EARLY ADVANCES IN SEISMIC STANDARDS FOR AMERICAN POWER REACTORS

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SUMMARY

This paper is a brief and wide-ranging version of the history of seismic standards in the USA within the development of power reactos. Topics include reactor siting, extreme earthquakes, extreme reactor accidents, seismic shutdown systems, and the evloution, application costs, and possible future of seismic standards. A call is make for a change in the power reactor licensing system.

INTRODUCTION

Earthquake reactor engineering joins two fields each causing strong emotional response. Both large reactor accidents and large earthquakes are so complex that they usually surprise investigators. Nuclear seismic standards in the USA have been a political football, and not a few engineers and scientists have seen their published conclusions quickly rejected. The nuclear reactor age now extends over almost 42 years, but many apparently contradictory conclusions can still be draw.

No reactor is known to have suffered an intense earthquake. Certainly the public has been little harmed by the several reactor accidents in the USA. There is no reported major reactor disaster worldwide, but Z.A. Medvedev documents that the US government held secret for more than 20 years its information on the great Kystym, USSR, reactor fuel processing disaster of the late 1950's. One can speculate on how much sounder the US nuclear industry and power reactor safety programs would be today if reports on that accident had stopped passage of the Price-Anderson Act.

The US Navy's power reactor design, construction, operation, and training programs appear outstanding, and mechanical dynamic designs today presumably go well beyond the current seismic objectives of the power reactor industry. It is unclear, however, that all of these skills have been passed on for industrial practice. Because of cost, reactors that generate electric power are tested neither to destruction nor under many possible accident conditions. Thus they are tested over time while being used. Power reactors are all licensed with the assumption that in no case will a great earthquake occur at the reactor plant site. As with geological formations and conventional buildings, even a small earthquake could trigger the failure of a weak safety system in a power reactor.

Over the last 25 years the purchase price of power reactors, in dollars per kilowatt, has risen about 25 fold, but only a moderate portion of this rise was due to governmental regulation or intervenors' successes.

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Several proposed reactors were halted following intervenor challenges based on earthquake dangers. Such arguments were also used in a lawsuit to overturn the Price-Anderson Act that eventually was rejected by the US Supreme Court. To this writer at least, it is as yet unclear if earthquakes will prove to be a major cause of reactor disasters, and it is still unclear if coal or fission is the more dangerous way to generate electricity.

However difficult in practice, the safety of the light water reactor (LWR) is in concept extremely simple: the fuel core must not melt. This is because more than 7 percent of an operating reactor's power comes not from fissioning but from the decay of fission products, and this decay is impossible to stop. If not cooled, the fuel cladding can begin to melt within seconds, the fuel can slump into a pile and melt and be impossible to cool even if covered with water. Thus the key problem is the integrity of the safety system ensuring the cooling of the core at all times, and the reactor plant foundations and structures are only essential parts of this system.

Construction of the first commerical power reactor began less than 12 years after the first sustained chain reation. Three years later all designers, builders, owners and operators were freed from essentially all third party liability by the Price-Anderson Act of 1957. The effect of this law was to take the reactor industry out of the free market system into a form of corporate socialism. If utility profits are allowed on the basis of capital costs, rather than on operating costs, power reactors are unusually attractive economically. This assumes that costs not go beyond control. Enthusiasm and federal financial support pushed the power reactor industry artificially at a rate beyond orderly growth in a period of extremely cheap fossil fuels. Today, paradoxically, in a time of expensive fossil fuels the US power reactor market appears to have collapsed. Perhaps it will revive.

