Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Structural mechanics aspects of nuclear non-reactor facilities

Hadjian, A.H., Massie, H., Blackman, J.
Technical Staff, Defense Nuclear Facilities Safety Board, Washington, D.C., U.S.A.

ABSTRACT: The DOE complex is more than fifty years old. Complex facilities continue to be used and, with the changing of the DOE mission, further life extension of these facilities is being considered. Differences in design, function and hazards between commercial nuclear power facilities and DOE facilities are highlighted leading to the identification of structural mechanics needs for DOE facilities.

1 INTRODUCTION

As defined by DOE, a nuclear facility is a facility whose operations involve materials in such form and quantity that a significant nuclear hazard potentially exists to the workers and the general public. Continued reliability to perform intended functions, not only under normal operating but also under abnormal accident conditions, is a major safety issue in these nuclear facilities, particularly when facilities are called upon to function past their original design lifespans. With the changing mission of the DOE, certain existing nuclear non-reactor facilities are being rehabilitated for not-so-well defined periods of extended use. This paper identifies the structural mechanics needs for continued use of these facilities for the intermediate term. Long term disposal of nuclear waste in Federal repositories is not considered.

The design of DOE nuclear facilities is based on fundamental safety philosophies that are similar to those applied to comparable NRC-licensed nuclear facilities. In general, the structural mechanics needs for DOE's non-reactor nuclear facilities are similar to those of the commercial nuclear power plants, except in those areas of the latter that deal exclusively with the reactor vessel and associated systems. Source term differences impact the level of emphasis rather than the commonality of the basic structural mechanics issues. In the following sections the emphasis will be on the identification of the important differences between structural mechanics needs between commercial nuclear plants and DOE non-reactor nuclear facilities.

2 DOE WEAPONS COMPLEX

With regards to structural mechanics issues, the DOE weapons complex differs from the commercial nuclear facilities in several important aspects. Among these are the following:

1. Whereas the commercial nuclear power program had to contend with basically a *single* system, the DOE facilities consist of a truly varied collection of different types of facilities with different missions, varied source terms and, hence, differing hazards.
2. Defense-in-depth (quality assurance, redundancy/diversity, elastic response, etc.) and other conservative elements of design that were successfully used to assure safety in commercial nuclear power plants, are generally absent from the majority of the DOE stock of facilities because they were built prior to the development of these requirements.
3. Because the design of nuclear power plants is dominated by postulated significant pressure and temperature loads, their capacity to resist other non-concurrent loads is large. This robustness to resist other severe loads is absent in DOE facilities and hence margins, in general, are relatively limited.
4. Most of the DOE facilities were built to a rainbow of evolving design criteria over the last 50 years. Thus, inherent structural capabilities and reliabilities differ from site to site and from facility to facility on any one site.
5. With the changing mission of the DOE, certain existing nuclear non-reactor facilities are being rehabilitated for not-so-well defined periods of extended use. Considering that most of these facilities are already at the end of their design lives, aging and life extension pose significantly more challenging problems.

2.1 *Classes of facilities and related hazards*

The primary purpose of the DOE weapons facilities, up until recently, was the production of nuclear weapons; and the production of plutonium and tritium were central to this mission. With the dissolution of the Soviet Union the emphasis at DOE has shifted towards waste management, decontamination and decommissioning (D&D), and environmental restoration. Thus, the DOE complex presently is comprised of the following, either idle or active, primary facility types: Research Laboratories, Research and Production Reactors, facilities for Chemical Processing, Assembly/Disassembly of Weapons, Weapons Testing, Storage, Waste Stabilization, Pretreatment and Vitrification. These facilities pose different hazards depending on the material forms (solids, liquid or gas), quantities and ongoing processes or functions.

At these DOE facilities, unlike commercial nuclear power plants, the handling, processing and storage of radioactive and hazardous materials are prime activities. And, therefore, the protection of the health and safety of the workers, the public, and the environment are prime considerations. To this end the *confinement* of radioactive and/or hazardous materials under normal operating conditions or during internal and external events is a design objective. Confinement requirements for these facilities differ depending on the form and level of the potential hazard. The managing of radioactive waste, storage of plutonium and tritium, and disassembly of weapons constitute most of the present hazard.

DOE classifies radioactive waste into four main groups:

1. High-Level Waste (HLW), a highly radioactive waste material resulting from the reprocessing of spent nuclear fuel. Most HLW must be handled by remote-control from behind protective shielding. Most of the HLW is in liquid form confined in waste tanks. Spent fuel is stored under water in basins.
2. Transuranic (TRU) waste, which results from reprocessing of plutonium-bearing fuel and irradiated targets, and from operations required to prepare the recovered plutonium for weapons use. Currently, stored TRU waste is usually found in 55-gallon drums placed on

concrete or asphalt pads.

