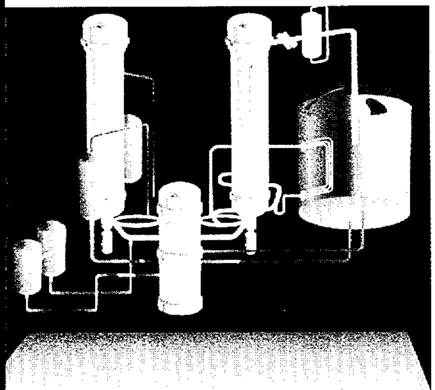
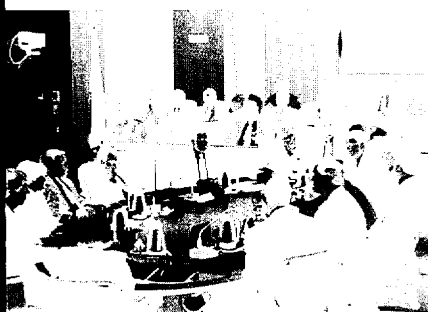


Nuclear Research Programs To Ensure Public Health and Safety



February 2001

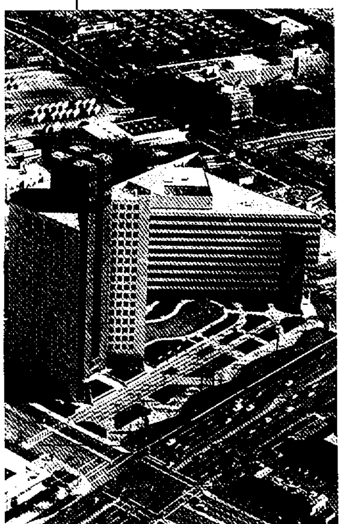
Contents

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: (202) 512-1800 Fax: (202) 512-2250
Mail: Stop SSOP, Washington, DC 20402-0001

ISBN 0-16-050678-6

Introduction

Nuclear Safety Research



NRC Headquarters

The Nuclear Regulatory Commission is responsible for assuring safety in the design, construction, and operation of nuclear facilities and in the other commercial uses of nuclear materials. As a key component of nuclear safety, the NRC carries out a research program to provide independent information and expertise needed to support the NRC's decision-making process and to identify and characterize technical questions that may become important safety issues in the future. NRC's regulatory research is designed to improve the agency's knowledge in areas where uncertainty in knowledge exists, where safety margins are not well characterized, and where regulatory decisions need, or will need to be confirmed. Thus, the development of sound technical bases allows proper focus on safety issues and more realistic decisions.

The NRC's research program is carried out by the Office of Nuclear Regulatory Research (RES). RES develops its program with consideration of Commission direction and input from program offices and other stakeholders, including the academic and international communities. Its mission includes: (1) complementing the front-line regulatory activities of licensing, inspection and oversight, (2) independently examining evolving technology and anticipated issues, (3) striving to be a center of excellence, and (4) having a major role in every strategic arena in implementing key strategies of NRC's Strategic Plan.

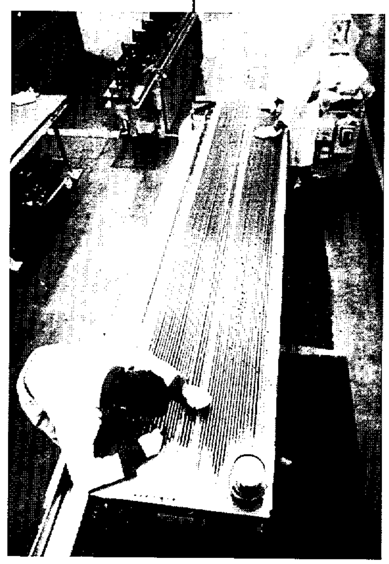
RES contributes to the agency's regulatory decision-making by providing technical advice, analytical tools and information for staff to identify and resolve safety issues, make regulatory decisions, develop regulations and guidance, conduct independent analyses to support decisions to grant or deny licensee proposed changes, renew plant operating licenses, evaluate operating experience, and evaluate proposed designs and technologies, and enhance efficiency and effectiveness of NRC programs and processes.