There was prepared for the Price-Anderson Act the first of many governmental estimates of the so-called hypothetical accident, said to be the maximum for a power reactor (LWR). Also, for each reactor there are prepared two Hazards Reports, now called Safety Analysis Reports. All such documents are essentially legal, not technical in nature. Verification of many statements is difficult because of insufficient data, and almost never are calculations included. The first of the studies of the maximum accident was the Brookhaven Report. In 1957 it set the deaths at 3,400 out to 15 miles, the radiation injuries at 45,000 out to 54 miles, and the property loss at $7 billion all with a probability per reactor year of 1 in billion to 1 in 100 billion. Usually these probability values, which are entirely undocumented, are ignored, but probability is the key to rational choice. The latest governmental estimate gives the number killed (1982) at 100 thousand. The increase in deaths is consistent with the increase in the core long-lived fission product inventory. There is no such large study outside of those of the US Government.

POWER REACTOR SITING

The paramount reactor siting regulation in the USA is the Federal 10CFR Part 100:"..The design of the facility should conform to accepted building codes or standards for areas haveing equivalent earthquake histories. No facility should be located closer the ¼ mile from the surface location of a known, active fault." Over the last 15 years this regulation has wisely been ignored through increasingly strict practice. Compared to the (unknown) return periods of many intense earthquakes, the earthquake histories of all US reactor sites are very short. Building codes, or building standards, such as the UBC, were never intended to, and cannot, ensure the integrity of the reactor safety system. In reactors, slight earthquake damage could at worst cause a major accident. The buried Norwalk CA fault was discovered only by petroleum exploration. An earthquake took place on a buried fault running across a fault scarp at Mannix CA. A large earthquake occurred on the "dead" White Wolf CA fault. No fault scarp was evident in the great Charleston SC earthquake. The three great earthquakes at New Madrid MO all were on a buried fault system. This is some of the evidence invalidation 10CFR Part 100.

Among the factors influencing reactor site selection are available land and cooling water, isolation and minimal population center distances, and power load centers. The best geological formations for siting power reactors are either of deep, overconsolidated clay or sound rock showing no displacement, but these are not at many chosen sites. Poor foundations greatly increase seismic risks, and several licensed power reactors have either had settlement problems or have been built into scarps of old faults. Even the best of current practice cannot anticipate such catastrophic foundation failures as that which occurred under a dock and cannery at Valdez in the great 1964 Alaska earthquake.

EXTREME EARTHQUAKE EFFECTS

Save for legends, the seismic history of the USA is less than, often much less than, 500 years. Although predominately in siesmic zones, great earthquakes worldwide are usually centered where none was known before. As no strong motion seismograph measurement has ever been made in the central region of a great earthquake anywhere, the extrapolated excitation value, made long ago by reliable seismologists, of 7.2 gravity cannot yet be ignored. Also, no important fault slippage dynamics measurement has yet been made. Extreme seismic values are shocking, for it is difficult for the public to realize how rare they are.

Large boulders can be hurled out of their matrices through the air (India). Accelerations just above 1 gravity have been well recored (USA). Landslides can move millions of tons over kilometers at hundreds of kilometers per hour (USA, Peru, etc.). Faults can break new ground through sould rock (USA). Many tens of thousands of square kilometers can be lifted or subside a few meters so that lakes can be formed or drained, and such areas can be badly torn up by lurching or liquefaction (Alaska, India, Mississippi Valley). Thus it is possible that all lifelines to a nuclear power reactor accident could be lost. Blocks of soil a kilometer in size can be moved a few killometers (China). Bay depths can decrease 400 meters or increase 250 meters (Japan). Volcanoes can rise out of cornfields (Mexico) or seashores (Iceland) or explode discharging over 150 cubic kilometers of soil into the air (Indonesia) or, some say, cause sea waves to rise more than 300 meaters across land (Thera). For certain, landslide-induced water waves can rise 540 meters (Alaska). Tsunamis can rise 60 meters (USSR). Over the last one billion years it is estimated in the Encyclopedia Britannica that the present land surface of the earth has been hit by 130 thousand meteorites each causing a crater of one kilometer in diameter or larger. The resulting earthquakes, perhaps with seawaves,are enormous. As even a child can find similar data in encyclopedias, continual reassertions as to the perfect safety of power reactors has been counterproductive.

