Chapter II

THE GENERAL IMPACT OF ATOMIC ENERGY ON TORT LAW

The purposes of this chapter are: (1) to acquaint the reader with the importance of atomic energy to society by describing some of the more important of its peaceful applications; (2) to describe how peaceful uses of atomic energy may result in injuries to persons and property; and (3) to suggest the legal problems that lawyers must deal with when advising clients of liability problems or trying tort liability cases in the atomic age. Analysis of the legal problems and possible solutions will be included in subsequent chapters.

A. Peaceful Uses of Atomic Energy

Any account of the peaceful applications of atomic energy is bound to become out-of-date rapidly because of the new discoveries that are being made almost daily. However, the potentialities of atomic energy in industrial, medical, agricultural, and research pursuits already are sufficiently well known to make it clear that atomic energy will play an ever-increasing role in society. The peaceful uses presently employed can be classified roughly into three major categories: (1) the use of the fission chain reaction process in reactors for the production of heat energy and radioactive isotopes; ¹ (2) the use of sources of radioactivity where the radioactivity itself is employed for specific purposes; and (3) the use of radioisotopes as a tool or a research instrumentality. Each of these uses, as we shall see, involves certain hazards that may cause injuries to persons and property.

1. Reactors and Their Hazards

The discovery of methods of harnessing the atom has revolutionized thinking on the problem of supplying the energy needs of modern society. It has been estimated whereas one pound of coal can produce about 1.4 kilowatt hours of electricity, one pound of uranium could, if fully consumed, release enough heat to produce 3,700,000 kilowatt hours

¹ The fusion process apparently has tremendous possibilities as a heat energy and neutron source, but since the technologic aspects apparently have not been solved, the fusion process will not be discussed.
of electricity and is equivalent in heat energy to about 1,320 tons of coal. In the United States, which is extremely wealthy in conventional fossil fuel resources, including coal, oil, and gas, the availability of nuclear energy derived in the fission process means that we can measure our energy resources in terms of centuries rather than a few generations. For portions of the world less well endowed with fossil fuel resources, the fission process makes possible the attainment of a standard of living previously thought impossible. The discovery of a means of using the fusion process to produce peacetime power would increase the magnitude of available energy sources to an even more astonishing degree. Clearly we can expect an ever-increasing utilization of nuclear energy as a power source throughout the world even in the United States where an abundance of comparatively cheap fossil fuels will make it difficult for nuclear power plants to compete economically, especially during the research and development stages. In fact, the Atomic Energy Commission has recently issued licenses for the construction of privately financed atomic energy power installations in the New York, Detroit, and Chicago areas.

To date, the truly dramatic potentialities of the controlled chain reaction in reactors designed to produce electricity have overshadowed many other possible practicable uses. Reactors may be employed to space heat buildings and residences, to propel ships, locomotives, and airplanes, to supply heat in many industrial pursuits such as the manufacture of cement and brick, to produce radioactive and other chemicals, to test materials, to act as blast furnaces in the reduction of ores, to treat diseases, and undoubtedly to accomplish many other tasks that are yet to be envisaged. The imposing array of methods of commercial exploitation of the fission process puts the legal profession on notice that it will within the next decade be required to handle innumerable legal problems involving atomic energy.

Assuming, as we must, that nuclear reactors are destined to become commonplace, lawyers must become acquainted with the technological processes involved to ascertain whether or not existing rules of tort law can be applied in cases of civil liability arising from reactor situations, or whether reactors will necessitate revision of the conventional rules of law. Without doubt, so far as the law is concerned, the unique feature of reactors is that they present a continuous threat to persons and property unless the utmost precautionary measures are taken. The fission process, if it can be controlled, apparently would not present as great hazards as encountered in the fission process.
chain reaction process involves the release of large quantities of all types of ionizing radiation which, as described in Chapter I, can have extremely deleterious effects on all forms of life and property. Therefore, one of the most important technological problems in reactor construction and operation has been that of providing essential safety for employees and the surrounding community. Moreover, the fission process creates a sizable number of radioactive waste materials that create secondary hazards and even perhaps greater danger in the long run.

Although all reactors have in common the purpose of utilizing a controlled fission process, they vary substantially in design depending upon the manner in which they are to be utilized. Furthermore, several possible techniques may be employed for the same utilization. For power purposes alone, several different designs have been constructed or are in the process of construction and still others are yet in the planning stage. Reactor technology is still in its infancy, and it is not to be expected that in the years immediately ahead any single design will have proved its superiority over others. Reactor designs can be classified in many ways: (1) by the types of fissionable material used; (2) by the speeds of the neutrons, either thermal (slow) or fast; (3) by the types of moderators (materials used to reduce the speed of the neutrons); (4) by the coolants used to maintain heat levels; (5) by the structure of the reactor cores (heterogeneous if the fissionable material is placed in the reactor core in units separated by moderators and coolants and homogeneous if the fissionable material is uniformly mixed with the moderator in the reactor core with the coolant surrounding the core); (6) by the chemical and heat reactions that occur in the reactor cores; and (7) by the ability of the reactor to produce fissionable material in the process of consuming fuel (breeder reactor). A single reactor design may incorporate several of these features. Obviously, a most important consideration for commercial reactors is the cost of the various types.

Up to the present time water and sodium-cooled reactors have played the predominant roles in American power reactor development. Actual experience is largely confined to thermal (slow neutron) water-cooled types. With Atomic Energy Commission financial assistance, Westinghouse has constructed a pressurized-water reactor for the Duquesne Light Company at Shippingport, Pennsylvania. Another type of water-cooled reactor, but one in which steam generation is permitted to occur in the reactor core (experimental boiling water reactor), has been developed by Argonne National Laboratory, and it has recently been re-
ported that the reactor operated at more than twice design capacity. Another type of water-cooled device is the homogeneous reactor being developed by the Oak Ridge National Laboratory. An experimental sodium-cooled graphite-moderated reactor, built by North American Aviation, Inc., became critical in 1957. General Electric Company and Pacific Gas & Electric Company have cooperated in the development of a boiling water reactor at Pleasanton, California which also became operative in 1957. The Atomic Energy Commission has already constructed one fast neutron experimental breeder reactor and is in the process of constructing a sodium-cooled experimental breeder reactor at the National Reactor Testing Station in Idaho. And, finally, the Commission has issued construction permits for three large power reactors.\(^8\) Other reactor concepts for which experimental work is being completed are an organic-moderated reactor and a liquid metal-fuel reactor. In addition, several low energy research reactors which are air- or gas-cooled have been developed.

Among the important factors to be considered in selection of a particular reactor for power purposes are: (1) safety in operation and in changing fuel elements; (2) economy in cost of fuel elements; (3) economy in cost of fuel reprocessing necessitated by efficiency-reducing contamination during the fission process; (4) reliability for continuous operation; (5) reliability of essential materials in withstanding nuclear forces; and (6) heat-producing potentialities. Each of the major reactor types has specific advantages and disadvantages for the production of power on the basis of current experience. Therefore, in view of technological problems involved, selection becomes a question of judgment. During the present initial development stages, the choices must be made largely in the absence of conclusive technological data. The lawyer advising clients engaged in atomic power reactor projects must evaluate the possible legal consequences of any particular selection.

The pressurized-water reactor seems to be the most highly developed technologically, but a considerable amount of information regarding specific features of the reactor remains classified. Nonetheless, on the basis of published data it would appear that pressurized-water reactors present several serious hazards, many of which are also inherent in other reactor designs.

\(^A\) boiling water reactor (180,000 electric KW) is now under construction by the Commonwealth Edison group near Joliet, Illinois; Consolidated Edison Co. of N.Y. is building a pressurized water reactor (275,000 electric KW) at Indian Point, N.Y.; Power Reactor Development Co. is constructing a fast breeder reactor (100,000 electric KW) at Monroe, Michigan. For the more complete details of the reactor program see AEC Semi-Annual Reports.
Since the pressurized-water reactor has been successfully operated in the submarine *U. S. S. Nautilus* and is being used in the first large size central-station nuclear power plant in the United States at Shippingport, Pennsylvania, it may be of assistance to sketch the principal technological problems and hazards involved. The Shippingport reactor employs fifteen to twenty tons of uranium, slightly enriched in the uranium isotope 235. The reactor core contains closely spaced, zirconium-clad fuel elements arranged in a cylindrical shape six feet in diameter and seven and one-half feet high. The core and the water which acts as the moderator-coolant are housed in a pressure vessel, thirty-three feet high, twelve feet in diameter, with the plate of the vessel being eight and one-half inches thick with a one-quarter inch cladding of stainless steel. Pressure in the vessel will be about 2,000 pounds per square inch which means that the water can reach a temperature of nearly 640° F before boiling. Therefore, the fuel elements cannot have a surface heat temperature in excess of 600° F. Three different heat exchange systems (steam generators) will be operated at once, with a fourth to be constructed as a standby. In each system water will have to be pumped at the rate of 16,000 gallons a minute to remove the heat. The reactor vessel and the heat exchangers are enclosed in strong gas-tight containers, located underground in concrete and steel vaults. The containers act as shields against radiation hazards and minimize the possibility of radioactivity escaping in the event an accident occurs.

