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Prospects for Nuclear Safety Research

Introduction

I am pleased to speak at this luncheon of the 22nd Water Reactor Safety Meeting in your presence as important members of the U.S. and international safety community. This is the 9th such meeting since I became Director of Research at the Nuclear Regulatory Commission (NRC), and an appropriate occasion to talk about reactor safety, the contribution of reactor safety research, and prospects for safety research in the years to come.

Reactor Safety 1979-1994

The Three Mile Island Unit 2 accident raised major concerns about nuclear reactor safety in this country and abroad, and led to a widespread review of plant performance and safety requirements by NRC. As a result there were many improvements made to emergency safety systems, control rooms and instrumentation, and operator qualifications and training. There is no question that plant safety has improved as a consequence.

Plant owner/operators have made safety improvements. One example is the reduction of the number of automatic reactor trips. They accomplished this by systematic review of plant conditions at the time of the trip, determination of the root cause, and, if the trip was not needed for safety, correction so that the condition will not reoccur. Unnecessary trips are a challenge to safety systems, and reducing unnecessary challenges is a safety improvement. The bar chart shown in Fig. 1 from the INPO 1993 Annual Report shows the record of progress in reactor trips. The message is easy to understand, and I will refer to it later.

Reactor safety research conducted by the NRC has also made important contributions to safety over the same period of time. There is, however, no simple measure, such as a numerical performance indicator, to show the improvement. Nevertheless it is possible to explain causes of safety improvement in meaningful terms. Here are four examples which have made a difference.

1. Reactor Vessel Research

Reactor vessels are vital not only in normal operation, but also in accidents wherein they must retain water for the purpose of core cooling to prevent fuel melting. Exposure of the vessel to neutrons throughout its life causes changes in the vessel steel. The most important changes are the increase of the nil ductility transition temperature or embrittlement, and the decrease in the ductile fracture toughness of the vessel and exposed welds. As vessels age, the effects of these changes become greater. Pressurized Thermal Shock (PTS) is an important safety issue arising from these changes. An example of PTS would be the actuation of a PWR safety injection system during a small break loss-of-coolant accident, as a result of which the reactor vessel temperature could drop quickly while the system is still pressurized: hence the term PTS. Reactor vessel research has concentrated on understanding the changes in order to establish safe limits to operation, and on the effectiveness of reactor vessel annealing when a vessel reaches the limits in order to restore the properties it had when it was new.

Had this research not been carried out, these limiting conditions on reactor vessel operation would not be known, and it would have been necessary to shut plants down on the basis of conservative estimates. Because of this research plants will be able to operate safely longer. I am talking about years of additional operation. Also, when the time comes, plants should be able to take advantage of reactor vessel annealing.

2. Probabilistic Risk Assessment

Probabilistic Risk Assessment (PRA), an idea proposed by Dr. Reginald Farmer in 1958, came to fruition in the 1975 Reactor Safety Study (WASH-1400). Unfortunately at that time its usefulness was not widely appreciated. Confidence in PRA increased gradually as a result of improvements and application to 30 or more plants. In 1990 NRC completed a 6 year study with major improvement of methods in the report on Severe Accident Risks (NUREG-1150). The Individual Plant Examination (IPE) program using NUREG-1150 methods and now approaching completion will provide a PRA study of every plant in the U.S. (except 1). In the course of the IPE every plant has made safety improvements as a result of discovery of accident vulnerabilities. This achievement is the direct result of NRC research and development of PRA, and its application by U.S. nuclear utilities. This is the first point I wish to make on PRA.

The second point is that we can use PRA to measure the effectiveness of safety research.

Fig. 2 shows the core damage frequencies (CDF) for PWRs from three sources: WASH-1400 (Surry), NUREG-1150 (Sequoyah, Surry, and Zion), and the Individual Plant Examination (IPE) PWRs (42 plants). I want to compare first WASH-1400 and NUREG-1150 CDFs, and second NUREG-1150 and the IPE. The WASH-1400 and NUREG-1150 values are almost the same, but major changes took place during the intervening 15 years between the studies: the NUREG-1150 analysis included many accident sequences not considered in WASH-1400, and many improvements were carried out on plant equipment as vulnerabilities were discovered. The NUREG-1150 CDF incorporates both. Consequently the comparison with WASH-1400 is not valid, and I assert that a reanalysis of the Surry CDF as it was at the time of WASH-1400 would in fact be substantially greater than the WASH-1400 value of 6 x 10^{-5} per reactor year. The difference between a revised value and the NUREG-1150 value would be a measure of the benefits attributable to the changes put into effect in large part due to the PRAs, and also to post TMI fixes. Doing this task today would take a lot of digging into records, and is perhaps not worthwhile, but I believe this kind of analysis should be done in the future, because it can measure the effectiveness of safety improvements derived from research. It will be helpful in budget justification. Notice the lengthy explanation I have given: I would prefer a simple indicator like that in Fig. 1.