3. Low-Level Waste (LLW), which is any radioactive waste not classified as HLW, TRU waste, spent nuclear fuel, or byproduct material.

4. Mixed Waste, which contains both radioactive and hazardous components. Hazardous waste is toxic, corrosive, reactive or ignitable.

2.2 *Unquantified conservatism*

The design of commercial nuclear power plants incorporate deliberate requirements (defense-in-depth, etc.) that lead to added conservatisms which are usually difficult to quantify. However, the quantification of these conservatisms is not a major concern in that most of the presently operating power plants were constructed more or less in a similar fashion. The issues described earlier regarding DOE facilities strongly suggest that a similar uniform conservatism could not have been achieved for the DOE facilities; and, therefore, methodologies need to be devised to consistently estimate the reliability, or the factor of safety, of the varied and significantly different DOE facilities. This becomes more critical, when it is remembered that, in a relative sense, DOE facilities do not have similar margins or robustness as the commercial nuclear power plants (item 3 of Sec 2).

3 AGING AND LIFE EXTENSION

Aging is the process by which the physical properties of structures and components, collectively referred to henceforth as structures, deteriorate with time or use. The rate of deterioration depends not only on the environmental conditions (exposure), but also on the initial selection of materials, quality of the construction and the level of lifetime neglect (e.g. lack of proper maintenance). Designing a prescribed life expectancy into structures is not done, even if considered a feasible feat. And in the general-use building industry ad hoc life expectancies are often assumed based partially on the historical evidence. Moreover, rehabilitation is considered not when the assumed end of life is reached but when deterioration becomes so obvious as to pose a serious hazard. An example, on the grand scale, is the status of the nation's infrastructure.

In the commercial nuclear power program life extension has become a challenging endeavor, even at midway in their design life, since plants are legally licensed for 40 years. The driving force is primarily the extension of the *economic* life of the existing plants, since it is cheaper to rehabilitate an existing plant than to build a new one. Cost-benefit studies strongly suggest that in the long run with proper maintenance, operating practices, administrative controls and replacements, life extension is the more cost-effective alternative. Certain identifiable construction practices and operating regimen of commercial nuclear power plants have made life extension, without a dilution of safety objectives, a viable solution to the ever increasing demand for electric power. Life extension of commercial nuclear power plants can therefore be defined as the identification and the implementation of repairs and modifications for continued operation at least at the original levels of safety. It is expected that life extension would require new technologies and changing regulations.

3.1 *Aging of DOE facilities*

The situation at the DOE complex is markedly different and more demanding than at commercial nuclear power plants in several respects:

a) DOE facilities date back to the early 40's, and therefore the expected "design" life of most structures is coming close to or is already ending.

b) Original designs, selection of materials and construction quality have not been as scrupulously controlled or documented at DOE facilities. This fact should adversely impact failure probabilities.

c) Considering the chemical processes used, the environment to which construction materials and equipment have been and continue to be exposed is usually more severe at DOE facilities.

d) The rehabilitation at DOE facilities usually envisages a changed mission, and hence modified safety bases than for the original designs. At certain facilities increased safety levels may well become necessary as a result of changed mission.

Several global issues need to be addressed from the outset if life extension, with or without changed mission, is to be reliable and cost effective:

a) Understanding of the aging mechanisms of materials in existing environments not only for routine operating conditions, but, more importantly, for extreme loading conditions such as earthquakes, tornadoes, high winds, floods, explosions, fire and heat, missiles, etc. Safety and economics require that problems of obsolescence, wear, tear, cracking, fatigue, fracture, stress, creep, erosion, corrosion, chemical change, fretting, irradiation and embrittlement, etc. be better understood.

b) Reliable non-destructive evaluations. Remaining life projections become an important safety issue when certain structural elements and components cannot be easily replaced. These life projections depend not only on the modified forces (stresses/strains) to be applied but also on the in-situ conditions of the materials and their ability to accommodate increased stresses/strains. Moreover, variability of results obtained from non-destructive tests must be adequately understood.

c) A better appreciation for structural deformations, load paths, stress concentrations, system fragilities, absence of redundancies, failure scenarios, etc. Understanding of the aging process and durability of materials in specific environments may not be sufficient. In fact, it may be overshadowed by design deficiencies of details and shoddy construction practices that would, particularly under extreme loads, lead to unacceptable behavior such as gross leakages, collapses, malfunctioning of monitoring and mitigating equipment, etc..

d) The determination of realistic load levels that are neither overly conservative nor grossly underestimated. Unlike new designs, the emphasis should be on the determination of adequate estimation of loads expected during the extended life. The use of proven probabilistic techniques (e.g., Structural Reliability) may be needed to justify continued operation.

e) There are different types of structures built to different codes and requirements. It should be therefore assumed that structural capacities/resistances of these facilities are not uniform; and, given present-day loads criteria, the development of a relative reliability index as a function of time since construction becomes necessary.

f) A prioritization scheme in terms of potential relative risk. Considering the relatively large number of facilities that would require rehabilitation and the availability of limited resources, the higher risk facilities must be brought up to levels of acceptable risk on a priority basis.

g) A better understanding of transport processes of gases, liquids and solids in different media, for the evaluation of risk to workers, the public, and insult to the environment following an accidental release of radionuclides.

