in Rochester, Minn, each year produces 6000 cu ft of LLRWs, and the disposal costs might reach $50/cu ft[7]; to reduce the costs the clinic uses storage and incineration.



Disposal facilities for low-level radioactive wastes. Top, Trench dug in clay at Barnwell, SC, for wastes with lowest content of radioactivity. Bottom, Facility in France; wastes are embedded in underground cubical structure of reinforced concrete, 20 ft on a side (from Russ[6]).

In 1987, the University of Cincinnati (Ohio) disposed of 1755 cu ft of LLRWs that contained 3.3×10^{10} Bq (0.9 Ci), the total cost of disposal was $53 445 (G. W. Alexander, Jr, written communication, May 16, 1988). In 1985, the cost of shipping a 55-gal drum from New York, NY, to Washington State and disposing of the contents was $400.[9] Arranging for disposal of the wastes is becoming increasingly difficult (E. Party, MS, oral communication, May 8, 1989). Several authors have reviewed aspects of the problem, listed some points about which investigators might be watchful, and suggested actions that might be taken to solve the problem and reduce costs.[9,16]

Eisenbud[17] estimated that if an engineered disposal facility cost $10 million, if one case of cancer occurred after every 2000 person-rems (20 person-Sieverts) of exposure, and if 100 persons near the facility each were exposed annually for 50 years to a dose of 0.003 mrem (0.00003 mSv), which according to NRC regulations is conceivable, then the cost of preventing one case of cancer among the 100 persons would be hundreds of billions of dollars. In contrast, the cost of saving a life by screening for cervical cancer is $25 000.

TRANSPORTING WASTES

Low-level wastes usually are reduced in volume before they are shipped, which decreases costs and increases the safety of handling, shipping, and storage and also increases concentrations. Compaction can reduce volumes by 90% and incineration by 95%, with most of the radioactivity remaining in the ash. Wastes are classified by the NRC on the basis of radioactivity per unit of volume Class A wastes, those with the least radioactivity, require only safe handling and packaging. Class B and class C wastes must be stabilized to keep their size and shape for 300 years and may be stored together. Class C wastes, which have the greatest concentrations of radioactivity, must include barriers against intrusion that are effective for 500 years Any form of LLRW may be packaged in a high-integrity container of plastic, steel, or concrete that will last 300 years.

Methods for transporting radioactive wastes vary according to the number of becquerels involved, the concentration of the wastes, the type of vehicle utilized, and the potential for escape of radioactivity to the environment.[4] About 90% of LLRW contains low radioactivity and may be shipped in wood or steel boxes.[6] Material that is moderately radioactive must be shipped in more secure containers, usually 55-gal metal drums Containers for highly radioactive materials are very rugged; some have double steel walls 1½ inches thick surrounded by 3½ inches of lead shielding This type of container must pass severe damage tests including a 30-ft drop onto a steel rod, submersion, and exposure to a fire of 1475°F (802°C) for 30 minutes

Some institutions contract with licensed brokers who collect and dispose of the wastes. Past experience with millions of shipments indicates that current precautions and standards have shielded the public and protected the environment adequately.[4] During 40 years of transportation operations, no person has been shown to have been injured by the radioactivity in a shipment of wastes.[6]

PAST AMA ACTIONS

In 1979, the American Medical Association (AMA) House of Delegates adopted Resolution 44 (1979 Interim Meeting) urging the NRC to allow separation of LLRWs from those of higher activity and to encourage the establishment of disposal facilities for LLRWs.

Resolution 171 (1979 Interim Meeting) directed the AMA to monitor the safety of nuclear power and to initiate model legislative action through state medical societies that would facilitate the safe disposal of LLRWs. The Council on Scientific Affairs thereafter prepared the report "Risks of Nuclear Energy and Low-Level Ionizing Radiation"; Recommendation 4 of that report stated that local laws should be modified to allow disposal of LLRWs utilizing model legislation developed by the AMA. In June 1980, the AMA's Department of State Legislation developed a model bill on the subject.

