CONF-781120--1

SAND78-2129C

NUCLEAR FUEL CYCLE SAFETY RESEARCH AT SANDIA LABORATORIES*

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November 1978

Abstract

This paper provides a brief introduction to Sandia Laboratories and an overview of Nuclear Regulatory Commission sponsored safety research with particular emphasis on light water reactor related activities. Several experimental and analytical programs are highlighted and the range of activities of a typical staff member illustrated.

*Talk presented at the 20th Anniversary Seminar, Nuclear Engineering Department, University of Michigan, November 10, 1978.

It is my intent in this short discussion to provide an introduction to Sandia Laboratories and to discuss some aspects of our nuclear fuel cycle safety research. This latter topic will be limited in two distinct ways: one, I will focus on work being done for the Nuclear Regulatory Commission (NRC); and two, only those activities directed toward light water reactor (LWR) applications will be included. I will conclude with some examples of the diversified projects available to an individual staff member based upon my own experiences.

The Sandia Laboratories are operated by Sandia Corporation, a wholly owned subsidiary of Western Electric, under a no cost, no fee contract to the Department of Energy (DOE). (VUGRAPH 1) Historically, under the old Atomic Energy Commission, the laboratories were established to support the Los Alamos Scientific Laboratory, and later the Lawrence Livermore Laboratory, with design and development of the non-nuclear components of weapons being developed by those laboratories. This remains the primary mission of Sandia. However, with the growth of national interest in energy research, and with the creation of the Energy Research & Development Administration (ERDA) and now the DOE, we have become involved in the full spectrum of energy R&D. This includes solar (including wind), geothermal, oil shales, and nuclear (both fission and fusion). Sandia employs about 7600 persons, roughly 6500 in Albuquerque, New Mexico, and 1100 at Livermore, California. The laboratories have an annual budget in excess of $300 million.

As I indicated, I will confine my remarks to LWR activities and in particular, programs in support of NRC. In the legislation that created ERDA and the NRC, Congress gave the NRC the mandate to conduct such research as might be necessary to support licensing activities and to provide independent confirmation of other research. In doing this, NRC was to create no new national laboratories. As a result, NRC funds through DOE, research activities at the various laboratories: Sandia, Los Alamos, Livermore, Oak Ridge and Brookhaven. At Sandia these activities are directed by A. W. Snyder, the Director of Nuclear Fuel Cycle Programs. There are three principal areas of involvement (VUGRAPH 2). Nuclear fuel cycle safety research, advanced reactor safety research, and reactor development and applications. Briefly, the nuclear fuel cycle research (LWRs are emphasized) involves system studies, public risk studies (similar to WASH-1400, the Reactor Safety Study), safety technology evaluation (primarily in the fire protection area), phenomenology (e.g., molten fuel/concrete interactions) and methodology development. Advanced reactor safety research is exploring containment safety (i.e., the core disruptive accident in fast breeders) and the associated phenomenology. The reactor development and applications area involves the management and use of the Sandia pulse reactors in support of safety research (as well as weapon-related activities).

Let me direct your attention to several areas of LWR safety studies (VUGRAPH 3). In the molten fuel/concrete interactions program we are attempting to determine and quantify the phenomena involved in these interactions which affect safety. This involves both theoretical studies and experimental programs with molten fuel simulants. We are also studying the triggering and explosivity (intensity) of vapor explosions involving molten LWR core materials and water. In the statistical analysis programs, the response surface methodology is being used to examine the propagation of uncertainties through the very complicated thermal-hydraulic codes used in loss of coolant accident (LOCA) studies. The first study well examine peak cladding temperature distributions as calculated using the code RELAP. The work may be extended to other codes and reactor types. In the area of LWR sub-cooled blowdown loads, Sandia is evaluating various LWR vendor models used for estimating hydraulic loads on reactor-vessel internal structures resulting from pressure pulse propagation during blowdown. We have begun to develop models for the analysis of the Westinghouse Upper Head Injection Emergency Core Cooling System, which is one part of the larger question of hydraulic phenomena analysis. Finally, in this area, we are testing the applicability and accuracy of existing codes for the prediction of two-phase jet thrust and impingement loads. We will use code calculations and test data to develop an approximate engineering model that can be used to support licensing reviews.