4 TECHNOLOGY TRANSFER

The biennial International Conferences on Structural Mechanics in Reactor Technology (SMiRT) provide the most appropriate forum for technology transfer from the commercial nuclear power programs worldwide for the resolution of the above issues. Plant life extension technology programs in Japan are particularly significant in that Japan has rather severely limited alternatives to nuclear power. The Division, *Life Cycle and Management of Nuclear Installations and Waste Technology*, is the focal Division of interest. This Division is concerned with topics of structural mechanics in reactor technology that considers the effects of operating conditions on structures, systems and components and their design including aging and extension of life, waste management and aspects of structural mechanics and materials technology for waste package design and transportation for interim storage and waste repository, problems involving robotics, thermal issues, fracture, hydrology and transport processes.

Several of the other SMiRT Divisions would also make significant contributions to the resolution of the safety concerns at DOE facilities. Highlights of these Divisions from SMiRT-13 (August 13-18, 1995) are listed below:

- *Seismic Analysis and Design*, deals with the fundamental aspects of earthquake engineering, selection and design of reference seismic ground motions, experience from recent earthquakes, seismic isolation, energy dissipation systems, probabilistic risk assessment.
- *Extreme Loads*, deals with extreme loads and coupled problems in structural dynamics, impact, blasts, explosions and other impulsive loads, projectile penetration, failure prediction and prevention.
- *Concrete and Concrete Structures*, deals with mechanics of concrete, concrete structures and non-homogeneous materials, constitutive laws and modeling, environmental and temperature effects, testing of materials and components.
- *Material Behavior in Continuum Mechanics*, deals with the mathematical and computational modelling of the behavior of solids, numerical and experimental methods, visco-elasticity and visco-plasticity, constitutive laws for monotonic, cyclic and dynamic loading.
- *Fracture Mechanics and Fatigue*, deals with fracture mechanics and fatigue, crack initiation and growth, inspection procedures, mechanized in-service inspection.
- *Pressure Vessels and Piping*, deals with issues related to piping and pipe supports, effect of the environment on materials, regulation and standards, evaluation of plant modifications.
- *Structural Reliability and Probabilistic Safety Assessment*, deals with structural reliability and probabilistic safety assessment, probability based design and licensing, role of in-service inspection in the evaluation of failure probability functions, construction error and significance of quality control on structural reliability estimates, model uncertainties.

Additionally, to allow for in-depth discussions of topics of current interest and the informal exchange of ideas, SMiRT organizes Post-conference Seminars, which constitute extensions of the work performed within the Technical Divisions. These Seminars are designated as Advanced Technology Seminars. Considering that remarkable progress in certain chapters of Structural Mechanics has been achieved within SMiRT, Technology Transfer Seminars are also held, aimed at engineers working in other fields.

5 REHABILITATION OF AGED FACILITIES

For any candidate facility for rehabilitation a three phase approach needs be implemented:

Phase I • *Assessment of the facility*
- Review of original design
- Operating data collection and evaluation
- Maintenance and repairs records analysis
- Performance records analysis
- Diagnostics of forced outages
- Walkdowns
- Interviews with facility engineering, operations, maintenance and management, past and present

Phase II • *Work to be performed*
- Non-destructive evaluations
- Analysis of materials
- Performance testing
- New technologies for structural response control
- Economic evaluations
- Design/Modification peer reviews

Phase III • *Implementation*
- Construction quality control measures
- Operational Readiness Reviews

6 CONCLUSIONS

The structural mechanics problems at DOE facilities are similar, yet relatively more complex than those associated with the commercial nuclear power plants. This added complexity stems from the fact that DOE facilities pose a variety of hazards, the level of inherent consevstisms is marginal, were designed to varying criteria, and most of them are close to or have reached the end of their design life. The biennial International Conferences on Structural Mechanics in Reactor Technology (SMiRT) provide the most appropriate forum for technology transfer from the commercial nuclear power programs worldwide.

The views expressed in this paper are solely those of the authors, and no endorsement of the paper by the Defense Nuclear Facilities Safety Board is intended or should be inferred.