Although it would appear that excess neutrons created in the fission process could be used to create new fissionable material from the non-fissionable fertile uranium 238 so that the fuel elements could be used almost indefinitely, this is not the case. During the fission process, the new atoms which are the "ashes" or "waste products" of the nuclear furnace accumulate, and they tend to absorb the neutrons so that the chain reaction cannot be sustained. Also, radiation causes the fuel elements to undergo changes both in size and in structure. Therefore, when approximately one per cent of the fertile material has been consumed, it will become necessary to change the fuel elements and remove the waste products. The Shippingport reactor will be a major test of a system of removing fuel elements while maintaining the entire reactor under pressure. If in removing the elements, pressure falls, so that the water reaches its saturation (boiling) point at a lower temperature, serious disruption of the reactor core may result in its disintegration with a possible release of radioactivity within the plant. In addition, if the underground chambers are breached, radioactive products may be
released in the atmosphere or into the subsoil, thereby endangering the surrounding community. In such delicate operations, it is not difficult to envisage the possibility that an accident may result in several persons being subjected to damage suits, including the reactor designer, the manufacturer of the mechanical apparatus for removing fuel elements, and the contractor who built the underground chambers, as well as the owner-operator of the facility.

Nearly all of the “ashes” of a nuclear furnace are radioactive, emitting both beta and gamma radiation. About eighty different radioisotopes are created in the fission process, and in the decay process the number increases to about 200 in a relatively short period of time. The half-lives of these radioisotopes vary from a few seconds to several years. Therefore, methods must be devised to protect personnel when spent fuel elements are removed and during the reprocessing of the fuel elements. Remote controls are therefore essential to the handling of the fuel elements. After removal, the fuel elements are stored under water for as long as 100 days. During the “cooling” period, short-lived isotopes decay sufficiently to make them an insignificant hazard in the separation process. Those isotopes with very long half-lives are insignificant because of their slow rate of decay. Despite the “cooling” period, however, the fuel elements, because of the isotopes of intermediate half-lives, remain highly radioactive. Therefore, in separating the fission products from the fuel, utmost safety precautions must be taken. If the reactor power installation does not have its own processing facilities, spent fuel elements must be transported in sealed and shielded containers to other establishments. If, in transport, a container is broken and persons are exposed to the radiation, thereby causing injury, a question arises as to who is liable—the carrier, the reactor owner-operator, the contractor hired to handle packaging, the manufacturer of the container, or all of them. By contracting out this function, can the reactor owner-operator absolve himself from part or all of the liability?

Because of the serious health hazard, waste fission products cannot be disposed of in the same manner as wastes from other industries. The wastes may be in liquid, gas, or solid form and, depending on the processing, may have different levels of radioactivity. Liquid wastes, which constitute the bulk of the material, are usually stored in underground tanks. As reactors become more commonplace, suitable storage sites will diminish in number, and accordingly this method of disposal is not considered very satisfactory. “The volumes of stored waste accumulated by 1980 are estimated at $20 \times 10^7$ gallons, by 1990 at $60 \times 10^7$
gallons and by 2000 at \(240 \times 10^7\) gallons."

4 Furthermore, the radiation may create high temperatures in the liquid wastes and thereby cause them to become so corrosive as to cause breaches in the containers.

Moreover, there is the problem of tankage leakage occurring because of deterioration of the material of the tank or as a result of geological changes resulting, for example, from an earthquake. If there is leakage, it may seep into rivers that supply water to communities or into individual wells. Therefore, extreme caution must be taken on a purely geological basis in selecting sites. Again, problems of marshaling proof to impose liability in the event of injury may become difficult. The problems are complicated by the fact that injury may not occur until years after the waste products were originally stored. If some of the waste products can be converted to useful purposes, a desired end that seems a reasonable possibility, some of the waste disposal problems may be eliminated or at least minimized.

Gaseous wastes are generally discharged into the atmosphere through high stacks. No significant hazard is created if the spent fuel has "cooled" for a considerable period, and if meteorological conditions are satisfactory for the dilution of the radioactive gases in the atmosphere. If meteorological conditions are adverse, however, dangerous quantities of gaseous wastes may endanger persons and property in the vicinity. Another hazard is found in the possibility of the air in a processing facility becoming contaminated by absorbing small particles of liquid or solid radioactive wastes. Since this can present a serious problem, all air expelled from the plant is filtered. To reduce this hazard, the processing vessels are usually maintained under air pressure less than atmospheric in order to minimize the escape of radioactive material into the air.

Solid wastes consist of substances that have been contaminated in a reactor or fuel processing facility, including those that have settled from liquid wastes. Some radioactive components and equipment can be satisfactorily decontaminated, but in other cases it is not possible or desirable to do so, and therefore it is usually buried in the ground. This creates some of the same dangers as underground storage of liquid wastes. On the Atlantic and Pacific coasts, some solid wastes are being buried at sea.


6 Maximum permissible concentration levels in the atmosphere should be established in the light of future discharge rate possibilities according to the Committee on Meteorological Aspects of the Effects of Atomic Radiation, National Academy of Sciences, National Research Council, "The Biological Effects of Atomic Radiation," p. 61 (1956).
However, for inland facilities, the cost of transporting solid wastes may be prohibitive. Thus, the reasonableness of the various methods of disposal may vary in accordance with plant location.

Throughout the entire fuel reprocessing operation two hazards are present. One is caused by the highly radioactive nature of the materials and the other arises out of the fact that the amount of fissionable material at a given point may become critical so that a fission chain reaction occurs. To protect personnel, adequate shielding against radiation must be provided. All process vessels, equipment, pipelines, valves, etc., must be leakproof and shielded. The equipment particularly must be properly designed and manufactured with excellent workmanship to reduce repair and maintenance problems. If maintenance is required, it can be handled only by those using remote control devices or entering the area after the equipment has been sufficiently decontaminated to avoid serious hazard. To avoid a chain reaction, which would cause serious damage within and possibly outside the plant, concentration of materials in any single vessel must be limited and separate vessels must be kept apart by an adequate distance. Since most of the operations in a fuel reprocessing plant are inaccessible to humans, remote control instrumentation is essential to handle the operation and to sample the materials at the various processing stages. A failure to install proper instrumentation or perhaps a failure in the instrumentation itself may result in the escape of highly radioactive materials into the atmosphere or in a concentration of fissionable materials which would cause a chain reaction.

In addition to fuel reprocessing problems, reactor technology also encounters a series of difficulties in connection with the fabrication and cladding of the fuel elements, the type of moderator used, the materials used in the reactor structure, and the type of coolant.

Uranium, other fissionable materials, and fertile source metals (such as thorium) react rapidly with oxygen; and also at high temperature water has a particularly corrosive effect on these materials. Since fine chips or lathe turnings are a serious fire hazard if exposed to the air, fabrication of uranium metals must be carried on in a vacuum or in an atmosphere of inert gas. Moreover, the fuel element in the reactor must be clad with a corrosion resistant material to prevent attack by air or by a water coolant and to prevent the escape of fission products and plutonium produced in the fission process. The cladding must possess nuclear properties that will not interfere appreciably with the fission process. Aluminum has been widely used as a cladding material in research reactors since it readily retains fission products. However, aluminum is
violently attacked by water at high temperatures. Therefore, it is not very suitable for power reactors since higher temperatures are more efficient in steam generation. It is for this reason that the Shippingport reactor fuel elements will be clad with zirconium which has suitable nuclear properties as well as a high resistance to corrosion. Even for zirconium the maximum safe surface temperature in water is only approximately 660° F, so that a maximum operating water temperature of only about 560° F is possible. Nevertheless, this compares favorably with the maximum permissible surface temperature with aluminum of 400° F. Neither aluminum nor zirconium is satisfactory for a sodium-cooled reactor which is to operate at very high temperatures. Stainless steel seems to be about the only present possibility for this purpose even though it captures neutrons at a higher rate than either aluminum or zirconium.

Another problem in respect to cladding is its removal when reprocessing the fuel. Aluminum dissolves easily, but stainless steel and zirconium are fairly difficult to remove. It may be possible that more effective mechanical methods can be devised for the purpose; but because of high-level radioactivity, this will have to be done by remote control. Because of the importance of the cladding, it can readily be seen that an error in the thickness or in the purity of the cladding material can cause damage of very serious proportions. Erroneously using aluminum cladding in fuel elements to be operated at too high a temperature for the metal could result in the disintegration of all or part of the reactor core, with a resulting release of large quantities of highly dangerous radioactive gases and particles. Similarly, running a reactor at high temperature levels approaching levels where the cladding disintegrates in an attempt to reach the maximum steam generation capabilities could result in an accident of catastrophic proportions. On the other hand, stainless steel jackets erroneously made thicker than necessary for the purpose may seriously impair the efficiency of the reactor because of excess absorption of neutrons. Careful engineering design is essential; and errors of judgment may, in the event of accident, give rise to legal liability.

