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JUN 04 1992

Quazi Hossain, Ph.D.
Symposium Chairman
Mail Code L-190
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, California 94550

Dear Dr. Hossain:

Subject: Symposium on Dynamic Analysis and Design Considerations for High-Level Waste Repositories

Reference: Letter from J. Carl Stepp dated May 1, 1992, on the same subject

I am enclosing a camera-ready copy of my paper entitled "Regulatory Views on Seismic and Fault-Displacement Parameters Needed for a Geologic Repository Design" for inclusion in the proceedings of the subject symposium.

I am looking forward to participating in the symposium and presenting my paper in August 1992. If you have any questions on this paper, please contact Dr. Mysore Nataraja of my staff at (301) 504-3459.

Sincerely,

Robert M. Bernero, Director
Office of Nuclear Material Safety
and Safeguards

cc: Mr. J. Carl Stepp
Electric Power Research Institute
P.O. Box 10412
3412 Hillview Avenue
Palo Alto, CA 94303

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ROBERT M. BERNERO

In February 1989 he became Director, Office of Nuclear Material Safety and Safeguards (NMSS) at the Nuclear Regulatory Commission (NRC). NMSS is responsible for licensing, inspection, and environmental reviews of all activities regulated by the NRC except reactors. This includes uranium recovery; fuel fabrication and development; industrial, medical, academic and commercial uses of radioisotopes; safeguards activities; transportation of nuclear materials; and radioactive waste storage and disposal. He had served as Deputy Director of NMSS for two years.

From 1984 until April 1987 he was the Director, Division of Boiling Water Reactors Licensing and Director, Division of Systems Integration at NRC. In these positions he directed technical safety review of U.S. reactors. Between 1979 and 1984 he served in the NRC's Office of Nuclear Regulatory Research as the Director of Research in Probabilistic Risk Analysis and Accident Releases or Source Terms. During 1979 he was deeply involved in the response to and the investigation of the Three Mile Island accident.

Earlier at NRC he held management positions in material safety standards, fuel reprocessing and recycle and reactor licensing.

Before joining the Atomic Energy Commission (later the NRC) in early 1972, he spent 13 years with the General Electric Company in nuclear work on reactors and radioisotope power devices for space applications and as a design construction and test engineer for naval nuclear power plants.

He holds a Bachelor of Arts degree from St. Mary of the Lake in Illinois, a Bachelor of Chemical Engineering degree from the University of Illinois, and a Master of Chemical Engineering degree from Rensselaer Polytechnic Institute.

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REGULATORY VIEWS ON SEISMIC AND FAULT-DISPLACEMENT PARAMETERS NEEDED FOR A GEOLOGIC REPOSITORY DESIGN

By Robert M. Bernero[1]

Abstract

This paper presents the regulatory views of the U.S. Nuclear Regulatory Commission staff on some of the significant issues related to the seismic and faulting design of a geologic repository. The issues addressed include: (1) misconceptions related to the use of Appendix A to 10 CFR Part 100; (2) deterministic versus probabilistic assessment considerations; (3) consideration of fault displacements in the design of a geologic repository; and (4) internal consistency of regulations for seismic and faulting design of nuclear facilities.

Purpose and Scope

Mr. Chairman and members of the American Society of Civil Engineers Organizing Committee, thank you for this opportunity to present the regulatory views of the Nuclear Regulatory Commission (NRC) staff on the consideration of ground motion and fault displacements in the design of the high-level waste geologic repository. There are many lingering questions in this area that need to be discussed by the technical community. I am pleased that this group has taken the initiative to tackle these difficult and, in many cases, controversial issues. Today, I will address some of these issues from NRC's perspective and hopefully initiate a dialogue that may lead to a satisfactory resolution of them.

As most of you know, the regulations that pertain to repository licensing are contained in 10 CFR Part 60. These regulations are structured around the multiple barrier concept and the principles of

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defense in-depth. The main focus of Part 60 regulations is on performance objectives. Compliance with performance objectives must be demonstrated for licensing a repository site and the associated designs. These performance objectives cover the pre-closure operations and the post-closure performance period of ten thousand years. Subpart E of 10 CFR Part 60 that deals with the technical criteria presents these performance objectives and also certain design criteria. These design criteria are generic in nature and not as specific as in reactor regulations. This difference is mainly due to the complexity of reactor design as compared to the repository design. Although it may be difficult, at times, to separate performance issues from those related to design, I intend to confine my remarks mainly to design considerations, as appropriate to this topical symposium.

