DANGER OF CRITICALITY AT TMI

By Dr. Michio Kaku
Prof. of Nuclear Physics
City Univ. of New York

Since the accident at Three Mile Island in 1979, most of the damaged uranium core has been removed by the GPU utility, and the general public widely believes that the last remnants of danger from the reactor have been successfully removed.

However, it is not widely known that the removal of the core was more difficult than expected, and that the utility was forced to leave several tons of uranium debris inside the reactor vessel. Because the core removal operation was incomplete, the question remains: can the remaining uranium create another accident, i.e. can it "go critical?" This is not an idle question, because the uranium in the core is the form of large quantities of loose debris which might, under certain circumstances, come together to reach critical mass.

The utility, of course, has issued press reports suggesting that there is no cause for alarm, that the remaining uranium debris cannot start another accident at TMI. These reassuring, calming statements, however, are quite different from the picture revealed by the official technical documents submitted to the NRC. Instead of projecting the image of a utility that has responsibly and skillfully removed all possibility of an accident, a careful reading of these technical documents shows that the utility has cut corners, made sloppy analyses, and made clumsy mistakes, which had to be corrected by the NRC. Worse, it also admits, in effect, that a criticality accident is indeed possible.

In fact, the very reason why the NRC asked the GPU in the first place to prepare these lengthy reports is precisely because a criticality accident is theoretically possible. (If a criticality accident were impossible, as they publicly claim, then the large volume of reports generated by the utility would have been completely unnecessary.)

The utility admits that not only is criticality possible, but it calculates the amount of uranium necessary to reach critical mass: about 200 pounds of uranium debris (a fraction of the total amount of uranium left in the core). In other words, if an accident were to somehow to rearrange the debris inside the core and bring 200 pounds of loose uranium together within the damaged reactor vessel, the core would go critical, and the accident at TMI would start all over again.

In its defense, the utility admits that a criticality accident, although theoretically possible, is in practice not likely because of the safeguards that they have taken. Their "maximum credible accident," however, is only a very slight rearrangement of the uranium debris in the core which brings less than 200 pounds of uranium together. Much like the optimistic reasoning that went on before the accident in 1979, the utility fondly believes that the "maximum credible accident" is a minor nuisance that will not disturb the sleeping core.

Surprisingly, a detailed reading of the technical documents prepared by the GPU shows large inconsistencies and gaps in their reasoning. In effect, the utility has tried to hide behind a mountain of jargon and technical reports to conceal from the public the truth about criticality. Not only is their calculation of critical mass probably too high, they have also ignored serious accident scenarios which can bring together enough uranium debris to initiate a criticality accident.

Dangers of a Criticality Accident

To understand the grave importance of a criticality accident, it is important to understand that the word "critical" refers to the population of neutrons within the core. The word "subcritical" means that the population of neutrons decreases with time, so that the number of fissions, and hence the amount of energy released by the core, diminishes. The debris in the reactor core, at present, is subcritical. This means that a quantity called "k-effective" is less than one.

The danger, however, is when the core becomes critical, or even supercritical. The word "supercritical" means that the number of neutrons grows with time. This means that the number of fissions also increases, and hence the amount of energy released by the core increases. k-effective is greater than one. Supercriticality can be reached, for example, in a reactor accident or in an atomic bomb.

A damaged core that is critical or even supercritical poses a potential grave danger. The problem is not that the core will detonate like an atomic bomb (this is impossible, since k-effective is much smaller than that necessary to create a bomb). However, the real danger is that a criticality accident will cause the temperature within the core to rise, causing the water to boil and perhaps explode in a steam explosion.

For example, in Jan., 1961, an experimental U.S. Naval reactor in Idaho, called the SL-1 (stationary low power reactor), accidentally went supercritical when workers inadvertently removed the central control rod from the reactor. The temperature within the core soared dramatically within milliseconds, vaporizing the water in the core, and the resulting steam explosion blew the reactor apart, killing three workers.

Similarly, the accident at Chernobyl was also caused by supercriticality. The official report states that (like the SL-1 accident) workers manually removed the safety mechanisms of the reactor. The reactor went supercritical, and the sudden burst of energy created a steam and hydrogen explosion which blew the roof off the reactor, creating the worst reactor accident in history.

Other types of criticality accidents of the past have happened with subcritical pieces of uranium or plutonium (which by themselves do not pose a danger) are brought together, creating a supercritical mass. For example, in 1945 and in 1946, two fatal criticality accidents happened at Los Alamos when Harry Daglian and Louis Slotin brought subcritical hemispheres of plutonium (from the atomic bomb project) together manually. The configuration rapidly changed from subcriticality to supercriticality, and the resulting flash of light released vast amounts of neutrons, which in turn destroyed much of the cells within the workers' bodies.

What Can Go Wrong

Given the surprisingly long and dangerous history of criticality accidents in the U.S. and Russia, it is important to give a careful analysis of the GPU reports, which downplay the importance of criticality accidents.

There are several problems with the GPU reports which can lead to a criticality accident.

