Hazards of Nuclear Power Plants

George L. Weil
1025 Connecticut Avenue, NW, Washington 6, D.C.

THE beneficial prospects associated with the development of nuclear energy have been widely publicized. On the other hand, discussions of some of the unpleasant aspects have been limited almost exclusively to technical meetings and publications. A realistic appraisal of the future of nuclear power must include consideration of the potential problems as well as the potential benefits. The discussion presented here (*1*) is focused on the hazardous conditions that could, under the most pessimistic assumptions, result from a major accident involving a nuclear power plant.

The three principal elements that must be considered together in order to establish a realistic overall perspective in any discussion of industrial hazards are (i) the types of accidents that can occur and the extent of property damage and personal injury that may be involved; (ii) the probability of occurence, and (iii) the positive benefits that may be balanced against the risks. Unfortunately, experience in the field of high-temperature, high-power nuclear plants is, for all practical purposes, zero. We can therefore, at this stage, discuss these matters only in very general terms, terms based in very small part upon the factual information and experience gained from the limited number of reactors that have been built and operated.

Reactors are not only expensive machines; they are also potentially hazardous machines, substantially more so, in fact, than any industrial machines with which we are currently familiar. This of course does not mean that reactors will not eventually be used industrially with risks comparable to those associated with other industrial machines. It does mean, however, that a much greater degree of caution and control must be exercised in their design and operation; and it means that safeguards, perhaps costly, must be provided in the design of plants if the industry is going to develop and play a major role in our national economy. In the absence of realistic information based upon experience, those concerned with the design of nuclear power plants and those responsible for their operation must make the most pessimistic assumptions with regard to potential accidents and their consequences. In view of the potential seriousness of the off-site hazards, it is reasonable to place the burden of proof to do otherwise upon the sponsor of the plant. With experience will come effective and practical methods for dealing with these problems.

Remember that this discussion concerning the maximum possible reactor accident and the present evaluation of the maximum damage and hazard that can result from such an accident is only one part, the negative part at its worst, in the over-all consideration and evaluation of nuclear power plants.

Two principal characteristics of a nuclear power plant allow us to conclude at the outset that we are dealing with a highly hazardous operation: (i) the contained radioactive materials, fission products, and some types of fuel used, and (ii) the fact that the plant will contain, under certain circumstances, considerably more fissionable material than the critical amount. The significance of the combination of these two factors can be appreciated in some small measure if we compare the situation with, say, large-scale production of both highly poisonous gas and explosives under the same plant roof.

Fission products are produced by the reactor fuel in the process of consumption. They are therefore unavoidably tied to the generation of nuclear power. For example, a plant generating 10,000 kw will produce about 200 lb of fission products in the course of a year. The fission products are highly radioactive and therefore, like the more familiar material radium, can produce serious injury or death. Fission products, which include a large variety of chemical elements, if inhaled or ingested are from 3 million to 2000 million times more toxic than chlorine, the most potent common industrial poison (*2*).

Two other characteristics further differentiate the potential hazard of fission products from more conventional industrial poisons: (i) they cannot be detected by the senses, even in lethal concentrations; and (ii) nonlethal exposures can produce permanent injuries that may not become evident until many years after the accident. In addition, the nuclear fuels themselves, plutonium and uranium-233, are highly toxic if inhaled or ingested.

I now come to the second principal characteristic of a nuclear power plant, which is its built-in capacity for self-destruction in an exceedingly short time—in a fraction of a second. This characteristic derives from the fact that the reactor core will, under certain circumstances in its operating life, contain substantially more fissionable material than the critical amount required for a chain reaction. This situation suggests the possibility of a runaway condition with a rapidly accelerating chain reaction and with a simultaneous rise in temperature.

If a reactor does get out of control its power output and temperature can rise very rapidly to the point where the nuclear reaction is stopped by either one or a combination of two effects: disruption of the reactor core, or melting or vaporization of the nuclear fuel. The best calculations of expected blast effects from a runaway reactor under the worst circumstances show that it would be relatively small (*3–6*). The blast could certainly damage the reactor and its associated equipment beyond repair, but outside of the reactor building its direct effects would be negligible.