One of the questions in this area deals with the potential applicability of Appendix A of 10 CFR Part 100 to a geologic repository. Scientists and engineers who have been involved in the design of nuclear power plants over many years regularly used the NRC regulations provided in Appendix A to 10 CFR Part 100 for siting nuclear power plants. Many of the same individuals or their colleagues are now involved in the investigation of the site suitability at Yucca Mountain and in the seismic and fault displacement design of a proposed geologic repository at that site. These scientists and engineers and others may want to know if the regulations provided in 10 CFR Part 100 are applicable to the geologic repository. I intend to address this question at some length today.

There is another important question that is somewhat related to the applicability of Part 100, Appendix A, to a geologic repository. That is: would the NRC accept probabilistic approaches for seismic and fault-displacement design, or do the design bases for the geologic repository have to be derived from a purely deterministic approach? I will discuss the use of deterministic and probabilistic approaches, today.

Next, I plan to address a potentially contentious question: will NRC accept the design of surface facilities and waste emplacement boreholes if they are located in the immediate vicinity of faults? It is a very important issue, because the Yucca Mountain site and its environs contain many faults and related geologic features. Therefore, the design of the repository may be impacted by how the relevant requirements are interpreted. I will talk about consideration of fault displacement in repository design from NRC's perspective.

And finally, I will address the question of whether NRC regulations are consistent, vis-a-vis the various nuclear facilities. There is no question that the regulations need to be consistent, where the same regulatory considerations and principles are involved. However, there are those who have stated that NRC regulations are inconsistent regarding the treatment of a repository when compared to other nuclear facilities. What I would like to emphasize in my discussion today is that the NRC rules for protection of geologic repositories against faulting and earthquake are not inconsistent with other NRC rules in providing appropriate levels of protection against radiological hazards.

Misconceptions Related to the Use of Appendix A to 10 CFR Part 100

I will begin with the issue of certain misconceptions related to the use of Part 100, Appendix A (Ref. 1). As the title of this appendix suggests, the criteria in this appendix were developed for nuclear power plants.

The NRC regulations that govern the geologic repository are given in 10 CFR Part 60 (Ref. 2). The regulations pertaining to ground motion and fault displacements are presented in general terms. The guidance in Part 60 related to seismic design and investigation, is not as specific as that given in Appendix A to 10 CFR Part 100 for reactors. Perhaps the difference in the level of detail between what is provided in Appendix A to Part 100 and that provided in Part 60 is one reason why questions are often raised regarding the need for additional guidance in this area. Another reason for these questions is that 10 CFR Part 72, whose facilities are similar to the surface facilities of a geologic repository, adopts, by reference, the regulatory criteria from Appendix A to Part 100, whereas Part 60 does not.

We do not intend to require the Department of Energy (DOE) to use the criteria of Appendix A either for surface facilities or for the underground facility of a geologic repository. The criteria reflected in Appendix A were developed for site investigation for the design of nuclear power plants. The NRC staff sees no reason for applying them to the geologic repositories. Appendix A of 10 CFR Part 100 is not appropriate for a geologic repository, given the differences in source terms, function, or periods of performance between a geologic repository and a nuclear power plant (Refs. 3,4).

As many of you are aware, there are similarities, as well as major differences in the nature of the two facilities. Some aspects of these differences may dictate differences in the design approaches. Let me review some of the key differences.

Nuclear power plants are designed for a 40-year life span. Therefore, even with life extension of these plants, the hazards of vibratory ground motion and fault displacement only apply to a life span of one to two generations. For a geologic repository, the pre-closure time is similar to that of a nuclear power plant, that is, the period of interest is of the order of two to three generations. However, one must also consider the post-closure time period, extending to thousands of years, during which time the post-closure performance objectives have to be met. In predicting the earthquake and faulting hazards, one needs to recognize these differences in the time periods of interest.

