Nuclear safety

Realistic risk estimates

by M. Levenson* and F. Rahn**

The safety of nuclear power plants has been defended – and attacked– on how likely it is that a major release of radioactivity will occur. Nuclear advocates say once every million reactor years at most. People opposed to nuclear power say it can happen at any time, and will happen often. At the heart of this debate is the probability of an accident occurring. Neither side has framed their argument around the worst release that could really happen – an essential ingredient in determining public risk.

In a reactor accident, the main concern is that engineering safety features will fail and the radioactive fission products in the core will then be spread into the atmosphere. The risk to the public from such a nuclear accident is based on three quantities.

- The probability of some sequence of undesirable events occurring. (There is no damage if the accident does not happen.)
- The consequences that would follow if these undesirable events occurred (There is no damage if no radioactivity is released.)
- The action taken to mitigate the accident, if it occurs.

In the last decade much work has been done to evaluate probability. A number of probabilistic methodologies have appeared; the most widely quoted is the Reactor Safety Study (Wash-1400) authored in 1975 by a research group headed by the Massachusetts Institute of Technology (MIT) Professor Norman Rasmussen. This study was funded by the US Nuclear Regulatory Commission.

The Wash-1400 report consolidates the engineering rationale that has been used for the design and assessment of complex technologies into a repeatable methodology. Rasmussen's first step is to identify the possible initiating events of an accident– what might break, what might fail, what might be done incorrectly, and so on. Then an event-tree is made up to show the possible propagations for each initiating event. For example, if a pipe break starts a loss-of-coolant-accident, then electricity to run the emergency water pumps may or may not be available. If electricity is available, the pumps may or may not start, and so on.

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As far as possible, the event-tree traces all events that could lead to a release of radioactivity. It then assigns a numerical probability to each event, one can find out the likelihood of a major nuclear accident by adding up all the branches of the tree and multiplying the probabilities. The Wash-1400 report concludes that a public catastrophe (1000 people die) might occur no more than once in a million reactor-years.

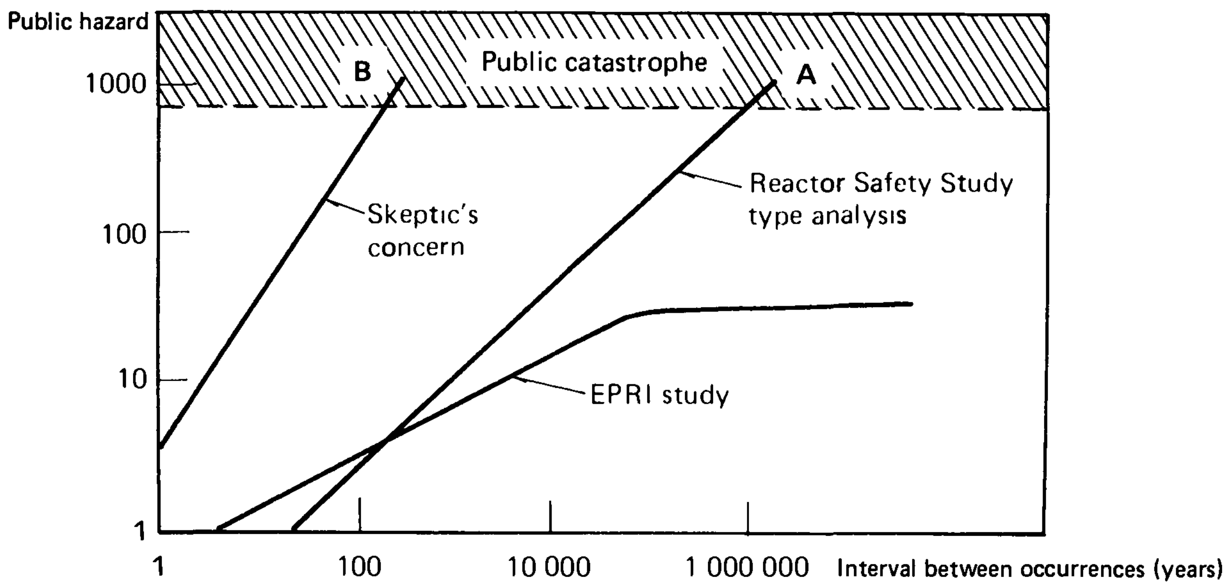
Risk is overestimated

A recent study* at EPRI has suggested that, however valuable the Wash-1400 study is at defining probability, it overestimates consequences by a large amount, and thus it overestimates risk. While Wash-1400 is an improvement over an earlier Brookhaven National Laboratory study (Wash-740) on the same subject, it is still quite far from what would really happen in a reactor accident. The Wash-1400 authors were hampered by a lack of ability to model, with precision, the physical conditions of the chemistry that exist during an accident. Their outcome is an efficient but simplified model, that makes conservative assumptions in many areas of complex or uncertain phenomena, particularly in the area of radioactive release. These conservatisms compound. As a result Wash-1400 has a tendency to overestimate the consequences of an accident significantly.

What Wash-1400 and other risk studies have not adequately included are a number of chemical and physical laws that are always at work to reduce radiation release. Some of these to keep in mind are.

- Stable, dispersible aerosols are difficult to create. Highly concentrated aerosols coalesce rapidly, and low-density aerosols increase their effective density extremely rapidly in the presence of water vapour, serving as condensation nuclei.
- Iodine is chemically and physically reactive in its many forms. Since nearly all the surface area inside the containment building is covered with paint, plastic or organic films, iodine retention is high. In addition, iodine will be absorbed on the surface of aerosol particles, which rapidly agglomerate and fall out. In either case, much of the iodine is quickly immobilized.