In November 1979, L. M. Freeman, MD, testified before Congress on behalf of the AMA that inability to dispose of LLRWs threatened the availability of diagnostic and therapeutic procedures. Dr Freeman emphasized that new disposal sites and procedures to reduce volumes of LLRWs were necessary.

In March 1985, the AMA wrote Senator Thurmond, chairman of the Senate Judiciary Committee, supporting the development of regional facilities for disposing of LLRWs and emphasizing the need to establish regional sites. The AMA's letter noted the important contributions of radiopharmaceuticals and radionuclides to the diagnosis and treatment of disease.

COMMENT AND SUMMARY

Without doubt, the benefits of the activities giving rise to LLRWs outweigh the hazards that are associated with the wastes, provided that the latter are treated in accordance with existing standards and the well-understood principles of radiation protection.

Congress has passed laws specifying that by January 1, 1993, all states must be responsible for disposing of their own LLRWs. If a state has not made arrangements by then to store its wastes at a regional facility or at its own disposal site, the state may be asked by those generating the wastes, for instance, power plants and hospitals, to assume all liability for any effects of the wastes. This emphasizes the need for each state to progress in a timely fashion toward meeting the 1993 deadline.

About 120 million nuclear medicine procedures are carried out each year,[6] and 25% to 30% of all LLRW is produced by physicians, physicists, pharmacists, scientists, technologists, and others involved with diagnosis, treatment, and medical care.[3,4,16] Those in universities, medical schools, and larger hospitals and laboratories are most likely to generate the wastes. Their activities benefit not only individual patients but society as a whole in terms of basic science studies and research. For example, about 90% of new drugs require evaluation using radioisotopes [1]

Hospitals, clinics, and physicians' offices can diminish the hazards of LLRWs by incinerating them, which reduces the volume of liquids, storing the substances until their radioactivity falls to safe levels, or substituting nonradioactive compounds. With incineration, the cost, licensing, and local approval of use of the incinerator may pose difficulties.[16] Increasing the importance of these measures is the likelihood that those generating the wastes will be expected to pay the costs of the disposal facilities. The facilities are likely to be expensive. About 235 000 cu ft of wastes is generated each year in the states of the Appalachian Compact, and the cost of storing the wastes is estimated to be $100 to $200 per cubic foot; thus, the annual cost of the facility conceivably could reach $47 million.

All physicians, including those in clinical practice as well as those in public health, and especially physicians in radiology and nuclear medicine, should help their states develop safe disposal facilities for LLRWs. With their training and background in the physiology of disease and their knowledge about risks to health, physicians should be able to provide advice and perspective about the radioactive wastes to those in government, public agencies, and industry who are responsible for making decisions about the problem.

Physicians have an important role in informing the public about the relatively small magnitude of risks associated with LLRWs. They should become familiar with the issues and inform their patients. They may have opportunities to communicate with the media and can lead discussions in classrooms and among groups in the community. Although knowledge about the biologic effects of ionizing radiation probably surpasses that of almost all other environmental factors in health and disease, there is an immense gap of public distrust regarding the uses and risks of radiation. Physicians and the professional groups of which they are members should help society bridge this gap.

RECOMMENDATIONS

The Council on Scientific Affairs recommends adoption of the following policy statement:

1. Many activities of society giving rise to LLRWs are useful; such activities include diagnosis and treatment of disease, research in science and medicine, and industrial uses such as generating electricity, detecting metal fatigue, and discovering oil.
2. The rules and recommendations for radiation protection promulgated by the NRC, the EPA, the National Council on Radiation Protection and Measurements, and the International Commission on Radiological Protection ensure that the framework is in place to build and operate facilities for LLRWs in a manner that protects the safety of workers and the public.
3. Physicians should inform their patients and help inform the public about the many beneficial uses of radioactive materials and about the measures and standards that are in place to reduce unnecessary exposures to these materials.
4. Physicians should minimize the diagnostic and therapeutic exposures of patients to radiation in accord with good medical practice.

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