Another major difference in the two types of facilities relates to the potential consequences of failure. The nuclear waste disposed of in the repository does not rely on active cooling systems, like the nuclear power plants, to maintain safe conditions. The consequences of failure due to earthquakes or faulting at a high-level nuclear waste repository, both during operations and after closure, will likely be significantly less than those at a nuclear power plant. During the post-closure period, the geologic repository will not be a system like a functioning nuclear power plant, because it is not a pressurized system and has no anticipated risks that could result in large releases of radioactive materials. In addition, the portion of the geologic repository for which the post-closure performance objectives must be met will be deep underneath the ground surface. This depth should make the geologic repository less vulnerable to vibratory ground motion than any surface structures would be. Available literature reports many case histories of underground tunnels and mines that have withstood vibratory ground motions much more successfully than nearby surface facilities.

A geologic repository will undoubtedly have unique problems. For example, the heat generated in the underground facility from high-level nuclear waste may make a geologic repository more vulnerable to damage from vibratory ground motion and fault displacement. Heat could affect a geologic repository's response in two ways. Heat could change the combined stresses on the repository system because the resulting stresses caused by earthquakes may be superimposed on the original stresses. In addition, the long-term effects of thermal loading could weaken certain types of rocks and may thus reduce the system's resistance to earthquakes.

The vulnerabilities of a geologic repository differ in other ways from those of a nuclear power plant. For example, some of the important damage modes of concern for a geologic repository are likely to be very different from those of other nuclear facilities. The concerns of vibratory ground motion and fault displacements are of a different nature at a geologic repository, because they can widen existing fractures and create new pathways for radionuclide transport between the ground surface and the underground facility, or from the underground facility to the water table. For a nuclear plant design, the concept of maximum credible seismic event is used as a design basis. However, in the case of the underground facility, the cumulative effects of relatively small but more frequent seismic events are also significant. Another concern may be changes in groundwater elevation as a result of seismic events. Thus, the design of the geologic repository needs to address a number of different issues regarding the effects of vibratory ground motion and fault displacement, including long-term performance impacts. However, as I mentioned earlier, I will confine my talk mainly to the design considerations and not get into the long-term performance implications.

Because of these differences, the NRC staff considers that the regulatory requirements for seismic and faulting design of nuclear power plants, given in Appendix A of 10 CFR Part 100, are not applicable to the design of the geologic repository. Appendix A was not developed with a geologic repository in mind. The concepts of the Operating Basis Earthquake and Safe Shutdown Earthquake included in Appendix A are not relevant to a geologic repository. Furthermore, the concepts of pre-closure and post-closure requirements are not addressed in Appendix A. For all these reasons, the question of the applicability of Part 100, Appendix A, to a geologic repository, is inappropriate. The question of why Appendix A was adopted by Part 72 and not by Part 60, is an important one, and I will address it in a few minutes.

Deterministic Versus Probabilistic Considerations

Another important topic I will address today deals with the issue of what constitutes an appropriate approach in establishing design basis earthquakes and fault displacements at a site. Over the years, Appendix A of Part 100 was used in reactor licensing to determine the design basis earthquakes. Appendix A requires the use of deterministic techniques to arrive at design basis earthquakes. Within the past two decades or so, scientists have been using probabilistic techniques to supplement the results of the deterministic approach. In the reactor area, much experience has been gained in using probabilistic approaches to evaluate seismic hazards in a number of probabilistic risk analyses. The question being raised for the seismic design of the geologic repository has to do with the choice of the approach for establishing the design basis events.

Let me clarify the NRC staff position on this matter. The staff position is that both deterministic and probabilistic techniques will play a role in the analysis of fault displacement hazards and seismic hazards. The appropriateness of either the probabilistic or deterministic approach will depend on what issues and regulatory requirements are being addressed; for instance, whether a subsystem performance objective or a total system performance objective is being addressed. Thus, different approaches, including combinations of the two approaches, may be needed for the pre-closure and post-closure compliance demonstrations. For example, the deterministic approach can provide the design parameters based on the maximum credible earthquake and maximum credible fault displacement, whereas the probabilistic approach can ensure that the uncertainties in the analyses are explicitly addressed. However, for the total system performance assessment, the probabilistic nature of the Environmental Protection Agency (EPA) standard indicates that probabilistic fault displacement and seismic inputs will be needed for the assessment.

In summary, both deterministic and probabilistic approaches would be used for pre-closure and post-closure compliance demonstrations, with appropriate levels of emphasis to reflect the intent of the regulatory requirements.