As I indicated earlier, some of the safety research is directed toward technology (VUGRAPH 4). In the Qualification Test Evaluation program we are examining testing methodologies, that is, how are such tests run; LOCA source evaluation and simulator adequacy; and the accelerated aging models for Class 1E (safety related) components. The goal is to insure that we learn what we need to know from such tests, and that indeed, components thus qualified will function as required under LOCA conditions. In the area of fire protection research we are actually evaluating fire barriers, coatings and suppression agents to establish their effectiveness. Both of these areas involve considerable experimental effort in-house and under contract. Programs are also underway to establish the capabilities of detectors (particularly as installed) and to apply fire hazard analysis techniques to selected plant areas. Although such activities may not seem to be "nuclear", they are nevertheless, an important part of safety research in LWR plants.

While the programs I've just discussed tend to deal with particular component phenomenology or technology, a broader "systems analysis" viewpoint is employed in the systems safety studies (VUGRAPH 5). Output of such studies are often in the form of value-impact (cost-benefit) assessments. For example, in the value/impact assessment, we will attempt to determine, on a risk related scale, the effectiveness of standard review plans, generic standard technical specifications and other "tools" used in the licensing review process, in reducing risk. Remember the basic goal is always to reduce the public risk from nuclear activities. This work is simply an attempt to put the emphasis in licensing on those areas which have the greatest potential for reducing risk. A similar goal exists for the systems interaction methodology study. Here we want to develop a review procedure which can be used to identify the interactions between plant systems that are important to public safety. Such an approach is advisable because numerous systems were developed to have specific functions; and these functions may be affected by the addition of subsequent systems without those effects being obvious. In the methodology applications effort, the techniques of the Reactor Safety Study (RSS) are being applied to identify the potential accident sequences that are the major contributors to public risk, and to do this for a representative spectrum of LWR designs. The foregoing are representative of some of the systems studies being pursued.

Risk assessment is playing an increasingly more important role in the review and licensing of nuclear facilities (VUGRAPH 6). One of our major areas of endeavor is to develop a methodology for the risk assessment of high level waste disposal activites and the application of the methodology to a reference waste disposal facility. This is a challenging task because of the complexity of geologic formations and the sparsity of data about them. The RSS consequence model has been used in numerous studies, but it has received some criticism for the way some consequences are estimated. Therefore, another effort is directed toward the extension, improvement and analysis of the consequence model and its various data bases which should improve its utility and acceptance. In a related area we are exploring the effect of liquid pathways on RSS consequence calculations. The goal is to establish the degree of radiation exposure to the population from those accident sequences in which some or all of the LWR core melts through the containment vessel. The original RSS model dealt with atmospheric releases. The interest in risk assessment has also led to the development of a program to examine the utility of the RSS consequence model code (CRAC) for site selection studies. Sandia has been active in studies related to risk in the transport of radioactive materials (the recent crash tests of spent fuel casks and the development of accident resistant containers for plutonium have received national attention). The most recent effort involves the development of a generic environmental assessment of the possible radiologic, non-radiologic and economic impacts on densely populated urban areas that might result from the transportation of radioactive material to and through such an area. Future activities may be directed toward assessing the risk from depleted, abandoned mines, mill tailings, shallow land burial sites and waste treatment facilities (solidification, interim storage, compaction, etc.).

The increasing concern over the past several years about the security of nuclear fuel cycle facilities has led to the development of various techniques to analyze such facilities (VUGRAPH 7). In our facility characterization work we are applying the techniques of fault tree analysis (originally developed for reliability studies) to the problem of safeguards and protection against sabotage. Fault trees are constructed in which the top or undesired event is a radioactive release in excess of the limits in the Code of Federal Regulations.

Then the plant systems are systematically analyzed to establish the basic events or actions which, if unchecked, can lead to such a release. Coupled with this event analysis is a vital area analysis which locates and defines those areas within the plant where the basic events can be made to occur. Our goal is to create a generic approach which can readily be used by licensees and the NRC to examine specific plants. (This characterization is also a key element in the safeguards methodology development work I'll discuss later.) The recommendations of earlier studies on sabotage at LWR plants have led to a program to estimate the potential value of variations in plant design and damage control measures in providing protection against sabotage at commercial plants, and to establish the impact of such measures on plant costs, operations and safety. To do this, we are starting with a plant that exemplifies the current state-of-the-art in design and then exploring modification or additions to it. This program involves electric utility companies, reactor-vendors and architect-engineering firms as well as the Sandia staff. There are two additional engineering programs that bear on safety and safeguards. Recent studies suggest that controlled venting of containments may be a way to avoid catastrophic failures from overpressures in the event of a LOCA. We will conduct engineering studies of various vented-filtered containment concepts to define system design requirements and then perform a value-impact analysis of the concepts. Another continuing concern is effective, reliable shutdown heat removal from LWR plants. In this study we will perform a value-impact comparison of various schemes for decay heat removal to provide a technical base for regulatory actions. This effort is coordinated with the plant design work since the techniques selected to insure decay heat removal will also have an effect on security considerations. All of these studies require a thorough understanding of LWR plants and how they operate because the emphasis is on practical solutions.