Other materials employed in reactors must also be chosen carefully. As noted in Chapter I, radiation can cause ionization of materials which may lead to chemical changes (particularly when they are interactive with water or organic materials) so that materials also suffer "radiation damage." Changes in the moderator, such as graphite, may affect the operation of the reactor; but relatively little is known about the nature
of the injuries to such materials or how they can be prevented. To add to knowledge in this area, the Atomic Energy Commission has constructed a materials testing reactor at Arco, Idaho. Non-metals also are affected by radiation, so lubricants and non-metallic parts of electrical equipment, control rods, containers, and seals, etc., may be adversely affected. Therefore, metals, as well as solid lubricants, such as graphite or molybdenum, must be used wherever possible. Where organic materials such as oil must be used, exposure to radiation should be minimized.

Apparently the only substances which may be used as moderators are ordinary water, heavy water, beryllium, and graphite. Ordinary water must be absolutely pure since impurities capture neutrons and may become radioactive, endangering the cooling system of the reactor as well as causing corrosion of metals. However, water has a relatively low boiling point so that pressures must be kept high if the generation of steam is to be prevented. As we noticed, in the Shippingport reactor pressures of approximately 2,000 pounds per square inch will be necessary. This is a substantial figure, about equivalent to the pressure at nine-tenths of a mile under the ocean, so difficulties are involved in fabricating and constructing the reactor vessel. Heavy water is much more expensive than is ordinary water, but it has better nuclear properties. However, it, too, boils at a relatively low point; so high pressures are essential for power production purposes. Both ordinary and heavy water suffer decomposition when exposed to radiation, and hydrogen and oxygen gases are released. Since these are explosive, they have to be removed and recombined. In the homogeneous reactor there is even greater decomposition because fission products are formed within the uranium-water solution. Beryllium has excellent nuclear properties but has been reported as susceptible to corrosion in water. There is evidence that, if the metal can be more highly purified, this may increase corrosion resistance. However, beryllium itself is a poison and constitutes a serious health hazard, so extraordinary precaution must be taken to prevent inhalation or ingestion. Graphite has been widely used as a moderator, but it is affected by nuclear radiation and reacts with oxygen at high temperatures. Therefore, in respect to moderators a difficult choice must be made, with all three factors of engineering suitability, safety, and expense being involved.

For power production, reactors have as a primary function the production of heat energy. Theoretically, extremely high temperatures, which provide the greatest efficiency in steam generation, are available in
the fission process. Modern conventional steam boilers, for example, operate at steam temperatures of about 1050° F. At high temperatures, however, uranium metal changes in size and shape to an extent that would seriously disrupt the reactor. Therefore, the temperatures sustained within the reactor must be carefully controlled to prevent distortion of the elements and to guard against the reactor's getting out of control.

To use the heat produced in the reactor and to maintain proper heat levels, a coolant must be circulated through the reactor and through a heat exchanger in which steam is produced. The coolant should have adequate heat-transfer capabilities, not be susceptible to radiation damage, and not seriously interfere with the neutrons during the fission process. The coolant must be pumped continuously to prevent heat levels in the reactor core high enough to cause the reactor to "burn up" with the resulting release of radiation. An undue temperature rise in even a small portion of the reactor may be disastrous, so the reactor must be equipped with automatic safety devices which can shut down the chain reaction when necessary. However, some heat fluctuation is inevitable, and therefore the design of the controls presents difficult problems. A failure in the safety devices could have tragic consequences. Similarly, all the pumps, heat exchangers, valves, etc., must be absolutely leakproof and undergo rigid testing so that chances of a failure are reduced to the very minimum.

As a coolant, air does not have good heat-transfer properties, and at high temperatures oxygen may cause damage to moderator, cladding, and structural materials. However, in research reactors, or reactors used to produce plutonium, where high temperatures are not essential, air can serve as a satisfactory coolant. Such air must be discharged through high stacks because of the contained radiation, but under unsatisfactory meteorological conditions hazards may develop. Hydrogen has good heat-transfer properties but constitutes a serious hazard because of its explosive qualities. Helium also has good coolant characteristics, but because of its high cost and lighter-than-air quality it must be kept within leakproof vessels.

Ordinary water seems particularly well-suited as a coolant because of its low cost and because of its suitability as a moderator. However, the water must be extremely pure, and it presents certain difficult problems because of its corrosive effect particularly at and above its boiling point.

*A recent report from the Argonne National Laboratory indicates that the fast breeder reactor may be very difficult to control.*
which is relatively low. Therefore, high pressures must be used. Heavy water is even better as a coolant because of its nuclear properties, but it is extremely costly. Liquid metals, such as sodium, may also be used because of their good heat-transfer qualities. However, sodium is very difficult to handle because of its explosive quality if it comes in contact with air or water. Moreover, sodium becomes highly radioactive when subjected to neutron bombardment, a fact which increases the shielding problem. Furthermore, sodium may solidify in the cooling system when the reactor is shut down and this necessitates auxiliary heating equipment. In the second submarine-type reactor, sodium was to be used as a coolant; but it was to flow through mercury, which in turn would flow through the heat exchanger to produce steam. In this way, the hazard that would be created (if a leak should occur and the sodium should contact the water with a resultant explosion) was to be minimized. However, because of leaks in the system the reactor was not accepted, and a Nautilus-type reactor was installed in the submarine. As in other instances in nuclear reactor design, compromises must be made and undoubtedly economic considerations will play a major role in commercial reactor ventures.

Reactors, like many other types of furnaces or engines, must have control mechanisms. In the case of reactors, however, largely because of the nature of the fuel, several difficult problems are encountered in devising methods of starting the fission process, increasing power to the desired level, maintaining the desired level, and shutting down the reactor. At least the critical amount of fissionable material necessary to sustain a chain reaction must be present. This critical mass depends upon the fuel, reactor design, leakage, etc. Moreover, since heat and fission products cut down the number of available neutrons, the amount of fuel placed in the reactor must actually exceed the critical size. Since a chain reaction builds up very rapidly and a too rapid increase in power can be dangerous, the obvious answer is to control the rate of the chain reaction process. The different methods that might be employed to control the chain reaction involve either the diminution or removal of fuel, or the moderator, or the reflector (a blanket of material which scatters neutrons back into the reactor core), or the addition of a neutron absorber. Boron and cadmium capture neutrons very effectively. Accordingly, control rods made of these materials may be inserted and withdrawn from either the reactor core or the reflector to control the chain reaction. Absorber rods, however, cause a high loss of neutrons. For some purposes natural uranium might be used as an absorber and at the
same time to produce plutonium, or materials might be used that would create marketable isotopes.

Not only are there different control mechanisms, but several different types of controls are needed in a reactor. To start the reactor, control rods called "shim-rods" are usually removed from the reactor core. Since the growth of the chain reaction must be closely regulated, shim-rods should be designed so that they cannot move at high speed. Once the reactor has reached the proper power level, "regulating rods" are necessary to control rapid, variable changes. These should be capable of rapid movement but over small distances so that dangerous increases in the neutron flux are not possible. The design should be such that complete withdrawal due to an operator's error or failure of any automatic controls would not permit an upsurge in power levels and a possible "burn up." As fuel is depleted and as fission products accumulate, regulating rods may be completely withdrawn. Further depletion or poisoning necessitates withdrawal of a shim-rod to maintain power levels, but a regulating rod must then be reinserted to the extent that a shim-rod is removed. Therefore it may be necessary to have a system of interlocking the two types of rods. Another type of control is provided by "safety rods" which are used to shut down the reactor quickly in the event of an emergency. They must move very rapidly. By using different drive devices, shim-rods may also be used as safety rods. Finally, "back-up" safety devices are necessary for extreme conditions, such as an earthquake, when the safety rods may not move. In some reactors, back-up safety is supplied by boron shot or liquid absorbers which can be quickly placed in holes in the reactor. In homogeneous reactors, "dump" valves can be used to pour the liquid off into vessels having subcritical size. All of the various controls can be designed to operate automatically as well as upon push-button control by the operator. Where the human factor is involved a failure of the operator to notice changes in the reaction as shown by the instruments may result in a serious accident. Recently an operator of one of the experimental reactors at Arco, Idaho, failed to understand oral instructions and started control devices in operation which were not adequate to prevent an accident. Apparently once the inadequate control mechanisms had started their movement, it was impossible to change to other methods. Where the controls are automatic, a failure of the measuring devices which start automatic control, or a failure in the automatic control mechanism itself, could result in a rapid upsurge in heat which would melt the reactor core and cause the release of dangerous quantities of radiation.
Because of the magnitude of the radiation hazard in the operation of reactors, extreme precautions must be taken to protect both employees and the general public. As a safeguard for the general public, reactors are usually located in exclusion areas. The AEC Advisory Committee on Reactor Safeguards has recommended that the exclusion area for a reactor capable of producing 250,000 kilowatts of heat power should have a radius of approximately five miles. This may be modified depending on the inherent safety features of the reactor and special construction features. For example, the Shippingport reactor will be housed in an underground chamber, and the experimental submarine reactor was located in a gas-tight steel sphere. In selecting reactor locations, the population density, geological conditions for disposal of wastes, and meteorological conditions must all be considered.