Before describing the maximum possible nuclear power plant accident, I want to emphasize that the probability of having such an accident will depend largely on such factors as the over-all design of the reactor and plant and the competence of the operators. Measuring instruments are available to detect hazardous conditions if they should arise, and controls and safety features are designed to nip them in the bud. However, if we are to appraise in general the potential hazards of nuclear power plants, we must assume that a runaway situation can be provoked, and we must examine the consequences under the most pessimistic conditions that might arise. Edward Teller, a member of the AEC's Advisory Committee on Reactor Safeguards, has said (*3*, p. 632):

> With all the inherent safeguards that can be put into a reactor, there is still no foolproof system that couldn't be made to work wrongly by a great enough fool. The real danger occurs when a false sense of security causes a let-down of caution.

The maximum possible accident can be considered along the following lines. Suppose that the nuclear power plant has been operating for a relatively long time without change of fuel; this means that a substantial amount of long-lived fission products has been produced and is contained in the core. In the course of start-up of the plant from a shutdown condition the nuclear reaction may get out of control; then the power output would increase at a rate that doubles its level every thousandth of a second, and the fuel temperature would rise accordingly. In a fraction of a second the fuel is melted and vaporized, chemical reactions take place between materials in the reactor core, and the rapid formation of gaseous products creates an explosion that damages the reactor structure and releases the radioactive fission products to the environment.

What damage has been done and what may further result? The reactor portion of the plant has been destroyed beyond repair. The building and a good deal of equipment have been contaminated with radioactivity and cannot be salvaged. Any operating personnel in the neighborhood of the reactor might have been injured or killed by blast damage at the time of the accident and, in any case, would have been exposed to the lethal properties of the radioactive materials released from the reactor. We assume that when the reactor structure is ruptured by the blast a large fraction of the fission products, perhaps 50 percent, is released in the form of a cloud that escapes from the reactor building into the overlying atmosphere. The radiation from this cloud would be lethal to a large fraction of the plant personnel, who could not be evacuated in the short time between the accident and appearance of the cloud. There might be fallout of radioactive material from the cloud, which would seriously contaminate the whole plant area.

The future course of events and the extent and type of damage and injury inflicted depend largely upon the local terrain and upon the meteorological conditions at the time of the accident. In line with taking the pessimistic position I will assume that the cloud remains close to the ground as it drifts slowly away from the plant with a prevailing wind of 3 to 4 mi/hr; that it passes over populated areas; and that an hour after the accident a rainstorm arises while the cloud is passing over farm land, over drainage areas that provide the local water supply, and over residential and industrial areas.

As a consequence of this assumed course of events the following injury and damage could result beyond the plant area (*5, 7–9*): (i) People in the path of the cloud within a distance of several miles from the plant could receive lethal doses of radiation. For example, this distance might be 5 or 6 mi for a 100,000-kw plant. (ii) If the cloud in its motion actually touched the ground, as would be the case under certain meteorological conditions, the distance within which people would receive lethal exposures as a result of inhalation would extend out substantially farther than it would if radiation from the cloud at a height of 50 or 100 ft were the only source of hazard. (iii) People exposed to the cloud and located at distances beyond the lethal radii for irradiation or inhalation would receive varying degrees of temporary or permanent injury. (iv) In the areas of rainout there would be widespread serious contamination—sources of food and water would be lost; population would have to be evacuated for an extended period from industrial, business, and residential areas. (v) Finally, not to be discounted are the many individuals who would be obsessed with continuing anxieties about their fate, even though they had sustained no observable injury at the time of the accident.

I have described a local catastrophe resulting from a nuclear power plant accident on the basis of a compounding series of pessimistic assumptions. I would now like to turn to some of the precautionary measures that can be taken in plant design, location, and operation to reduce the potential hazards of nuclear accidents. It should be noted that each of these measures can involve a substantial increase in over-all plant cost, operating expenses, or both. Their practicability therefore will be determined by a balance between their effect on the cost of the power generated and their effect on the cost of insurance if greater risks are accepted. Some of the obvious measures that can be taken are briefly as follows: (i) Select the basic reactor design that is inherently the most stable. There is a wide range of variation among reactor types. (ii) Locate the plant in a remote, unpopulated, unproductive area. This would clearly be impractical for a nuclear power industry. (iii) Locate the plant on a site large enough so that the risks of off-site damages and injuries are substantially reduced. Since land costs are high in industrialized and populated areas, the increase in fixed charges on the plant could easily price the power out of competition. (iv) Since the blast damage at the time of an accident is manageable, it is considered feasible to design the reactor building to be gastight and to contain any gaseous fission products released from the reactor. This general approach is the most promising. (v) In reactors using liquid fuels one can consider continuous removal of the fission products. This is probably practical and economical up to a certain point, beyond which the additional operating costs would become prohibitive. (vi) Construction of a widespread warning system and means for rapid evacution or sheltering of people in the path of the cloud.