Design of Facilities for Fault Displacements

Let me now address another important issue that deals with the design of surface facilities and emplacement boreholes near known faults at a site. The state of the art in engineering provides confidence in the ability to design surface facilities and, to a lesser degree, the engineered barrier system for vibratory ground motion. However, designing for fault displacement is another matter. The current state of the art dictates that caution be used in deciding to design facilities to accommodate fault displacement. The question frequently raised is: would the staff accept or reject a repository design if the surface facilities or the waste emplacement boreholes were located near known faults? In other words, "is NRC staff going to require some mandatory set-back distance for locating important facilities or components away from faults?" The question is particularly relevant for the Yucca Mountain site because of the large number of faults present in the environs of the site.

Let me respond to the question by first commenting on our regulations and then making some recommendations to DOE, for its consideration. As far as NRC regulations are concerned, 10 CFR Part 60 does not specify a fault set-back distance for locating the facilities. Thus, NRC staff would not use a criterion for acceptability of the design of facilities based on some minimum distance from faults. However, if DOE decides to locate structures important to safety near known faults, it will have to demonstrate that such a design can meet the performance objectives of 10 CFR Part 60, with reasonable assurance.

Some people in the engineering community have expressed an opinion that if the surface facilities and waste emplacement holes are designed for a small amount of fault displacement (e.g., 4 to 5 cm.), they would have confidence in the safety of such a design. Some engineers also believe that it should be possible to safely design for even larger fault displacements. The real problem is whether it is possible to demonstrate to the NRC staff, and to convince the technical community and the interested parties that such a design is safe against large or repeated fault displacements, considering both near-term (operational) and long-term (disposal) safety performance.

Therefore, it would be prudent to use caution regarding design to accommodate fault displacement. It may be difficult to develop a convincing case about the safety of facilities designed to accommodate large or repeated fault displacements. The key requirement from NRC's perspective is that the design for fault displacement must provide reasonable assurance of meeting performance objectives. We recommend that if the DOE contemplates designing for fault displacement, it would be advisable for DOE to resolve the adequacy of such a design with the NRC staff and other affected parties, as soon as possible.

Consistency of Regulations

Finally, let me discuss an issue that has been raised recently--namely that if we do not adopt Part 100, Appendix A for a geologic repository, then the regulations will be internally inconsistent. Specifically, the issue is raised in view of the fact that NRC has adopted Appendix A for 10 CFR Part 72 (Ref. 5) facilities, that is, for Independent Spent Fuel Storage Installations (ISFSIs) and for the Monitored Retrievable Storage (MRS) facility. The 10 CFR Part 72 regulations state that if an ISFSI or the MRS is to be located west of the Rocky Mountain front, then the seismic hazard should be evaluated by the techniques of 10 CFR Part 100, Appendix A. Some assert that since the surface facilities for the geologic repository are likely to be similar in nature to an ISFSI or an MRS, the regulations governing the two types of facilities would not be consistent unless Part 100, Appendix A, is adopted for the surface facilities of a geologic repository also.

Acknowledging the similarities of repository surface facilities to an MRS, I will first touch on the basis for the adoption in Part 72, of 10 CFR 100, Appendix A. When preparing 10 CFR Part 72, the staff recognized that the seismic design requirements for ISFSIs could be simpler than those for nuclear power plants. However, the staff recognized that, in most cases, independent spent fuel storage facilities would be collocated with nuclear power plants, with sites that already had been analyzed thoroughly. Therefore, the staff chose to reference Appendix A of 10 CFR Part 100 in 10 CFR Part 72, as both a conservative approach and a matter of convenience because the Appendix A siting and design criteria were the only such regulatory criteria available at the time. The staff has examined the regulatory criteria found in Part 100, Appendix A and determined that there is no need to rely on the seismic investigations and design criteria that were developed for nuclear reactors, when designing a repository facility.

There is yet another commonly held misunderstanding with regards to Appendix A. Some people incorrectly assume that Appendix A precludes siting nuclear facilities in the vicinity of capable faults. It also appears that some have interpreted the regulations to require a specific set-back or a separation distance of the facilities from faults. Let me clarify NRC staff's position on this issue. NRC rules in 10 CFR Part 100, Appendix A do not exclude nuclear power reactor sites within a specific distance from a fault. However, nuclear power reactor sites that are located such that there are capable and/or seismogenic faults within five miles will require more extensive geologic and seismic investigations and analyses. Thus, nuclear reactors are generally not located near capable faults because of the difficulty in demonstrating that their intricate design meets appropriate requirements, not because the rules specify a minimum separation distance from a fault. Similarly, 10 CFR Part 60 does not exclude siting within a specific distance from a fault. However, the staff would require extensive geologic and seismic investigations and analyses for any repository sited near faults. Thus, the regulations are not inconsistent in the area of designing for faults because neither Appendix A of 10 CFR Part 100 nor 10 CFR Part 60 require avoidance of faults.