Problems of reactor and earthquake hazards share the quality that many are found to be more difficult upon closer examination. Recent studies, reported by A. C. Johnson, indicate that an old, possibly precambrian, buried fault system near New Madrid MO may have been reactivated, causing the great 1811-12 earthquakes, by a stress system that is common to a large area of the central USA. This raises the large question of the buildup of stress on other, buried faults in this wide area. The return period of the 1811-12 earthquakes has been estimated to range from 600 to 1800 years.

The two largest earthquakes of this century were of Richter magnitude 8.9, and the 1971 San Fernando earthquake, of magnetude 6.5, had the largest measured accelevation (1 gravity). It is unclear what the correlation with accelevation or intensity could be, but the ratio of energy releases is almost 4000.

The author of this paper has drawn a series of new seismic risk maps that are based solely on the design earthquakes of licensed power reactors. It has been frequent that new power reactors are added to a plant site. Usually each new reactor will have both a larger operating basis earthquake and a larger safe shutdown design earthquake, yet all are at one site. As such earthquakes are design, legal values rather than technical information, it is not surprising that such maps fail to square with accepted risk maps. Save to illustrate the point that the source data are poor, the maps are worthless, and none is included in this paper.

THE EXTREME REACTOR ACCIDENT

It was the Nuclear Regulatory Commission's Risk Assessment Review Group that pointed out the statistical shortcomings of WASH-1400, the $3 million internal document that was to have settled the power reactor risk question. This document was rejected shortly before TMI. H.W. Lewis, a statistician who was chariman of the RARG, later gave an example of a truely hypothetical maximum reactor accident where probability is completely ignored. An earthquake could cause a core meltdown, and a steam explosion then blows the top off the secondary containment. Just at that time a tornado strikes sucking all possible fission products into a storm that rains out just-lethal doses, deposition them on many great cities, to case the maximum loss. There are no calculations, but on might guess that the deaths would be in the millions and the damages in the trillions. While this disaster may be statistically humorous, the public would not be amused because it has never been trained to think calmly about chance. Anyone who has failed in showing high-school mathematics to an editor of a large newspaper, for example, might agree on how difficult teaching probability to the public will be. Citizens must listen carefully and decide on risks. That is a key problem. Coal is dangerous and petroleum is limited and of uncertain supply. The public will not willingly accept power shortages once they begin. Finally, statistician H.W. Lewis makes the flat statement that coal power is more dangerous than nuclear power, and the future may show him to be correct.

For many years the safety system of power reactors has been designed for a "hypothetical" accident not yet discussed. In effect the accident is solved by definition. It is misnamed the Maximum Crediable Accident, misnamed because it was exceeded both at TMI and in the fast neutron Fermi power reactor accident. The reactor suffers a double-ended rupture of a large primary pipe, the safety system functions as designed, and the public is unharmed because the core is kept cool and solid. As it is defined as solved, there is no necessity of probability in this accident.

EVOLUTION OF REACTOR SEISMIC STANDARDS

All early US research, test, plutonium production, and even the first commercial power reactors were built and run with no evident consideration of earthquakes. Also, the early LWR's had no way of cooling the core once the primary system had been ruptured. Devices to hold the melted fuel, called "core-catchers", were considered but never installed.

One early reactor, located in a seismic zone, was built for wind loading but not for seismic forces. An early reactor Hazards Report includes the statement by a well-known seismologist pointing out the good record of conventional buildings designed with earthquakes in mind. Likely the consulting seismologists on many reactors set the design earthquake while being completely unaware of the possible maximum accident and likely the reactor engineers were completely unaware of how intense an earthquake could be. Probably WASH-740 had not been read by anyone involved. All of this is quite possible under the Price-Anderson Act and 10CFR 100.