The second comparison, i.e., of NUREG-1150 and the average of the IPE PWR CDFs is valid, because the IPE methods were based on NUREG-1150 methods, and because most of the IPEs submitted by the plant owners are of high quality. I conclude from the comparison that the IPE and the changes resulting from it have been very beneficial from the point of view of safety, confirming the first point on PRA that I made.

3. Severe Accident Research - Direct Containment Heating

Direct Containment Heating (DCH) is the challenge to a containment building of high pressure melt ejection from the reactor vessel of a PWR during the station blackout sequence. Research took two approaches to this issue. The first was in NUREG-1150, a probabilistic approach. The conclusion was that the risk of this sequence is low, because it is very unlikely that the primary system would be at high pressure at the time of reactor vessel failure, for the reason that the pressurizer surge line or the hot leg would fail early in the sequence because of very hot gas flowing through the relief valve, causing pipe failure on the way.

The second approach to resolution of this issue was to perform tests of the DCH phenomena and sequence in 3 facilities: 1/6, 1/10, and 1/40 scale tests.
The tests and their analyses showed that the likelihood of containment failure, given the event itself, is very low for PWRs such as Zion (6 plants) and Surry (10 plants), because most of the melt is caught in the compartments along the path and does not reach the containment free volume. The conclusion of this research is that the existing Westinghouse large, dry PWR containment building plants have adequate margin in their design basis to withstand the challenge of this unlikely beyond design basis accident. As a result of this finding, there is no need for additional measures to protect against DCH.

4. Advanced LWR Research

In 1990 General Electric and Westinghouse initiated applications for certification of their advanced passive LWR concepts (ALWR), the SBWR and the AP600. Because of novel features of the passive emergency core cooling systems for these plants, for which there were no performance data available, the NRC initiated confirmatory research of these systems in order to provide assurance that they would operate effectively in accident conditions. The research programs are now underway, with construction of a scale model test facility for the SBWR at Purdue University, and the conversion of the LSTF thermal-hydraulic test facility at the Japan Atomic Energy Research Institute to provide a scale model of the AP600. Testing began in January of this year at the latter facility. The AP600 tests in Japan have already provided important data on the AP600 scale model, making it possible to test the thermal hydraulic codes that will be used for licensing the AP600. The AP600 scale model tests, though not yet complete, are a major contribution, along with separate tests by Westinghouse to proof of safety, and thus an important safety research accomplishment.

These few examples, I think, illustrate clearly major contributions of research to reactor safety, and are proofs of its importance.

I have been talking mostly about NRC research accomplishments, and now I want to talk about the broad prospect ahead for nuclear safety research, and not just NRC research. Because the demand for this research is linked to the general prospect for nuclear energy in the U.S., it is helpful to see how it might evolve, and specifically whether it will decline, remain stationary, or grow. I do not predict but rather look at certain indicators, which taken together can point out a favorable trend, or the contrary.

Nuclear Energy Prospects in the U.S.

The indicators selected are shown on Fig. 3, and I define them briefly as follows:

Resource Base: domestic uranium resources

Policy: totality of local, state, and national requirements to build and operate a nuclear plant

Economics: competition with other energy generation sources

Environment: effect of plant operation on air quality and atmospheric carbon dioxide

For nuclear energy these four indicators are not controversial and for the most part factual. The remaining four also have a factual basis, but are more controversial, and public perception of them, which may differ from fact, is more important. The definitions of these are as follow:

Waste Disposal: public acceptance of nuclear waste disposal

Nuclear Proliferation: perception of link between nuclear fuel cycle and weapons

Health and Safety: public concern about health and safety of nuclear plants

Renewable Energy: perception of abundant sources just around the corner

Although public perception is generally slow to change in a direction favorable to nuclear energy, it can change suddenly in an unfavorable direction, as in the case of Health and Safety after Three Mile Island.

In Fig. 4 I now compare these indicators as perceived 15 years ago, today, and how they might be over the coming 15 years. In 1979 after Three Mile Island (TMI) there were just two indicators that were favorable: Resource Base and Economics. Plant capital and operating costs were under reasonable control, and nuclear electricity was competitive with the alternatives. Renewable Energy was a nascent issue then. All other indicators were unfavorable to nuclear generation, and especially Health and Safety because of the TMI accident. So too was Nuclear Proliferation, until the public recognized that the LWR once-through fuel cycle was not prone, in the absence of clandestine reprocessing plants, to proliferation. As is evident from the

tally, the totality of indicators did not favor nuclear energy in 1979, with 5 out of 8 unfavorable.

Today the tally components differ somewhat from 1979. Health and Safety is a non-issue, that is to say neither favorable nor unfavorable, because of improved plant performance, and the passage of time since TMI. Economics has turned unfavorable for several reasons. Increasing operating costs of nuclear plants make them less competitive, and cheap natural gas is available on 10 year contracts for low capital cost gas turbines, or combined cycle plants. Also, it is a fact that base load plant construction of any kind is at a standstill because of reduced electrical load growth and excess generation capacity. The bottom line of the 1994 tally is little changed from 1979 and unfavorable to new construction.