1) estimates of critical mass may be too low
2) chemical explosions, fires, power loss, etc. are not analyzed
3) human error is neglected

Critical Mass

Only with the gravest reluctance has the utility given to the public the documents relating to the calculation of k-effective and the estimate of critical mass. Only after repeated requests has the utility released documents showing how the calculations were performed. This certainly does not increase the public's confidence in the utility.

A careful reading of the documents, however, shows some glaring inadequacies. The key calculation of k-effective and critical mass, in fact, was not performed by the utility at all (it involves solving a time-dependent, second-order partial differential equation in three dimensions). The calculation, in fact, was performed at the Oak Ridge National Laboratory.

Unfortunately, the utility has stonewalled all attempts at obtaining the key ORNL report. However, the brief description of the ORNL study in the GPU reports allows one to reconstruct how the calculation was performed. There are several key flaws in the study. Because the precise shape of all the core fragments in the vessel is unknown, the ORNL report simply assumed a perfect, two-dimensional geometrical configuration of uranium for its calculation. Then they used this rather dubious assumption to calculate the neutron population within this highly symmetrical geometric shape. Then they proudly concluded that this idealized model accurately describes the type of accident that can happen with random debris.

However, reality is often more complicated than simple-minded computer models. As we often say in the business, "Garbage in, garbage out," (i.e. if your assumptions and inputs are false and unrealistic, then the computer calculations, no matter how elaborate, will also be worthless). In reality, photographs of the bottom and sides of the reactor vessel (taken by small cameras that were sent into the radioactive core) show that the debris is in highly irregular shapes and sizes, with no regularity, making a realistic calculation of the neutron population quite difficult.

The solution to the problem, of course, is to release the ORNL computer codes to the public and let independent scientific groups rerun the calculation and make improvements. (For example, it would be simple for me to reproduce the ORNL calculation on the VAX computer at the CUNY, or the supercomputer at Cornell.)

However, the fact that GPU stubbornly refuses to make the ORNL calculation available leads one to suspect, until proven otherwise, that they are hiding something.

Catastrophic Accident

Under normal, routine operations, the utility is correct in stating that it is unlikely that 200 pounds of uranium debris will come together and create a criticality accident. However, this is not the point. Over a period of many years, the probability of unexpected accidents increases greatly. For example, a fire in the reactor containment, a chemical explosion (e.g. initiated by the presence of hydrogen gas), a sudden loss of power due to a failure in power systems, etc. have all taken place at reactors around the country. At the Brown's Ferry accident of 1970 in Alabama, a fire was accidentally set off by workers using a candle to inspect the reactor. The candle fire set off the insulation, which created a fire which raged for several hours out of control, gutted the reactor, disabled the safety systems, and almost caused the core to be uncovered, which would have initiated a meltdown. The reactor crew was completely overwhelmed, and the local fire department had to be called in, which successfully put out the fire.

Similarly, hydrogen gas explosions are rather common at reactors. Because hydrogen gas is generated in the normal operation of a reactor, special care must be taken to insure that the hydrogen gas does not come in contact with a spark or flame. (In fact, a hydrogen gas explosion took place during the TMI accident of 1979, which shook the reactor, overpressurized the containment, but fortunately did not damage key pipes or cables.) Furthermore, crucial power systems have suddenly been lost due to lightning bolts and other unforeseen incidents.

The point is that all these serious accidents have, indeed, happened at reactor sides around the country and that they can, under certain circumstances, cause a rearrangement of the uranium debris beyond critical mass.

Human Error

Most of the accidents in the past were caused by a combination of design flaws and human error. Although design errors can be technically eliminated, human error cannot. As a result, it is not surprising that human error figured prominently in all previous reactor accidents. From the SL-1 accident of 1961, the Fermi I accident of 1965, the TMI accident of 1979, and the more recent Chernobyl accident, human error was the trigger that initiated the accidents. Human error can trigger an accident at TMI as well. For example, the neutron and heat levels of the core must be carefully monitored at all times. Over the years, workers may neglect these monitors or, like in the SL-1 or Chernobyl accidents, be tempted to tamper with the reactor and make unauthorized changes.

Summary

In summary, both the utility and its critics agree that a critical accident at TMI is possible. This is not in dispute. Although GPU in public maintains that a criticality accident is not possible, its own technical reports state otherwise.

What is in dispute are two issues:

a) how accurate is the estimate of critical mass (200 pounds)

b) given that 200 pounds is much less than the total amount of debris in the core, what catastrophic accidents can cause this amount of uranium to come together?

The utility stands behind the ORNL report, which they refuse to release. However, the report is simple-minded to the point of being incorrect. Because they cannot make a realistic calculation of the uranium debris, they make unrealistic assumptions in their computer model. This, in turn, may lower the actual critical mass estimate down from 200 pounds.

Furthermore, the utility believes that the maximum credible accident is a rather mild jostling of the core. However, the actual history of accidents at reactor sites (including crippling fires, hydrogen explosions, human error, etc.) shows that it is possible that the core may experience a large disturbance which might rearrange the loose debris inside the core and restart the accident at TMI.