Serious reactor earthquake engineering began in the later 1960's, some 25 years into the nuclear reactor age. At that time, it was assumed that all seismic disturbances were small and all reactor structural elements were one-dimensional and responded elastically. Energy was transferred only in the fundamental mode. The safety system's electronic (vacuum-tube) circuits were certified as meeting seismic excitation requirements, at least in some cases, in the following way. The chassis with its functioning circuit was inverted. If it continued to function it was agreed by all to be able to serve reliably in an excitation of 2 gravity. Also, for example, the design earthquake for a reactor in southern Florida was limited to a repetition of the Charleston SC earthquake of 1886 at Charleston, and that of a reactor in Alabama the great earthquakes at New Madrid MO, also hundreds of kilometers away. It was not considered that such earthquakes could occur any closer, and, of course, over that great distance the intensities dropped to trivial levels.

A few aspects of reactor safety were superior in the early days. As almost all who were involved were highly motivated, design, construction, operations, and maintainance were superior. Hazards reports were candid. Secondary containment was of steel and thus had superior design and seismic responce qualities. Many of the early power reactors were built complete to turnkey by the reactor island manufactures, but that practice was soon abandoned. Again, the US Navy's nuclear power work was superior even in the early days. Improved opportunities in all aspects of reactor safety design, including seismic design, have come in the last 15 years. It seems fair to say that the US leads the world in both reactor and reactor earthquake safety.

Today a reactor can be located with careful analysis of the support soil. All vital structures, piping, and safety system supports can be analyzed using time history computations for input excitations reaching 0.5 gravity. Torsion, yielding, and duration of excitaiton can enter calculations. Appendages can be designed with periods far from any that might cause huge amplifications. Smaller safety system components can be tested on shaker tables. Electronic cirucits are solid state and thus can be far more rugged than were the old vacuum tube.

COST OF SEISMIC STANDARDS

Cost breakdowns on power reactors in the USA are held proprietary by the owners and architect-engineering companies, so only estimates by outsiders are ordinarily available. Today it appears that for routine design and construction, using a time history input having 0.2 gravity, the total cost would be raised comparatively little. At near 0.3 gravity such costs begin to rise at an increasing rate, and at near 0.6 gravity the design for seismic excitation becomes a major factor in costs.

It does seem reasonable to have a minimum design excitation at near 0.2 gravity, but a rational system has not been agreed that would allocate safety funds. The now rejected document WASH-1400 could be used as a start for doing this, and it might be shown that earthquake funding would drop in comparison with other safety needs.

SEISMICALLY ACTIVATED REACTOR SHUTDOWN SYSTEMS

Any simple and automatic device that can increase the assurance that the reactor core can be kept from melting is of great value. Also, as no reactor has been operating in an intense earthquake, it cannot be certain that the chances of the very dangerous reactor power transient without scram are not increased in that case. Earthquake engineers not familiar with power reactors might be surprised that none in the USA is equipped with a seismic scram. Such a device might be a more complex version of the startup mechanism on a strong motion seismograph, and there is now much experience with these. It is true that in theory the reactor operators should always be able to scram the reactor manually, but the TMI accident showed that operators can completely misunderstand what is happening to the reactor core and safety system. Only in the very earlist days were reactor operators also engineers or physicists. The argument made by the industry against seismic scrams, and never documented, is that they would increase spurious scrams, and all scrams are certainly costly. As in essentially all exchanges between the industry and regulators, these arguments were passed through lawyers. It is the opinion of the author that many reactor safety decisions have been on legal, more than technical, bases.

In order to keep the core from melting, water must be pumped with great reliability, and so diesel-electric emergency power generators are installed. Although such machines run on ships and locomotives in intense shaking, the problem in an earthquake is quite different: generators must be started cold under excitation with great reliability. Shock loading tests on diesel generators planned for use in hardened missile sites were not encouraging.

A seismic scram might be built so that, on the first arrival of a strong earthquake pulse, it could start safety equipment, such as the energnecy generators, functioning. This pulse could likely be from the high-velocity P-waves, which are relatively weak compared to the lower velocity S-waves. When the strong shaking arrives, the reactor could be scrammed by the device or manually by the operator. Even a few seconds of core cooling just after scram is of great value if the core later were to be dry for a short time, for melting migh be avoided.