What about the future? Watch the indicators. It is important to look ahead and see what the future may bring. Both the nuclear industry and the regulators must plan for future needs. My view is that major changes in the indicators could occur in the coming 10-15 years. The test for Renewable Energy will be cost competition with base loaded thermal plants for new construction. The question will be how much of a premium will the public be willing to pay for Renewable Energy. With the advent of advanced passive LWRs, Health and Safety could become favorable to Nuclear Plants. I do not expect Waste Disposal to turn favorable to nuclear power in this period, but it is possible that it could become less controversial or a non-issue, if the development of the Yucca Mountain repository or an alternative shows success. The Environment, in the event of resolution of the effects of carbon dioxide release, will favor nuclear energy. Policy also could shift: plants can be constructed in 6 years, and policy changes could reduce the long lead times; the NRC's Part 52 Rule for Standard Design Certification is important in this respect.

Economics is a big question mark primarily because of the future availability of cheap natural gas. We know that gas price is inelastic for increasing demand beyond transmission capability. Furthermore, conventional wisdom looks to a continuation of technology improvement in searching for and developing new resources. If conventional wisdom is wrong and gas prices rise, Economics could swing in favor of nuclear energy. Finally, the Resource Base could become a more decisive consideration than it is today, particularly if natural gas imports from Canada and Mexico rise: In that event, the large U.S. resource of uranium is likely to be recognized again.

So, watch the indicators!

Future Nuclear Safety Research

What research is likely to make a difference in years to come? Here I refer to research again broadly, not simply NRC research. One way to answer the question is in terms of the indicators. In this context the eight again can be separated in 2 groups, as shown in Fig. 5.

The first five, i.e. Resource Base, Policy, Environment, Renewable Energy, and Nuclear Proliferation, are externalities, because developments and changes in whether they will be favorable or unfavorable will take place without strong linkage to LWR development. The last three are linked to technology development, and are the areas where research can make a difference.

1. Economics. This is the province of nuclear development which the nuclear industry supports. Although it is not in a strict sense nuclear safety research, I mention it, because I believe that performance improvement can never be completely separated from safety, and it should be carried out in the context of meeting recognized safety goals. Performance improvement means increasing availability, controlling operation and maintenance cost, and fuel cycle improvement. For advanced design extending the design life of systems and components, and reducing capital cost are also important. Improvements in any one or all of these factors can improve the evaluation of nuclear plants in comparison with competitors.

2. Waste Disposal. The policy change that set LWRs on the course away from reprocessing and toward the once-through fuel cycle took place 20 years ago. I do not think that anybody anticipated in 1975 that it would take 20 years and more to resolve the issue of spent fuel storage, and the issue is far more pressing today than it was then. The issue is in part amenable to resolution by science and technology, and in part depends on a change in public perception: the NIMBY ("not in my back yard") syndrome. Science and technology are at work on deep geologic storage, and on development of enduring encapsulation. My position is that there should be enough flexibility in the process leading to actual storage of spent fuel, so that there is room for trial, error, and correction, an essential step in all of science and engineering, without which we may have a Catch 22: to do a job, you first have to prove it; you cannot prove it if you cannot try it.

3. Health and Safety. Operating reactors are demonstrably safer than they were 15 years ago, through the effort of reactor operators, the NRC, through research by the industry and NRC, and through international connections in all these activities. It is important to maintain safety of operating reactors, through their remaining life, including license

renewal. That is likely to be 30 to 50 years or more into the future. We have learned much about aging mechanisms and managing them, but important tasks remain, such as improved non-destructive testing to detect flaws and to indicate the remaining life of primary system components, steam generator tubes, and safety related electromechanical equipment, such as pumps and valves. We should understand that the more than 1500 reactor years of operation now behind us came from new and middle aged plants, but little or none from plants near the end of their design lives. Therefore, we should be ready for surprises as operating plants reach the end of their life. Doing this requires that we maintain an active aging phenomena and management program.

The ALWR developments and reviews are preparation for tomorrow: they lead to new and improved standard designs. When the process is complete I think the PRAs of these advanced designs will show significantly lower CDFs and risks than the currently operating plants. I think it likely that regulation will be risk based through application of PRA by the time these plants become a reality. On the systems side the research is not yet complete, and there is more to do on passive ECCS performance, containment cooling during accidents, and instrumentation and controls. There is also a need for more work on human decision making and reliability, and on the effect of organization and management on safety. It is important now to carry through and complete the work so that all important safety issues for these new plants are resolved, and so that there are no big questions left on the table that could hang over licensing and operations for the future.

So I say to you there is plenty of important nuclear safety research to be carried out. There are 109 operating plants in the U.S., and there are many nuclear power plants operating in countries where rapid societal changes are taking place and the institutions responsible for nuclear safety need strengthening. Research has a role to play in these activities. For these reasons I believe nuclear safety research is justifiable, although full funding for it will be harder to obtain than in the past. It will be the responsibility of those who plan and lead the research to make the case for it convincing and effective, and, with the researchers, to see to it that the research produces useful and important results.