Some of the most serious problems of radiation safety are encountered in respect to the operating personnel. As indicated in Chapter I, the biological effects of radiation are not as yet fully understood, but it is known that radiation can cause several types of personal injury. The National Committee on Radiation Protection has established maximum exposure limits for humans, maximum radiation levels in air and water, and maximum limits of radioisotopes that may be accumulated within the body. To assure that the maximums are not exceeded continuous radiation monitoring is essential. Personnel should have individual monitoring devices so that if any employee receives unusual doses of radiation, measures can be taken to avoid further exposure in excess of the maximum. In certain cases radioactivity in the thyroid gland, where radioiodine accumulates, should be measured. In some cases analysis of the urine and feces should be made to determine if radioisotopes are being ingested. All areas around the reactor should be monitored to determine the amounts of radioactivity on surfaces and within the air. If radioactivity is high, protective clothing and masks should be worn or remote control systems should be introduced. Outside the plant, there should be continuous monitoring of the air and plant life to determine whether or not hazards are being created. There are several types of monitoring instruments that can be employed. A failure of these instruments to record properly could result in the continuance of operating procedures that endanger both personnel and the community by allowing radiation to exceed the permissible levels.

To protect personnel and also to permit the satisfactory operation of the reactor control instruments, it is essential that the reactor be shielded. However, as we noticed in Chapter I, neutron and gamma radiation
cannot be reduced to zero because neutrons and gamma rays are exponential in nature. Therefore, the problem is one of reducing these rays to safe levels. For mobile reactors, such as in aircraft, shielding because of its bulk presents a major problem. Accordingly, in aircraft design other technical considerations may take precedence over the lowest possible radiation levels.

Shielding should be capable of slowing down fast neutrons and absorbing gamma radiation (for which heavy elements are best suited), moderating slow neutrons (hydrogenous substances perform well), and capturing neutrons without producing high-energy gamma radiation (for which boron appears to have exceptional qualities). The same material may perform all three tasks. Iron has been extensively used as a suitable heavy element. Lead is particularly capable of absorbing gamma radiation and slowing down neutrons, but it has not been widely used as reactor shielding because of its low melting point and its softness, making it unsuitable as a structural material. Ordinary concrete is very effective for moderating slow neutrons, but it is not satisfactory as a shield because of the absence of heavy elements. However, heavy elements, such as iron turnings or mineral barytes (largely barium sulfate) may be used in the concrete instead of sand and gravel, making an effective shield. To reduce the size of concrete shielding, the incorporation of boral, a combination of boron and aluminum, seems to be promising. At the present time, a shield of concrete and heavy elements appears attractive because of its low cost, but experimentation with air-water, lead-water, or ceramic shields may prove fruitful.

In the shielding process, other difficulties are encountered where instruments, controls, and beam holes for inserting materials for producing radioisotopes must penetrate the shield. The various instruments and pipes may require further shielding to reduce the amount of radiation to which personnel are exposed. When experiments are being conducted, or fuel elements are being handled, mechanical or human reactor controls must be carefully coordinated. Possibilities of leakage must be checked continually, and personnel must be carefully trained to avoid contact with radiation beams.

Although we have explored only superficially the technological problems of reactor design and operation, it seems clear that the slightest human or mechanical errors may create conditions that endanger personnel and the surrounding community. The magnitude of possible injuries is astounding. A release of large quantities of radiation may result in all the types of personal radiation injuries discussed in Chap-
A whole city may have to be evacuated and decontamination processes used. In some cases, decontamination would not be satisfactory, and therefore the contaminated articles would have to be removed or that particular location may become uninhabitable until radiation naturally diminishes to safe levels. The accidental contamination of a community's water supply alone could cause untold personal injuries and disrupt the entire economic life of the community. There can be no doubt that a major reactor accident could cause damages measured in the millions and hundreds of millions of dollars. This magnitude of potential damage litigation is apparently not encountered in other industrial pursuits.

2. Radiation Sources and Their Hazards

The development of the nuclear reactor brought with it a very important byproduct—radioisotopes. For the first time a neutron source of sufficient power was available to produce radioisotopes of many different elements in abundance and at low cost. The physical phenomena of radiation, even that derived from relatively rare and enormously expensive radium, was early recognized as being extremely important in industry, medicine, agriculture, and other pursuits. When, after World War II, the government permitted purchase of radioisotopes produced in its reactors, a whole new technology was immediately stimulated, and innumerable practical uses of radiation have been developed. In fact, it is principally in the uses of sources of radiation to accomplish specific purposes that commercial exploitation of atomic energy has occurred in the United States, although reactors planned or in construction will soon change this. The estimated savings through process and quality controls in industry alone have been estimated as being at a rate of $400 million annually. Moreover, new radiation devices which have considerable promise are being rapidly developed, and the number of industrial users (now approximately 1,600) can be expected to increase in the years to come with resulting major contributions to the economy. First we will discuss some of the current and potential uses of radiation sources, and then we will proceed to review the nature of some of the hazards to persons and property arising therefrom.

Thickness and Density Measuring Devices. By measuring the change in intensity of a beam of radiation it is possible to determine variations in the thickness or density of material through which the radiation beam passes. Typically, in gages employing radioactivity, the radiation source is stationary and is placed on one side of the material. On the other side
is placed a geiger counter, ionization chamber, or other device which can measure the changes in the radiation. These gages have been particularly useful in industries producing sheet materials, such as steel, aluminum, copper, brass, plastics, paper, film, and tape. Radioactive thickness gages have advantages over mechanical gages. Because no mechanical contact is required, it is not necessary to stop or cut rolling sheet material to insert the gage. If the material to be measured is too hot, too soft, or easily marred by handling, radioactive gages have a further advantage. Moreover, radioactive gages are more sensitive and give higher precision than mechanical gages. In addition, they are easily adapted to automatic controls which can even be used to adjust the rollers thus permitting automatic correction of the defect.

Because radioactive thickness gages require no interruption of production, permit narrower tolerances to be maintained (thereby saving material), and can be used with automatic control devices to correct errors, their use means substantial savings in many industries. For example, the amount of rubber needed to make a safe tire reaches a limit beyond which quality is not improved by additional material. Surplus rubber was formerly used as a safeguard but with radioactive gages exact amounts can be readily measured and savings have ensued without sacrifice of quality. Radioactive thickness gages may also be used to measure the thickness of plating or of abrasives, such as sandpaper, with similar advantages and consequent savings. Further possibilities exist in the measuring of the density of solids and liquids, such as oil, chemicals, soap chips, etc.

The radioactive material which is incorporated into the gage is usually placed in a sealed metal container which has at least one area which is so designed that the radiation can pass through at the desired level of intensity. Necessarily, the container must be inspected regularly to see that no radioactive materials have escaped to contaminate surrounding equipment. In practice, the gages are sometimes sold outright by the manufacturers, but in many instances the radiation source is rented so that the supplier retains title. The supplier of rented radiation sources also undertakes the responsibility of inspecting. The manufacturers have in some instances sold the radiation source without such service where the user has the necessary equipment and experience to handle the health and safety problems connected with the gages.

Similarly, liquid level gages can be used in many industries to locate substances in containers that are closed and hence inaccessible. The location of the level depends upon recording the intensity of a beam of
radiation. When the liquid, the height of which is being measured, comes between the source and the detector, there is a sharp decrease in the detector's radiation. Or in the alternative, radioactive floats are introduced into the liquid, and their radioactivity is detected from outside the wall. The point of radioactivity reveals the level of the liquid.

Radiography. Radiographic testing which is used to inspect the internal structure of metal castings, welds, etc., is not a new technique. X-ray machines and radium sources were previously used, but the availability of large quantities of high energy radiation sources such as cobalt 60 has made it economically feasible to undertake more extensive radiographic testing. The testing process consists of placing a radioactive source on one side of the specimen to be tested and a photographic film on the other. The film when developed reveals any flaws or cracks in the specimen since more radiation will penetrate the areas of defect and cause greater exposure on the film. Radiocobalt is approximately one-fiftieth as expensive as radium and it has a greater gamma ray generating capacity for its weight. Cobalt sources can be machined to any shape before they are made radioactive by exposure to neutrons within a reactor. However, radiocobalt must be clad prior to usage because it tends to flake after exposure to neutron bombardment.

Medical Uses. Radioisotopes and radiation sources have considerable promise for therapeutic uses by the medical profession. X-ray machines and radium have, of course, been employed for a number of years. Radioactive iodine and phosphorus have also been available as specialized therapy tools in very limited quantities for the few scientists having access to particle accelerators. Today, however, over 800 varieties of radioisotopes are available in substantial quantities for medical use. Availability is no longer a problem.

One therapy technique makes use of the destructive qualities of radiation. The radiation is directed at diseased tissue to destroy the undesirable cells. However, healthy tissues located near the diseased tissues are also in danger of destruction, so the process must be cautiously handled. The radiation may be supplied from a source external to the body, it may be placed within the body near the diseased tissue, or a radioisotope may be injected in the body when the particular isotope has a tendency to concentrate chemically in the particular diseased organ. If reliance is placed on the selectivity of a particular isotope for certain body tissues, the half-life of the radioisotope is important. Too long a half-life may result in the continuation of radiation which damages healthy tissue long after the diseased tissue has been destroyed. Like-
wise, the biological half-life or rate of elimination from the body is important in such use of radioisotopes, as was explained in Chapter I. Considerable research is still needed before the therapeutic techniques now used experimentally can become standardized.