As part of its critical role at the agency, the office coordinates research activities within the NRC and leads the agency's initiative for cooperative research with the U.S. Department of Energy, the nuclear industry, universities, and international partners. Research sponsored by the office is performed primarily by national laboratories of the Energy Department, but universities and private firms also are used. Further, the RES staff possess broad knowledge in many scientific and engineering fields and is frequently called upon for its expertise by other offices of the NRC.

RES' efforts focus on such issues as reactor fuel behavior and high burnup fuel, plant aging, plant material conditions, spent fuel and waste storage, digital instrumentation and controls, thermal hydraulics and severe accident codes, probabilistic risk analysis, new reactor designs, radiation protection, decommissioning of nuclear facilities, operational data assessment and human performance studies.

Fuel Behavior and High Burnup Fuel:

Reactor accidents involving a large release of radioactivity can only happen when fuel melts. There are only two ways to melt fuel: (1) too much power, and (2) not enough coolant (water). Too much power can develop if there is a loss of reactivity control and insufficient coolant, and insufficient coolant can result from a large water leak in the reactor. The NRC requires that reactors be designed such that they can withstand major reactivity accidents and loss-of-coolant accidents with very limited fuel damage such that melting could not occur. Postulated accidents of these types are studied using experiments and analyses to demonstrate that fuel damage will be adequately limited. These accidents are being reexamined to confirm that recent increases in nuclear power plant output or newer alloys used in metal rods housing nuclear reactor fuel preserve the original low limits on fuel damage.

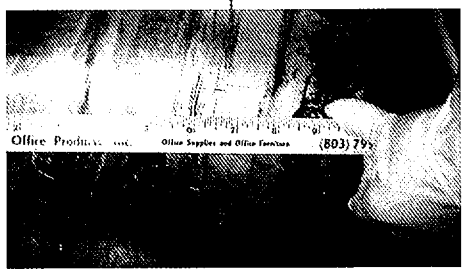


Examination of Fuel Rods

Nuclear fuel for light water reactors release energy through fission (the splitting of a uranium atom). The fuel consists of uranium dioxide ceramic pellets that contain both fissile and fertile materials. Fissile material is material in which fission can be caused by neutrons with low energy. A fertile material is a substance which can be converted into fissionable material by absorption of a neutron. The fissile material is used up and converted to energy and fission products. This process causes changes in the structure of the fuel and results in a gradual deformation of the fuel and a reduction in the neutron population and thus a less efficient nuclear reaction. The total energy released in fission by a given amount of nuclear fuel is called the fuel burnup and is measured in megawatt days (Mwd). The fission energy released per unit mass of the fuel is termed specific burnup of the fuel and is usually expressed in megawatt days per metric ton (Mwd/t).

Fuel damage criteria, established in the 1970s, were developed for normal operation and several postulated accidents. The fuel damage criteria were defined in terms of the amount of energy released from the fuel. The industry, for economic reasons, has requested and, the NRC has approved, fuel burnup to higher levels than was originally anticipated. RES is focused on a reevaluation of NRC regulatory criteria for fuel damage and modification of related analytical tools for higher burnup fuels. It is essential to investigate the behavior of the fuel and fuel rods under high burnup conditions to confirm fuel integrity and reliability under these conditions.

Plant Aging:



A crack is discovered in a weld in the loop hot-leg pipe of a reactor coolant system.

A better understanding of the effect of age-related degradation on structures and passive components (e.g., buried piping, masonry walls, and flat bottom tanks) is needed to ensure that adequate margins are maintained under all design load conditions for the current and any extended operating life of nuclear power plants. This research assembles the age-related degradation data base for structures and passive components, identifies their age-related degradation mechanisms, develops a technical evaluation of the effects of their degradation and the significance to risk, for more risk-informed licensing decisions.

Steam Generator Tube Integrity:

Steam generators are devices which use the heat of water circulating through the reactor core to generate non-radioactive steam to drive turbines. The hot radioactive water flows through steam generator tubes heating the non-radioactive water which is outside the tube. Thus, the tubes form a critical boundary, preventing the release of radioactivity and, therefore, are designed to maintain their structural integrity under operating and postulated accident conditions. Various forms of degradations have occurred in steam generator tubes.

With safety paramount, the steam generator integrity research program assesses the adequacy of inspection for identification and characterization of degraded tubes, causes of degradations, and methods for evaluating and maintaining integrity. This helps ensure that the tubes are designed to maintain structural integrity under operating and postulated accidental conditions.