During the pre-closure or operating phase, a geologic repository must comply with the performance objectives of 10 CFR Part 60 and the health and safety requirements of both 10 CFR Part 20 (Ref. 6) and the applicable parts of the EPA standard (40 CFR Part 191, Ref. 7). During the post-closure phase, it must comply with performance objectives of 10 CFR Part 60, which include implementation of the EPA high-level waste standards (40 CFR Part 191). The NRC regulatory requirements regarding siting and design are different for the different types of nuclear facilities and the NRC health and safety standards are consistent with the NRC philosophy of defense in depth. I want to assure you that the NRC rules and practices for geologic repositories are based on the same principles for radiological health and safety as are the other NRC rules for fault displacement and earthquake protection for nuclear power reactors, ISFSI's, or MRS's.

Summary

Let me summarize by reiterating the major points before concluding my talk.

- The NRC staff position is that Appendix A does not apply to the design of geologic repositories.

- The staff considers that a deterministic approach should be used for the preclosure analyses, in conjunction with a probabilistic approach, to systematically take into account uncertainties in seismic and faulting hazard evaluation. For post-closure analyses, probabilistic evaluations are more appropriate as inputs to performance assessments.

- NRC regulations do not prohibit siting of a repository near faults. However, prudence suggests exercising caution regarding design to accommodate fault displacement.

- NRC regulations governing different nuclear facilities are consistent with regard to the protection of public radiological health and safety.

Closing Remarks

I would like to make some additional points that we have not addressed in this paper. We have only looked at the design issues related to the seismic and fault displacement considerations. However, there are larger issues related to the demonstration of compliance with pre- and post-closure performance objectives. In evaluating overall performance of the repository for time periods of 10,000 years or more, analysts will have to be concerned not only with the vulnerability of the engineered barrier system to tectonic effects, but also the vulnerability of the natural system itself to tectonic effects. There are many questions that need to be answered:

- How could earthquakes and fault displacements produce changes in the fracture characteristics during the 10,000-year post-closure period?

- How could tectonic and volcanic effects influence water table and hydraulic gradients? And finally,

- How can these phenomena affect the geologic repository's performance over 10,000 or more years?

These are more complex questions than the questions dealing with the narrow issue of repository design. There are no easy answers to these questions at this time. Completion of a comprehensive program of site characterization and performance assessments, such as DOE has planned for the Yucca Mountain site, is needed to develop the ability to predict the response of the natural and engineered systems to future vibratory ground motion and fault displacement and their effects on design and long-term repository performance. That is where the real challenge lies in attempting to find convincing answers to these questions. This conference is certainly a good start in the direction of discussing some of the crucial questions facing geologic repository designers and performance analysts. I sincerely appreciate your efforts and wish you success in your endeavors.

Acknowledgements

A number of members of my staff have assisted me in preparing this paper. I would like to mention three names for their special contribution -- Dr. Dinesh Gupta, formerly of my staff, Dr. Mysore Nataraja and Dr. Keith McConnell.

References

1. U.S. Code of Federal Regulations, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," Appendix A to Part 100, Chapter I, Title 10, "Energy."

2. U.S. Code of Federal Regulations, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Part 60, Chapter I, Title 10, "Energy."

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4. Gupta D., "Vulnerability of the Geologic Repository to Vibratory Ground Motion and Fault Displacement: Regulatory Perspective," Transcripts of the presentation made by the NRC staff to the Nuclear Waste Technical Review Board, January 22, 1992.

5. U.S. Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," Part 72, Chapter I, Title 10, "Energy."

6. U.S. Code of Federal Regulations, "Standards for Protection against Radiation," Part 20, Chapter I, Title 10, "Energy."

7. U.S. Code of Federal Regulations, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Part 191, Chapter I, Title 40, "Protection of Environment."