As an external source, cobalt 60, a very powerful gamma emitter, is replacing radium because of its low cost and less hazardous nature. The radioisotopes currently used most extensively internally are radioiodine 131, a gamma emitter, and phosphorus 32, a beta emitter. Because iodine is naturally attracted to and retained by the thyroid gland, radioiodine can be used for some of that gland's disorders. Hyperthyroidism, or excessive hormone secretion of the thyroid with disabling symptoms, has been checked, if not cured, by radioiodine. Cancerous growths in the thyroid can be treated by the radiation from radioiodine. Angina pectoris has been relieved by radioiodine, apparently because it eases the load on a diseased heart by slowing down the activity of the thyroid. Radiophosphorus, which has an affinity for bone marrow, will radiate the blood-forming tissues and decelerate the production of blood cells. Administration of radiophosphorus has provided relief to patients afflicted with an oversupply of red cells (polycythemia subra vera) and has controlled, though not cured, the oversupply of white cells (leukemia).

Sterilization of Food and Drugs. Radiation sources can also be used to sterilize foods and drugs. Microorganisms present in pharmaceutical products and items intended for human consumption can, if desired, be completely exterminated, but the quantity of radiation needed for the purpose increases greatly as lower forms of life are attacked. Absolute sterilization may require a dosage as high as approximately two million roentgens. The danger inherent in using this amount of radioactivity in foods and drugs is apparent when we consider that approximately 400 roentgens constitutes a lethal dose for at least half of the human population. Apprehension has been expressed about the possibility of inducing subtle changes in the irradiated food or drug materials which could not be detected by ordinary chemical and physical means. The hazards in this respect do not arise from radioactivity as such, but from its side effects, such as the creation of pathogenic conditions or toxicity.

However, short of sterilization, pasteurization of foods and drugs by means of ionizing radiation can be accomplished by much smaller doses of radioactivity. In pasteurizing a product most of the pathogenic bacteria are killed, but not all. Intensive experiments are being carried on to achieve practical results in this area. It has been reported that in
England irradiated onions and potatoes have already been supplied to the submarine crews of the Royal Navy. The United States Army is carrying on a $5,000,000 research program along this line.

The advantage of either sterilizing or pasteurizing by the use of radiation consists of accomplishing these goals without significant increases in temperature. Consequently there is the possibility of treating products that are heat-sensitive, protecting them from deleterious changes produced by heat sterilization, or from change of taste or other quality that might result therefrom. Packaged meats, canned milk, dried eggs, ice cream, and other mixes may be cited as examples. The sterilizing or pasteurizing operation is normally applied after packaging, thus eliminating the possibility of contamination after radiation, a very important advantage.

Cold sterilization of penicillin or other antibiotics, medical supplies, and sanitary products, bandages, sutures, etc., can also be effectuated; plasma and other blood components are made to last longer and the likelihood of transmitting contagious disease is reduced. Beneficial effects can be produced by sterilization of hormones, vitamins, antibodies, and other products. Fruits, vegetables, and beverages can also be treated to increase appreciably their shelf-life.

**Static Eliminators.** The hazards of static electricity, which is produced by friction, can be eliminated by the use of ionizing radiation. Static charges occur in manufacturing operations of sheet plastic, paper, motion picture film, in coffee plants, in leather fabrication, in flour milling, and in many fine grinding operations. Automatic processes may be reduced in efficiency or even impeded by static electricity. The cutting of filmy materials, or the carding and warping of textile fibers are examples. Even more serious is the possibility of building up large electrostatic fields sufficient to give off sparks and thus create fire hazards in explosive atmosphere, such as that formed in industrial works using inflammable fluids or explosives, or that of a hospital operating room.

Radioactive sources can be used to ionize the air surrounding the point of origin of a static charge. The ions in the air are attracted to surfaces of opposite signs, and the charge is neutralized.

**Exploration for Oil.** The oil industry has found in the use of radioactive sources a more efficient means of exploring the bowels of the earth. A portable neutron source, usually a mixture of radium, polonium, and beryllium is lowered into the bore-hole of the well, along with a detecting device. To prevent the detector from being directly activated by neutrons from the source a shield is interposed. The operation con-
sists of making readings of radioactivity reflected from the surrounding matter the nature of which is to be determined. Dry strata absorb the neutrons, but when neutrons encounter hydrogen atoms, many of them are "scattered back" and are revealed by the detector. A counter measures the activity, and electronic devices relay the information to the surface. The presence of either water or oil is shown by the hydrogen content thus revealed, and electrical conductivity tests are used to complete the identification. The use of radiation has revealed the existence of large reserves in many fields long believed exhausted.

Agricultural Uses. The ability of radiation to induce changes in the hereditary features of plants and animals has been turned to advantageous use by science. Neutron irradiation of chromosomes and genes produces mutations that are frequently harmful, but occasionally beneficial changes are induced. This fact has already led to the production of rust-resistant oats and better barley, wheat, and corn. A variety of peanuts has been produced which is leaf-spot resistant and yields about thirty per cent more quantity per acre. A radiation-caused mutation in penicillin mold has made possible a much greater producing type. The radiation doses needed to bring about mutations are much larger than amounts lethal to humans and animals. In the process a minute portion of the total number of specimens show good mutation. The others are discarded as useless. It is for this reason that plant and seed irradiation is more practical than animal activation. Amounts of radioactivity large enough to produce mutations would have to be administered to large numbers of animals, and a considerable number of them would have to be sacrificed to obtain the favorable mutations in some of them. Nevertheless, radiation is currently being used on poultry to increase egg production.

Again, atomic energy offers at least partial relief from this country's three billion dollar yearly loss of agricultural yield due to insects. Low energy radiation renders various species of insects sterile, thus facilitating their eradication. Similarly radiation may be employed in the control of weevils and other insects in stored produce, in the elimination of insect contamination in consumer packages of grain products, and for coating underground cables to inhibit mold and fungus growth. It has recently been suggested that railroad cars equipped with radiation sources be moved about the country during critical crop stages to reduce crop damage due to insects and spoilage.

Miscellaneous Uses. Brief mention should also be made of certain other uses of radioactivity which indicate the important role that it will
play in the everyday life of the future. The use of cobalt 60 gamma rays to vulcanize rubber by radioactivity, instead of heat, shows promise of improving resistance of rubber compounds to oil impregnation and increasing their serviceability under high or low temperature conditions. Radioactive devices for the scientifically correct measurement of time are expected to be used in navigation, communication, and related research, such as the study of variations in the rate of rotation of the earth. Conversion of sea water to fresh water may someday be brought to pass by use of radiation. Large-scale catalysis of chemical reactions is envisioned. Radioisotopes have been found to have useful applications in ventilation and air conditioning where they can minimize or eliminate hazards from explosions in ducts conveying finely ground materials. Better means of processing plastics, increasing their temperature resistance, and adding to their strength can be achieved by the use of atomic energy.

Phosphorescent or fluorescent materials, activated by radioisotopes, make excellent luminous compounds, and the stock pile of fission products increases the availability of colors, of degrees of brightness, and of longer-lived materials. They can be used on instrument dials, road signs, advertising structures, and as safety markings for buildings and mines. For example, when disruption of electrical power interrupts normal service, luminous signs might be used to guide personnel to safety.

Ionization of the air-fuel mixture may be used to improve the performance of internal combustion engines, for flame propagation is believed to depend in part on the agitation of the gas molecules. Because ions are agitated atoms or molecules and can be created by radiation, a long half-life isotope in a combustion engine may well improve the efficiency of low octane fuel and prevent knocking.

Another probably common future use of radiation sources, based on the same principle as that employed in logging oil wells, is the determination of the density of the soil upon which structures or highways are to be built, and the amount of moisture in it. Simplification of construction procedures and improvement of quality and safety features in the building of highways, airport runways, or earth dams can be achieved by this means. Neutron sources and detectors will be used but will function on the surface instead of at considerable depths as in the case of oil wells. The tests will be conducted at intervals along the path to be used.

Paul Weidlinger, a consulting engineer of the American Society of Chemical Engineering, suggests that powerful radiation could be used to rearrange the molecules in wood so that the result would be a stronger
and more durable product. Better plywood could thus be provided for houses, boats, and industry. The structural members of the material would be much thinner and lighter, and yet they would be stronger and more elastic. Fire resistance could be increased to the extent of eliminating the necessity of fireproofing and the cumbersome, expensive accessories that come with it. Exploiting the ability of hard radiation to cross-link molecules, the plywood industry might be enabled to forego the use of glues. According to Mr. Weidlinger, enormous pressures may be used to cross-layer thin veneers, and heat action may cause the extrusion of natural lignin, while the application of hard gamma rays may cause the molecules to join without raising the temperature. This process would permit the processing of building materials into various shapes and would truly be like taking the substance apart and completely reassembling it.

Innumerable other possibilities for the use of radiation, such as in batteries or for space heating of homes, have been suggested and are being investigated. Undoubtedly many other uses will be developed that will make the total contribution of radiation to the economy of possibly startling proportions. Therefore, we can expect radiation sources to become even more commonplace in the relatively near future.

It must always be remembered, however, that utilization of radioactive sources creates hazards to persons and property because of the damaging effect of ionizing radiation. Recently, as pointed out in Chapter I, a group of prominent scientists has concluded that any radiation, no matter how small, is damaging to the living and perhaps more importantly to the descendants of the living. Therefore, users of radiation must exert all efforts to reduce radiation hazards.