The growth of concern over security has also fostered a need for methods, short of staged intrusions, to evaluate security systems at LWR plants (VUGRAPH 8). Our endeavors here involve providing guidance for physical protection system design, primarily "tools" the licensees can use as they develop systems, and the associated evaluative tools for the NRC staff. In this program the application of utility theory to such evaluations is being examined. A very broad development of evaluation methodology for physical protection systems is also underway. In this area we are looking at the interactions of such items as intruder detection, delays from physical barriers, guard responses, plant layout, etc. The program has already produced techniques for evaluation with a wide range of sophistication. EASI (Estimate of Adversary Sequence Interruption) using analytical techniques and estimates of performance parameters can be run on programmable hand calculators. At the other end of the spectrum is SAFE (Safeguards Automated Facility Evaluation). This technique uses the detailed facility characterization described earlier coupled with path finding algorithms to establish possible adversary paths. These paths are assumed to be traversed by the adversaries and the interactions between the adversaries and the physical protection system are followed. This includes engagement models to *specifically explore guard-intruder interactions. Sufficient* trials are run to generate statistically meaningful estimates of the probability of interrupting any particular sequence. This does not provide an absolute measure of safeguards effectiveness, but it does identify those characteristics of the physical protection system most important to protection of the facility. The methodologies are more advanced for fixed facilities, but parallel effort are underway for evaluating physical security of material in transit. Again, there will be a spectrum of tools emerging, some will require little input but will permit a wide range of options to be explored quickly. Others will enable the analyst to include considerable detail about all components of the transport system and adversary force and examine the interactions.

At this point I would like to indicate the variety of activities with which individual staff members are involved. Let me do this by just touching on my own activities over the past 2-1/2 years (VUGRAPH 9). Many state and local governmental officials have asked "what kind of reactor accident should we plan for; what can we expect if one does occur?" A joint NRC-EPA Task Force report addresses guidance in that area. In support of that guidance, we used the RSS consequence model to characterize the off-site consequences of a range of possible Class Nine accidents at typical Nuclear Power Plants (NPP). This characterization includes predictions of down-wind doses for bone marrow, thyroid and lung, as well as airborne and surface activity concentrations. These descriptions are designed to be used as technical support for emergency response exercise planning and drills.

In the safeguards assessment and design effort we coupled the plant characterization, path analysis and simulation modeling of physical security for the first time and demonstrated how they might be employed to affect security system design.

I mentioned earlier the risk assessment of the transport of radioactive materials in urban areas. As a special part of that study, we explored the possible ways an adversary might attempt to harm the public by releasing material. Based upon these analyses, we estimated the possible consequences, in terms of potential early fatalities, illnesses and latent cancer fatalities, of sabotage events. The results may lead to additional studies, including experiments, to better define the potential radioactive source terms for the consequence modeling calculations.

As some of you are aware, the NRC has recently taken steps to place resident inspectors at LWR plants. A question that we have addressed for the NRC is "what independent inspections and tests could and should NRC inspectors conduct to adequately *verify that safety related equipment would function as required* if called upon?" This required that we look at all the systems (safety and security) and their impact upon public risk. This is another example of the kinds of broad systems studies in which we are involved.

Finally, I am now deeply involved in the plant design work I described earlier. As you see, I've been privileged to be involved in a fairly broad spectrum of activities, which, though related, provided a diversity of problems and challenges.

In conclusion (VUGRAPH 10), let me summarize some areas of the research functions in which Sandia staff members are involved. The relationship of these areas to the research I've discussed is fairly obvious. There is a spectrum which ranges from detailed phenomenological modeling (both physical and biological) to the integration of such models into a systems analysis. I would be glad to discuss any questions you might have, either here or privately, later-on. Thank you.