* *Realistic estimates of the consequences of nuclear accidents* M. Levenson and F Rahn, Electric Power Research Institute (EPRI), Palo Alto, California 94303, USA (1981)



Various assessments of public hazard.
• Most detailed probability analyses such as the Reactor Safety Study (Wash-1400) indicate that a public catastrophe might occur no more than once in a million reactor years (A). • Many people fear that this is not correct and that such a catastrophe might occur more often (B). • EPRI study suggests that natural processes limit both the spread of radioactivity and associated public hazard.

• Aerosols tend to be trapped when passing through cracks and penetrations in pipes, compartment walls, or containment buildings.
• The aerosols, highly concentrated and physically dense, settle out close to their source. Although the original mass of particulates may be large, only a small fraction survives this settling process and remains airborne.
• The containment building and equipment inside it present a large surface area for fission-product plate-out and adsorption. Because of the many compartments of the building and the complex piping and hardware, escaping material must pass multiple surfaces to escape.
• Moisture conditions in the reactor containment building will cause most of the soluble fission products that become airborne to go into solution. Since a core-melt accident is the result of coolant loss, it will always be accompanied by large amounts of steam and water. Therefore, a fog or rainlike condition will exist, even if the containment spray is never used. This is due to the fact that the heat capacity of the building and equipment causes condensation and dripping from all the surfaces. These phenomena will wash out large fractions of fission products present, before their release to the atmosphere. As mentioned earlier, moisture tends to further agglomerate aerosols and to increase their density.
• The earth itself acts as a filter for any escaping fission products in the event of a "melt-through" or "atmospheric release" accident. If the overpressurization were to blow out the penetration or seals in the containment building, the path for escaping radioactive materials usually would be through other buildings. This would provide further opportunity for radioactivity plate-out and fallout.
• In the event of a massive containment building failure, the presence of large amounts of water and vapour, plus the heat capacity of the containment building and debris, would immobilize a large fraction of the radioactivity.

The effect of each of the above is to reduce the magnitude of predicted releases and greatly to reduce the quantity of iodine and particulates relative to noble gases present in the releases. Both changes would reduce the consequences to the public. The number of early and delayed fatalities that would actually occur in the area of the reactor would be much lower than predicted in previous studies, such as Wash-1400. For instance, a ten-fold reduction of the iodine and particulate source term* implies *no* early fatalities resulting from an accident.

Evacuation unjustified

This new assessment, based on the laws of chemistry and physics, has an importance beyond the technical issue. The kind of mitigating action that is taken following an accident must be based upon the *actual* risk to the public. When an accident occurs, the health and safety authorities will have to decide how to protect the public. They will have to consider, on one hand, the many risks of evacuation deaths due to traffic accidents and heart attacks, as well as the psychic trauma brought

*Source term is a phrase used in the licensing process It means the postulated amount of radioactive fission products released in a reactor accident on by the stresses of evacuation; on the other hand they will have to weigh the actual radiation risk. If the release of radioactive material were badly overestimated, the mitigating actions that followed would be unnecessary and perhaps dangerous.

Evacuation is currently the recommended response to most postulated radiation releases. But in almost all cases it is unnecessary. Numerous evacuation models that consider the dynamics of radioactive plume dispersal and population movements have been made in the last decade. Even with the models and source terms used in the Wash-1400 study, the technical basis for large-scale evacuation is marginal. When more realistic source terms for radioactive release are used, based on physical and chemical laws, there is even less justification for such an evacuation.

If a core-melt accident occurred (failure of all engineered safeguards plus failure of containment building), the off-site doses would probably exceed the US Environmental Protection Agency's Draft Protection Action Guide level, but only within a very short distance from the reactor – maybe less than a mile or two. Only within this area would it appear that evacuation might be prudent. (By contrast, the EPA suggests an evacuation of a 10-mile radius area for a similar core-melt release.) Even so, evacuation may be no more effective than staying inside with doors and windows closed to limit the radiation dose to the population. The time between the start of an accident and actual threat to the public is relatively long – a matter of hours and days rather than minutes. Morever, if a threat were to materialize immediately after the start of an accident, sheltering would be the only option. While evacuation plans may be prudent, they should be based on realistic conditions that could exist at the time of an accident.

Again, it is important to have a realistic view of the danger. Calculations that use "conservative" assumptions are generally believed to increase safety margins, but in fact they can *decrease* the safety margins by introducing hazards not considered in the calculations. Evacuation is full of dangers, both real and perceived. The idea that immediate or large area evacuations are desirable or necessary for public safety is probably wrong on both counts.

Not enough recognition is given to the safety margin provided by sheltering and controlled air supply. This means nothing more complicated than staying indoors, closing the doors and windows, and shutting off exhaust fans. The merits of evacuation as against sheltering depend a lot on the particulars of a given accident. Severity, site location, and meteorological conditions are among the considerations Only in a few conditions, and only for a few persons, is evacuation likely to be better than sheltering.

Compare like with like

Precise answers on whether to evacuate some persons, when to evacuate them, how far, and in which direction are specific to each site and each accident. But in no case can the analysis be called complete if sheltering calculations have not been included, and if nuclear and non-nuclear risks have not been considered on an equally conservative basis.

The real risk to the public from a nuclear accident is a function of three quantities: probability of the accident; consequence of the accident; and effect of the mitigating action taken. The current procedure of using "conservative" assumptions at each stage in the calculations has the result of producing a risk estimate that is high by an order of magnitude, or two, more than the normally assumed large safety margins.

When these conservative assumptions are used by regulatory agencies in the licensing process, they add another "uncredited" margin of safety. This may add to the total risk by severely overestimating source terms and thus the benefits of activities like evacuation. These errors, in turn, may lead to placing large segments of society at unnecessary risk.