The number of ways in which the use of radiation may result in damage is almost unending, but some deserve particular mention. The transportation of radioactive materials from their point of origination to refiners and suppliers and eventually to consumers involves unusual hazards. Not only must carrier personnel be protected by shielding, but also protection must be afforded persons who are near the transportation vehicles, such as passengers or the casual passersby or persons working in buildings near railroad sidings where boxcars transporting radioactive materials happen to be resting temporarily. A train or airplane accident may cause rescuers to be subjected to damaging radiation if the container has been broken by the impact of the wreck. Persons so exposed will not know of their injury until possible corrective measures may be too late. Therefore, radioactive materials should be transported
in the most secure fashion and notices of a possible hazard should be conspicuous.

Radiation sources are, of course, a hazard to personnel in the immediate vicinity. Areas of high radiation levels must be blocked off or personnel unwittingly will be absorbing harmful radiation. Location within buildings but close to public passageways may cause harmful exposure to children playing outside the factory. The uninformed petty thief may carry home an extremely dangerous radioactive source unless the materials are carefully guarded and inventoried. A plant explosion or fire may break the container, scattering the radioactive material. Police and firemen who come to assist in putting out the conflagration may be exposed. Plant visitors or even trespassers, such as children, must be excluded from access to the source so that the radiation beam will not be directed at themselves or others in the vicinity. This very incomplete list of possibilities suggests the desirability of free use of exclusion areas with an abundance of warning devices and notices.

Radiation injuries may also occur because of the cumulative effect of radiation, although the particular exposure is below safe maximums, as is also pointed out in Chapter I. For example, an employee may have undergone radiation during therapy and then received additional radiation at work because of the impossibility of perfect shielding against gamma radiation. Or a patient may have been given radiation treatments by one doctor and then given further radiation for possibly another ailment by a second doctor. In both cases the amount of radiation at any one exposure would have been considered safe, but a cumulative radiation injury may occur. This suggests that monitoring of personnel should be continuous and perhaps every individual in the community should have a complete accurate record of exposures so that cumulative radiation can be estimated and damage avoided. Registration on a national basis was actually recommended by the Committee on Genetic Effects of Atomic Radiation of the National Academy of Sciences.

The erroneous shipment of a gamma source when the consumer has requested a beta source could lead to innumerable injuries because of the vast differences in required shielding. Radiation injuries to persons and property may result from leakage in containers. Radioactive materials may be accidentally shipped to consumers of articles produced in the factory using radiation sources. Radioisotopes may be accidentally thrown into sewers which empty into streams from which water is taken

7 E.g., the explosion in the Sylvania Laboratory in New York City.
for drinking or industrial uses. If a film processing plant used water containing radioactive materials, the film would be damaged. Disposing of radioactive materials in dumps that may later be the site of buildings may eventually result in injury to the occupants. When the radiation level is no longer sufficient for the particular use but is still harmful to human life, adequate methods of disposal must be found or the same hazards may develop as in the case of disposal of the waste products created in the fission process. The possibilities for injuries seem interminable, and unusual hazards are encountered because of the unique nature of radiation whereby injuries are suffered without the immediate interposition of the human sense perception.

In conjunction with use of radiation sources, it should be noted that, although potential hazards are created by their use, failure to use radiation techniques may similarly create hazards that may result in legal liability. For example, a crucial casting for a mechanical device that has not been tested by radiography may break causing injuries to persons and property. Similarly, drugs or blood plasma not sterilized by radiation may seriously infect patients. Furthermore, it is entirely possible that radiation usages may become so standardized in certain industries that a failure to take advantage of them may be evidence of negligence in any litigation based upon injuries caused by the product.

In judging what radiation hazards are unacceptable, the hazard must always be weighed against the great benefits which can come from the use of atomic energy mechanisms.

3. Radioactive Tracers and Their Hazards

Radioisotopes have already been used in large quantities in tracing experiments and techniques in biology, industry, medicine, and agriculture. Since the beginning of the United States Atomic Energy Commission’s post-World War II program thousands of shipments have been made to thousands of institutions in this country and abroad. Moreover, the federal government is financing an extensive research program with laboratories at Brookhaven, Argonne, Los Alamos, Oak Ridge, Rochester, Arco, and other places.

Because of the radiation they emit, inconceivably minute quantities of radioisotopes can be detected by very sensitive instruments. A so-called “labeled” or “tagged” atom, i.e., a radioactive isotope of a given chemical element, as explained in Chapter I, is identical in its chemical behavior with its non-radioactive sister atoms. It can be “traced” through a series of chemical or physical reactions even in the presence of
great quantities of non-radioactive atoms of the same substance or of different substances. Complex and mysterious biological and industrial processes can be better understood by the use of proper radioisotopic tracer materials. Isotope labeling establishments are currently supplying numerous tagged compounds, such as sugars, organic acids, amino acids, pigments, alkaloids, proteins, and others. Medicinal plants are being grown in an atmosphere of radioactivity to produce labeled drugs.

There are, of course, limitations upon the practical use of tracers, and often a radioisotope of suitable degree of activity or half-life is not available. For example, no usable radioisotope of oxygen, nitrogen, or aluminum has been produced, or the amount of an isotope needed for a certain tracer application may be too large to be safe. Moreover, the process of synthesizing the radioisotope into a compound possessing physical and chemical properties identical with the material under study is sometimes impossible or impractical. Despite these difficulties, however, tracer techniques are widely used and highly successful. The equipment needed for utilization of tracers is not expensive; the cost of the radioisotopes themselves is low, and important additions to knowledge may be made by their utilization. Their possible usefulness for known processes and for many not yet envisaged has caused authoritative sources to hail them as one of the most significant contributions to the welfare of man so far derived from atomic energy, perhaps the most useful discovery since the microscope.

A brief account of some of the more important current applications of tracer techniques will reveal the importance of radioactive tracers to society.

Tracers in the Oil Industry. The oil industry has found profitable uses for radiotracers. After a period of use the walls of a pipeline may become encrusted with wax. Special scrapers, with a number of blades, are driven through a pipe by compressed air to remove obstacles and accumulations. If a scraper sticks in a pipe instead of emerging at the other end, its location is difficult to determine. To facilitate identification of the spot, a source of cobalt 60 in an aluminum container is attached to the scraper. A Geiger counter outside the pipe registers a response to the gamma rays emitted by the cobalt even through several feet of earth, and thus locates the scraper.

Gasoline, diesel oil, stove oil, or oils of different qualities may be shipped successively through the same pipeline, and it is necessary to spot with accuracy the interfaces between any two substances as shipped. If a small quantity of radioactive material is injected into the line at the
interface, geiger counters placed at the desired cut off points indicate the arrival of a new substance by signaling the radioactivity. Operators can then turn valves to direct the new shipment to its proper tanks. The advantage of the tracer technique is that it accurately locates the interface and measures the extent to which the adjacent materials have intermingled in the pipeline. The amounts of radiation needed for this and similar strictly tracing functions are not particularly hazardous provided proper care is exercised in handling the radioactive materials themselves.

Again, tracers have contributed to making oil well drilling safer and simpler. The use of acids in wells to render limestone or sandstone formations permeable is often necessary, but it has been a hazardous and time-consuming operation for the reason that thousands of feet of tubing had to be removed and disjointed to install accessory equipment for acidizing purposes. Radioiodine now reveals the level of the acid, which, by applying pressure according to instructions received from readings, can be kept at the bottom of the well without danger of corroding tubings or the casings of the well.

Metal Wear Testing. A process has been developed for measuring the wear of engine parts and comparing the performance of different lubricants and fuels. It is based on a weight loss system and is a quick and effective procedure. Under previous practices, an engine would be run for a long time, even months; then it would be dismantled and the weight of the parts being tested would be compared with their weight before the test. Using the "tagged atoms" procedure, piston rings or other parts can be irradiated in a reactor, placed in the engine, and the engine started. At any desired time interval, the oil may be drained off, and a geiger counter used to determine the amount of radioactive metal worn off in the operation. Accurate testing is possible without the expensive and time-consuming dismantling otherwise required. It is asserted that better engine oils have been produced as a by-product of this speedy and precise method of testing.

The same technique can be applied to tools of many kinds to appraise their resistance and predict the duration of their life. Cutting tools may be made radioactive in a reactor. During their use microscopic fragments of metal are worn off and intermingled with the metal chips of machined pieces. The radioactivity of the wastes determines instantly the wear of the tool. Previous methods required extended wearing of the tool to test it effectively.

Foods and Food Processing. By means of radiotracer simpler and more reliable methods of toxicological evaluation of ingredients are
open to the food industry. Food additives, whether for flavor, color, and texture, or as a preservative, must be harmless. Radioactivation of such additives, or proper labeling with a radioisotope, allows the research staff of the industry to follow the absorption, distribution, storage, and excretion of ingested foodstuffs. Any abnormalities in the metabolic process such as excessive accumulation or distribution may reveal nutritional hazards and call for discontinuance of a practice or the substitution of a safer chemical.

Again, it often happens that food processors are interested in knowing the rate of water penetration into food products. Experimental samples are processed with radioactive water, and radiographic tests are made which indicate the water distribution at different stages. This technique has assisted the manufacture of better products.