THE FUTURE OF SEISMIC REACTOR STANDARDS

Although nuclear energy was discovered by the detection of highly radioactive fission products (at very low concentrations), continual assurance of the public of the absolute safety of nuclear reactors went unchallanged. For the first 25 years enthusiasm for nuclear power in the USA was almost unbounded. No book and few newspaper articles critical of the program were published. There was essentially no dissent among the thousands of specialists working in the field or in universities. There were many large grants from nuclear agencies each year. Even today, for example, the certainty that power reactors make unusually attractive targets, even for conventional bonbardment, causes little attention. (In a long-past licensing hearing it was decided that this problem was only for the US Department of Defense). It was no surprise that neither the public nor the news media could look at the TMI accident calmly when it happened. Indeed, recordings of the NRC commissioners showed that they were also at a loss at that time. Thus it seems that careful response documents should be prepared for all such unlikely events as the accident caused at a power reactor by a great earthquake. A continuously recording device, something like the black box on airliners, could be of great value for all reactor accidents. There is none.

Following the success of light water reactors as the power source for submarine reactors, the USAEC embraced this concept, out of many alternanatives, as the electric generating reactor of choice. Light water reactors must use expensive fuel, enriched in gaseous diffusion plants, and they were chosen with the belief that an economic fuel cycle was certain. In this, the plutonium, created when the uranium 235 is burned, would be recovered by the chemical reprocessing of the spent fuel. This did not work out, for reprocessing proved to be so expensive that all commercial plants are closed, and prospects are not good for their reopening. This brings into question the whole application of the LWR. It could well be that another concept will prove to be the cheapest and maybe safer. In general, each of the many reactor types is quite different from the others with different hazards problems and safety features. Indeed, few of today's LWR's are closely similar to each other, for there have been four manufactures, many models, much modification, and backfitting. Although unusually attractive, standardization of power reactors will be far in the future.

No matter what type of thermal reactor (burner) is used, if such reactors were to supply most of the nation's electric power, the uranium 235 would not last for many decades. A new type of reactor, the breeded, would have to be used, and so far the US has been developing the liquid metal fast neutron breeder reactor. In this reactor, the hazards problems, including the seismic hazards, are indeed serious and quite different from those of the LWR.

At some 35 years into the nuclear age there were many LRW's on order in the USA. Then there was a massive and sudden withdrawal of interest by the utilities. Even today there has been little explanation of the change, but the basis must be cost. Within about five years about 80 orders were cancelled or delayed, no orders were placed, and many fossil-fuel plants were ordered. It seems unclear what the future of the LWR in the USA will be.

Plans must continue for the eventual return to nuclear electric power generation in the USA, however. It is difficult to imagine that an expanding world economy will have other than predominately nuclear power within, and likely much less than, a century. Even if nuclear fusion power were to become economically feasible, hazards, including seismic hazards, might be large despite the contrary publicity.

The delay caused by the rejection of power reactors today in the USA might come to be seen as a blessing in disguise. Perhaps now all power reactor safety can be put on a sound basis. The Price-Anderson Act should be scrapped. Even in 1957 it covered only about 8% of the government's caculated maximum property loss in the WASH-740 accident. The utilities should form their own insurance pool as they were said to have been planning in case the US Supreme Court had overturned Price-Anderson. Admittedly the idea is naive, but perhaps a simple law could be passed requiring the utility to spend as much on safety as on the generation of nuclear power. This would at least allow an engineering approach to the problems rather than legal ones. Reform, simplification, and elimination are called for through the entire legal and beaurocratic system for power reactors in the USA. If there are to be licensing hearings, each side should have equal funding. Perhaps the government could begin again and teach the citizesns to listen to and judge seriously arguments on alternative power sources, including the seismic hazards to power reactors.