SANDIA LABORATORIES

- OPERATED BY SANDIA CORPORATION - SUBSIDIARY OF WESTERN ELECTRIC
- PRIME CONTRACTOR TO DEPARTMENT OF ENERGY
- NON-NUCLEAR COMPONENTS FOR WEAPONS
- FULL RANGE OF ENERGY RESEARCH
- >7000 EMPLOYEES; BUDGET > $300 MILLION/YR.

NUCLEAR FUEL CYCLE PROGRAMS

DIRECTOR, A. W. SNYDER

- NUCLEAR FUEL CYCLE SAFETY RESEARCH

  LWR SAFETY RESEARCH
  SYSTEM SAFETY
  RISK ANALYSIS
  FACILITY ANALYSIS
  SAFEGUARDS METHODOLOGY

- ADVANCED REACTOR SAFETY RESEARCH

  REACTOR CONTAINMENT SAFETY STUDIES
  RADIATION PHYSICS AND REACTOR SAFETY
  ADVANCED REACTOR SAFETY ANALYSES AND PHYSICS

- REACTOR DEVELOPMENT AND APPLICATIONS

  APPLICATIONS
  DESIGN AND DEVELOPMENT
  ISOTOPES AND HOT CELLS

NUCLEAR FUEL CYCLE SAFETY RESEARCH

- REACTOR SAFETY STUDIES - I

  MOLTEN FUEL/CONCRETE INTERACTIONS

  VAPOR EXPLOSIONS

  STATISTICAL ANALYSIS OF LOCA

  SUB-COOLED BLOWDOWN LOADS

  UPPER HEAD INJECTION

  TWO PHASE JET LOADS

NUCLEAR FUEL CYCLE SAFETY RESEARCH

- REACTOR SAFETY STUDIES - II

  QUALIFICATION TEST EVALUATION

  FIRE PROTECTION RESEARCH

  FIRE DETECTORS IN-SITU TEST

  FIRE HAZARD ANALYSIS

NUCLEAR FUEL CYCLE SAFETY RESEARCH

- NUCLEAR FUEL CYCLE SYSTEMS SAFETY

  VALUE/IMPACT ASSESSMENT OF REGULATORY REVIEW

  SYSTEMS INTERACTION/METHODOLOGY APPLICATION

  RSS METHODOLOGY APPLICATIONS

NUCLEAR FUEL CYCLE SAFETY RESEARCH

- NUCLEAR FUEL CYCLE RISK ANALYSIS

  WASTE DISPOSAL RISK METHODOLOGY

  CONSEQUENCE MODELING

  LIQUID PATHWAYS

  APPLICATIONS OF CRAC TO SITING

  TRANSPORTATION OF RADIOACTIVE MATERIALS

NUCLEAR FUEL CYCLE SAFETY RESEARCH

- NUCLEAR FACILITY ANALYSIS

  NUCLEAR FUEL CYCLE FACILITY CHARACTERIZATION

  NUCLEAR POWER PLANT DESIGN CONCEPTS FOR SABOTAGE PROTECTION

  VENTED-FILTERED CONTAINMENT CONCEPTUAL DESIGNS

  ALTERNATE SHUTDOWN HEAT REMOVAL CONCEPTS

NUCLEAR FUEL CYCLE SAFETY RESEARCH

- SAFEGUARDS METHODOLOGY DEVELOPMENT

  GUIDANCE FOR PHYSICAL PROTECTION SYSTEM DESIGN

  PHYSICAL PROTECTION OF NUCLEAR FACILITIES

  PHYSICAL PROTECTION OF MATERIAL IN TRANSIT

EXAMPLE OF DIVERSE INVOLVEMENT OF STAFF

- EMERGENCY RESPONSE
- REACTOR SAFEGUARDS SYSTEM ASSESSMENT AND DESIGN
- TRANSPORT OF RADIOACTIVE MATERIALS
- INDEPENDENT VERIFICATION STUDY
- PLANT DESIGN FOR SABOTAGE PROTECTION

SUMMARY OF RESEARCH AREAS

- ANALYTICAL

  THERMAL-HYDRAULIC MODELING

  CONSEQUENCE MODELING

- RISK ASSESSMENT

  MODEL DEVELOPMENT

  WASTE DISPOSAL

  MINING/MILL TAILINGS

- SYSTEM STUDIES

  METHODS DEVELOPMENT

  APPLICATIONS OF MODELS