Even the much debated effects of smoking may be investigated by the use of radioactive tracers. A tobacco company has reported that it is conducting experiments to determine the disposition of the several ingredients of tobacco that are inhaled. Different constituents of tobacco are tagged and followed in the pathways inside the body. The distribution and rate of elimination thus observed may reveal important facts about the pathogenic effect of certain tobaccos or some of their constituents.

The contributions of tracing techniques to the improvement of many agricultural processes and to the expansion of knowledge concerning agricultural practices have been outstanding and are undergoing constant expansion. It truly can be stated that imagination and ingenuity can extend the use of radioactive tracers to cover most areas of human activity.

The efficiency of conversion of feed into meat by animals can be determined by tracing. The effect of adding certain elements may lead to better feed products. The utilization and elimination rate of feed components may reveal the cause of a diet deficiency and suggest ways of restoring pastures to a high nutritional value or of rendering valuable an area of supposedly little worth. Experiments with tracers reveal whether inadequate growth in animals is due to low dietary intake or to the intake of adverse food elements.

The use of tracers has revealed to science the processes of synthesis of foods and the degradative reactions that occur rapidly within the body. Earlier beliefs are being replaced by more adequate understanding. Advances in dietetics have been made possible by nutritional studies based on tracing techniques.
The mineral components of certain feed supplements have been followed in their paths through an animal system. To satisfy animal needs for small amounts of iodine, iron, copper, cobalt, zinc, etc., such substances are placed in "salt blocks" scattered around pastures. The use of radioisotopes reveals that certain minerals are being leached out without reaching the animal. This discovery has led to the manufacture of blocks containing water insoluble compounds. The effects of fluorine on calcium metabolism in animals has been studied with the use of tracer isotopes to measure the rate of bone growth and to determine the amount of fluorine, if any, to be used in water. Experiments have shown that the growth in the bone structure of animals supplied with a high fluorine content in their diet is only half that of the growth registered by animals that are fed a normal or low amount of fluorine. This discovery even has implications for use of fluorine to retard tooth decay in humans.

Again, a substance called thiouracil shows great growth promoting possibilities and can be fed to pigs, poultry, and other farm animals to improve the efficiency of feed utilization. A drawback consists of the fact that thiouracil depresses the function of the thyroid gland and may even be deleterious to humans feeding on animals fattened on a thiouracil diet. Experiments have shown that if the substance is withheld from the diet of animals for two or three days before they are slaughtered for human consumption, no significant amount is retained by the time they reach the market. This knowledge was gained by the use of radioactive iodine as a tracer studying its uptake by the thyroid gland when mixed with thiouracil. As a result of these demonstrations, the Food and Drug Administration has approved thiouracil as a satisfactory diet ingredient.

**Agricultural Uses.** Radioactive tracers have disclosed much valuable information on the rate of plant uptake of commercial fertilizers. Tracers reveal under what conditions and at what stage of a growing cycle fertilizers should be applied for best results. Phosphates, tagged with radiophosphorus, permit discovery of the portions of phosphorus derived from the soil and the portions coming to the plant from fertilizers. Thus it has been found that corn takes up phosphorus from applied fertilizers in its early stages, but that later the uptake is principally from natural phosphorus deeper in the soil. Tobacco growers have introduced savings as a result of the knowledge that phosphates spread at the surface have little value for their crops.

Radiotracers can also be used to evaluate the natural fertility of the soil. The inhibiting effects of certain mineral components of the soil can
be assessed. It has been learned that a fertilizer may be good for a certain year, but that it will be harmful to a future type of crop in the system of rotation. This has furnished valuable guidance for growers in the selection of their rotating crops. Dr. Walter F. Libby, a member of the United States Atomic Energy Commission, has estimated that proper utilization of radiation sources and radioisotope tracers in agriculture could save upwards of $200,000,000 per year by reason of improved methods and materials.

Photosynthesis, the process by which plants store sunlight and turn it into chemical energy, is the basis of all life on earth, and it is slowly unfolding its mystery through the aid of radioactive tracers. The hoped-for dream of researchers is the artificial reproduction of the photosynthesis cycle which would make possible the production of organic foodstuffs from inorganic materials—from water, carbon dioxide, and solar energy. This would even tend to obviate the necessity of complete reliance upon soil and plant life as the source of food supply as we know it now.

*Tracers in Medicine.* Great strides have been made in medicine with the use of radioisotopes as tracers. Radioiodine and radiophosphorus have proved most useful. When radioiodine is administered to a patient in a solution of water—the so-called “atomic cocktail”—it will quickly tend to concentrate in the thyroid gland. If the iodine taken up by the thyroid is less than the normal amount, cancer of the gland may be suspected; if too much concentration is registered, the gland may be overactive and need treatment. A detecting instrument placed over the gland signals the amount of radioactivity and tells the skilled technician much that the doctor needs to know.

A new method of cancer diagnosis which utilizes tracing techniques has been inaugurated. It has been found that certain substances tend to concentrate in areas of overactive metabolism such as cancerous tissues. This fact has been exploited by injecting radioisotopes into the system and detecting the point or points of higher concentration of radioactivity. This technique helps to pinpoint the location of the tumor and may reveal the malignant nature of many kinds of growth.

Radiocarbon and radioiron have yielded useful information about anemia and diabetes. The reason for overproduction of white cells in leukemia sufferers is better understood as a result of the use of tracers. For example, tracers have revealed that the white cells in leukemia patients are deficient in zinc.

Radioisotopes disclose the distribution of drugs in the body. They
also facilitate studies of blood flow by taking advantage of the fact that the time employed by the blood to circulate between two given points can be determined by injecting radiomaterial at one point and determining the time of its arrival at the other.

During a surgical operation it is often vital to know the amount of blood lost by the patient. An accurate method is afforded by the intravenous injection of radiiodine. The dilution of the radioisotope in a sample of blood extracted after sufficient time for mixing has elapsed, reveals the present blood volume. Blood preservation studies have been aided by the use of radiochromium tagged red cells. The life processes of red cells are studied in this manner.

The hazards connected with the utilization of radioactive tracers are substantially similar to those involved when using radiation sources. However, in tracer techniques only small amounts of low energy materials are needed, and consequently the degree of hazard is not as great. Moreover, tracer techniques are usually employed by highly experienced personnel who are fully knowledgeable of the dangers. In industrial applications of radiation sources untrained employees are more likely to be utilized.

Once again, as with radiation sources, a failure to use radioisotopes as tracers may create hazards. If a fertilizer or drug is tested with the new tracer techniques, injuries may be avoided. A failure to determine possible dangers in a product by using the tracer technique may be evidence of negligence in some instances. Therefore, although injuries may result from employing radioisotopic tracers, other injuries may occur by not taking advantage of their value as a research and testing instrument.

B. General Tort Liability Problems

In reading the foregoing discussion of the scientific aspects of atomic energy, its peacetime uses, and the potential hazards, lawyers without doubt have reviewed in their minds the legal principles applicable to litigation in the tort liability field. We shall now briefly describe some of the legal problems that we feel may be arising in the future with considerable frequency, and in the succeeding chapters we shall analyze the more important rules of law currently applied in the tort and workmen's compensation fields and discuss possible solutions for specific problems unique in connection with peaceful uses of atomic energy.

It should be especially emphasized that there will be an important interrelationship between the law and atomic energy. In other words, the
law will affect atomic energy operations, for the lawyer will be obliged to advise his clients to pursue certain courses of action to avoid certain legal consequences. At the same time atomic energy will affect the law by stimulating the development of new legal principles to the new technology, either by the courts or legislatures, or both.

Perhaps the most crucial question is what general rules of tort liability will or should be applied to atomic energy activities. Should the ordinary rules of negligence apply? Or should rules enforcing strict liability as in the case of an "ultrahazardous" enterprise be applicable? Should the same rules, negligence or strict liability, be applied to reactor operation as to the use of radiation sources or radioisotopes? As we mentioned earlier, the failure of the common law to adapt itself to industrial injury problems led to the enactment of statutory workmen's compensation. If common law rules are not again to be superseded, this time by statutory rules in the area of atomic energy enterprise, careful consideration must be given to the evolution of judge-made common law. Or perhaps it may be found that, in some aspects at least, only statutory solutions will serve adequately to adjust atomic energy to the law. If, in judicial proceedings to impose civil liability, negligence must be found before the one who causes the damage is obliged to respond in damages, individual members or, indeed, the whole of society will bear a greater direct risk and burden. If strict liability rules are applied, a restricted part of society, i.e., atomic energy enterprise, must bear a greater direct economic burden, either through payment of claims or through increased costs of insurance. These economic burdens may, of course, be passed on to the general public in the form of increased prices for the product of such enterprise. In many instances, however, the potential economic burden may deter entrepreneurs from undertaking atomic energy activities. The nature of the general rules of law to be made applicable will also have its effect on the safety measures to be used in atomic energy operations. If strict liability is imposed, entrepreneurs will doubtless take the utmost precautionary measures which, of course, will increase the economic costs of utilizing atomic energy, undoubtedly retarding its development to some extent.