These are some of the positive measures that can be taken to minimize the risks. There are other elements that can strongly influence the degree and extent of the hazards associated with a nuclear accident. These elements were all introduced as pessimistic assumptions in my description of the maximum possible accident. The considerations that tend to temper somewhat the harsh effects produced by deliberate compounding of pessimism include these: (i) The wind could carry the cloud over less heavily populated and sensitive areas than those assumed. (ii) The wind could be strong and the atmosphere turbulent. This would rapidly disperse the cloud and dilute its concentration. Although it would allow less time for evacuation, the hazards would extend over a substantially smaller area and the people would be exposed to the maximum radiation over a shorter period. (iii) A considerably smaller fraction of the fission products might be released into the atmosphere at the time of the accident. (iv) There would not necessarily be any fallout or rainout.

As a closing thought I would like to recapture a little of the over-all perspective that is all too easily submerged in a discussion focused on accidents and hazards. An important step in the development of any new process for large-scale industrial use is an understanding of possible abnormal, as well as normal, behavior of the equipment and an appreciation of the consequences in the event of malfunctioning. Only with this basic understanding of the process under all conditions can effective steps be taken to minimize the risks. In every field understanding leads to control. We now believe that we understand reactors. There will, of course, always be some risks, but the past 12 yr of safe activities with many different types of reactors is convincing testimony to our understanding of the technology and encourages us to believe that the problems of the future can be met with equal success.

References and Notes

1. Based on an address before a meeting of the Atomic Industrial Forum, Inc., Plaza Hotel, New York, 28 Sept. 1954.
2. K. Z. Morgan and M. R. Ford, "Developments in internal dose determinations," *Nucleonics* **12**, No. 6, 26 (1954).
3. *Atomic Power Development and Private Enterprise*, Hearings before the Joint Committee on Atomic Energy, 83rd Congress, 1st Session, June–July 1953 (Government Printing Office, Washington, D.C.).
4. E. Teller, "Reactor hazards predictable," *Nucleonics* **11**, No. 11, 80 (1953).
5. H. Hurwitz, Jr., "Safeguard considerations for nuclear power plants," *Nucleonics* **12**, No. 3, 57 (1954).
6. M. M. Mills, "Hazards of low power research reactors," *Proc. 3rd Annual Oak Ridge Summer Symposium*, TID 5031 (Technical Information Services, Oak Ridge, Tenn., 1951).
7. J. J. Fitzgerald, H. Hurwitz, Jr., and L. Tonks, *Method for Evaluating Radiation Hazards from a Nuclear Incident*, KAPL-1045 (Knolls Atomic Power Laboratory, Schenectady, N.Y., 1954). Available from the Office of Technical Services, U.S. Dept. of Commerce, Washington, D.C.
8. "Reactor exclusion areas," *Nucleonics* **12**, No. 3, 75 (1954); *ibid.* **12**, No. 4, 78 (1954); F. W. Gilbert, "Decontamination of the Canadian reactor," *Chem. Eng. Progr.* **50**, 267 (1954).
9. R. B. Mesler and L. C. Widdoes, "Evaluating reactor hazards from airborne fission products," *Nucleonics* **12**, No. 9, 39 (1954).

Need for Public Understanding of Science

Gerard Piel

Scientific American, New York, N.Y.

IT would be difficult, I am sure, to work up a debate in this company* on the question whether the American people ought to have a better understanding of science. No one present would want the negative side of that argument. When it comes to ignorance, we are all likely to sound like Calvin Coolidge's preacher on the subject of sin; we are against it.

We can congratulate ourselves, nonetheless, for our unanimity on this question. Not so long ago there was a respectable body of opinion in science which held that what the people don't know won't hurt them. A little knowledge is a dangerous thing, the argument ran; let the shoemaker stick to his last. Decisions on technical matters, whether in public affairs or in industry, ought to be made by experts qualified to deal with the hard and often complicated facts. The less such questions get embroiled in the misconceptions and prejudices of half-informed laymen, the better for everyone.

Admittedly, something of a case can be made for this point of view. I have not done justice to it as it was argued to me by a distinguished chemist some 15 years ago when I asked for help on an article for the lay public. Perhaps he is present here tonight. Perhaps, to borrow a troublesome metaphor, I should have let sleeping dogs lie!

Since we might have a debate after all, let me dispose of my honorable opponent's position right now.

* This paper is based on a talk given at the southeastern regional meeting of the American Chemical Society in Birmingham, Ala., 21 Oct. 1954.