We have already seen that reactor operation, radiation sources, and the storage and disposal of radioactive wastes all involve unusual hazards that might be characterized as ultrahazardous in nature. We must ask ourselves many questions. What effect, if any, should be given to governmental approval of the operation as set forth in the form of atomic energy licenses? Should or does such approval preclude the
courts from applying strict liability rules, particularly when the operation has been carefully inspected from the standpoint of health and safety by federal or state authorities? What is the effect of federal approval on state authority? Should liability be imposed for injuries to trespassers in view of the unique hazards? Should visitors and licensees be required to assume radiation risks? Should liability be imposed where an "Act of God," such as an earthquake or tornado, has caused injuries by spreading radioactivity throughout a community? Do workers "assume risks" such as possible genetic damage?

The scope of potential liability based upon the applicable principles of tort law will have an effect on the type of business organization that may be used in atomic energy pursuits. If strict liability is imposed, it may encourage the establishment of separate corporations to handle atomic energy, legal entities divorced from business organizations already established in industry. Should use of a corporate device with limited assets be permitted in so hazardous a field? Should minimum insurance coverage be required by law? Lawyers in the atomic energy era will be called upon to assess all legal possibilities and undoubtedly will be asked to give advice that will protect investors to the greatest possible degree against possible tort claims. At the same time cognizance must be taken of the legitimate claims of individuals and groups who may be injured by atomic energy activities.

In addition to the problem of the general rules of law to be applied to atomic energy, there are a number of specific problems that may arise. In determining the location of an atomic energy facility, consideration must be given to the potential hazards and to the desirable exclusion area. Even before a plant is constructed, nearby inhabitants and landowners may seek to prevent the construction by seeking injunctions on the theory that the plant will be a nuisance. Some may seek to enjoin the construction while others may seek damages on the theory that the plant destroys property values. What will be their measure of success? What will be the effect of zoning ordinances in trying such cases? What will be the effect of licensing by the Atomic Energy Commission? Will use of underground chambers or gas-tight steel spheres reduce the success of what is by some called "nuisance" litigation? Lawyers must analyze these questions in the light of local rules of law as well as federal laws and regulations, not to mention international legal principles, to advise properly when plant locations are being selected.

A number of individuals and industrial organizations are currently engaged in designing nuclear reactors and atomic energy devices and in
supplying consulting services in the atomic energy field. In the current stage of technological development, the alternatives have yet to be tested conclusively, so designs must be selected in the absence of conclusive data. What liability may be imposed on designers and consultants if the installation causes injuries? Once one type of installation or process is proved to be safe, what effect will this have on the area of choice if negligence claims are to be avoided? Can consultants and designers immunize themselves from liability? Should they be allowed to do so? For what kinds of injuries should they be liable? Should they be liable only to those in the immediate vicinity of a nuclear accident, or should they be liable to the film manufacturer who happens to purchase cardboard to package film that was made with water into which radioactive materials had leaked? When are the injuries so remote that liability should not be imposed?

The construction firms and manufacturers of equipment used in atomic energy facilities also face possible tort litigation. Should or will the building contractor be held liable to persons injured due to slight defects in construction that permit leakage of radioactive materials? Should negligence rules be applied or strict liability rules? Should or will the manufacturer of equipment used in reactor or radiation devices be liable for injuries resulting from defects in the product? Does it make a difference if the manufacturer did not know his product was to be used in a reactor and the defect would have caused only minor damage, or perhaps none at all, if the equipment had been used in a conventional industrial operation? For what kinds of injuries should contractors and manufacturers of equipment be held liable? If a radiation source is rented, what should be the liability of the owner for injuries resulting from accidents? What is the effect of assuming an obligation to inspect radiation sources on the liability of the user and of the inspecting firm? Can liability be avoided by contract terms or by disclaiming any warranties in respect to products?

What should be the liability, if any, of the owner-operator of a reactor who sells radioisotopes to others who negligently or accidentally cause injuries to persons and property? Because of the dangerous nature of the product must the seller investigate and ascertain the capacity of the purchaser to use the product safely? What is the effect of the securing of a license to use radioactive materials from the Atomic Energy Commission? Would the seller be liable if he sold radioisotopes to a person not having a license? Can possible liabilities be avoided by any legal techniques? If reactor-owners are liable for immediate injuries caused by products sold to others, are they equally liable for remote injuries
where there has been a chain of intervening events with the possible lapse of a number of years?

Not only are there problems regarding specific rules of liability to be followed but also there are a number of problems arising out of the peculiar nature of radiation injuries. Since the plaintiff is required to sustain the burden of proof in litigation, he must first prove that his condition resulted from radiation, and thereafter he may find it very difficult to prove that his injury was caused by radiation from a particular source. Many of the same injuries occur even in the absence of radiation, and thus there is the problem of the multiple cause or cumulative effect of radiation. Should the burden rest on the atomic energy user to prove that radiation did not cause the injury? If the burden of proof is placed on the atomic energy user, can he ever avoid liability even under negligence rules? If the burden of proof is made minimal for injured persons, will this create a convenient vehicle for nuisance litigation by any person having any complaint in an area where there has been the slightest rise in radiation levels? Should new rules governing the burden of proof be developed for atomic energy tort cases? What kinds of monitoring records should be kept to defend possible future injury claims? How can injured persons receive damages when classified data is involved which cannot be introduced as evidence? Should special courts capable of receiving security information be established? Or should the government assume liability when it prevents the introduction of the evidence necessary to prove an injured person's case?

What claims can be made by a person who has received radiation damage only because of its cumulative nature when all of his exposures were below safe levels? Can he recover from only the person who caused the exposure to go above the maximum permitted before cumulative effects begin? Or are all who contributed to the cumulative effect liable? Should every person be required to keep his own personal exposure record so that employers and doctors can rely on the record in subjecting an employee or patient to radiation? Can victims of degenerative genetic damage seek damages from those who exposed their ancestors to harmful radiation? Should society bear the risk of genetic injuries? What advice should the lawyer give the atomic energy entrepreneur?

In addition to the problems of proving injury, its cause, and the role of the defendant in causing the injury, other problems arise in respect to the procedural aspects of trying atomic energy tort cases. One problem is that of the adequacy of the typical statutes of limitations. When does the cause of action arise so as to start the statutory period—when the radiation accident occurs or when a person discovers his injury? If the
former, what protection, if any, should be given persons who discover injuries perhaps years later after the statutory period has run? Should a person who knows he has caused harmful exposures of radiation be required to notify possibly affected persons? If the statutory period does not commence until injuries are discovered, users of atomic energy will be called upon to defend against claims years later when witnesses are dead and evidentiary materials are no longer available. Should users of atomic energy, because of the peculiar nature of atomic injuries, be required to assume the risks of stale claims?

Other problems arise out of the possible progressive nature of atomic energy injuries. A person may receive an exposure which caused temporary sterility as its first noticeable effect. Years later malignancy may develop requiring amputation of limbs and perhaps death will ensue still later. If the person sues at the time he discovers sterility, can he attempt to prove possible future consequences? If he recovers only for the sterility, can he sue again at a later date when he discovers a malignancy? If legal rules prevent him from suing twice, should he be advised to delay damage actions until the latest permissible moment within the statute of limitations? Should any new rules be developed to handle possible progressive injuries?

Another problem in atomic energy tort litigation arises out of the complex nature of the subject matter. Are juries equipped to handle highly technical data or will the technicalities so overwhelm them that they will be unable to assess the evidence? Will inability to handle the subject matter lead to verdicts for persons claiming injury or, on the other hand, for the defending users of atomic energy? Will the judges be able to give proper instructions dealing with scientific data? What should lawyers advise clients when faced with determining whether tort litigation should be tried by the judge or jury? Can hindsight be kept out of the deliberations in determining negligence and causation issues?

Still other legal problems may arise because of the fact that a release of radioactive materials does not respect state or national boundaries. Which law should be applied in determining liability of an owner-operator when radiation has transcended state or national boundaries? What law should be applied if injuries occur on planes and trains traveling across state and national lines? The answers are crucial, of course, if one state follows ordinary negligence rules and the other invokes strict liability. Can legal devices be used to avoid liability under the law of other states or nations? Should there be an attempt to obtain uniform legislation covering atomic energy tort law so that the conflicts problems will be minimized?
Many of these problems also will be present in the workmen's compensation field. The same problems of proof, of the statutory time limitations, and of the peculiar nature of atomic energy injuries will be in evidence. In addition, workmen's compensation statutes will have to be evaluated to determine if they provide satisfactory coverage for atomic energy industries. If the state has lists of compensable injuries, radiation injuries must be included. If general categories are set forth in the statute, they will have to be examined to ascertain if the coverage is as broad as necessary. Moreover, the scale of benefit payments may have to be revised to allow compensation for injuries that may not cause a diminution in wage earnings, such as sterility.

These are among the many problems concerned with the tort liability aspects of atomic energy that have occurred to us. Undoubtedly others will occur to the reader and still further problems will arise in the future. Nonetheless, this listing serves to illustrate the problems that must be evaluated to determine what legal principles will be applied on the basis of common law concepts. Once these are evaluated, consideration should be given to changes in the law that should be made, either by the courts or legislatures, for the satisfactory accommodation of atomic energy in our society. In the succeeding chapters, we shall discuss the current rules of law as applied to atomic energy problems, and we shall suggest possible developments for the future.
TORT LIABILITY

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