Reactor Pressure Vessel Internals:

The cylindrical, steel reactor vessel and its internal equipment that houses the fuel rods provide the heat source for the generation of steam to turn a turbine for the production of electricity. Cracking of reactor pressure boundary components, such as piping, continues to be observed. Degradation of these components could cause leaks or breaks that could impair the ability to shut down and cool the reactor core. Issues being addressed by RES include: (1) crack initiation and growth, (2) cracking due to stress corrosion, and the effects of irradiation on stainless steel.

Structures:

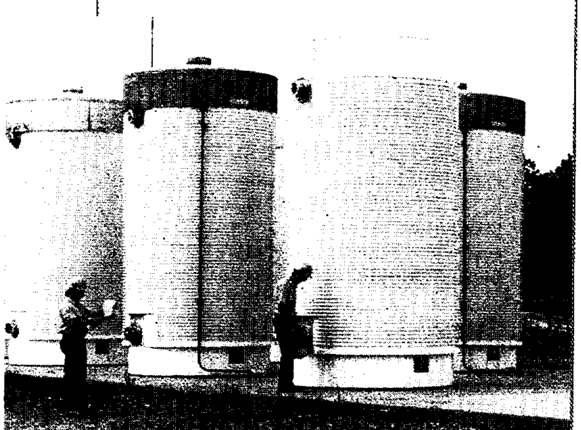
Aging structures can lead to changes in structural properties, which could lead to weakening and failure. Degraded structures are of particular concern when subjected to external loads such as earthquakes. Risk studies for degraded structures are being conducted.

Plant Material Conditions:

This research area focuses on the evaluation of structural integrity and material conditions of components and systems in nuclear power plants and other nuclear facilities under normal operating and accidental conditions. The research addresses material exposure to reactor operating temperatures, stresses, irradiation environments, water coolant chemistry, cyclic loading, and general wear. Research also includes evaluation of non-destructive examination methods for performing in-service inspections of plant components and systems.

Spent Fuel and Waste Storage:

There are two licensing issues associated with the long-term storage of spent



Storage casks at the Surry Nuclear Power Plant in Virginia

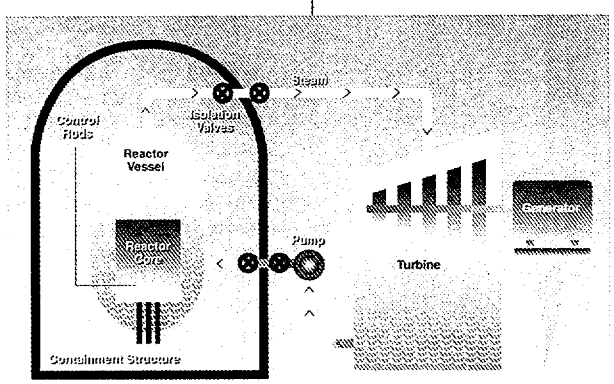
nuclear fuel. The first is the renewal of existing dry cask storage licenses and Certification of Compliance for intermediate burnup fuel. The second is the licensing of dry cask storage for high burnup fuel. RES is developing the technical basis for ensuring the continued safe performance of dry storage systems for long-term storage of spent nuclear fuels and high-level radioactive waste under extended service conditions, 20 to 100 years.

Digital Instrumentation and Controls:

The general direction of the nuclear industry is to replace their analog instrumentation and control equipment with digital equipment because of the difficulty in replacing analog equipment modules and the advantages of newer equipment. It is expected that plants will retro-fit their protection systems, control systems, and eventually the majority of their control rooms. This will result in a mixture of analog and digital (hybrid) equipment that will require complex interfaces with an increased potential for errors. For example, industry is currently developing new modern control and diagnostic systems to improve reliability, and advanced neutron and flow sensors to reduce the uncertainty of power measurements. While digital technology has the capability to improve both operational performance and safety, there are challenges to the introduction of this technology into nuclear power plants. RES is developing research projects to keep up with the ever-changing digital technology, its complexity and unique failure modes associated with it, and to provide guidance to the industry with sufficient lead time.

Thermal Hydraulics and Severe Accident Codes:

Thermal-Hydraulics: The energy source of nuclear power reactors is the nuclear fission process that occurs within the fuel. Water is pumped into the reactor and passes over the fuel elements. In passing over the fuel elements the coolant (water) is heated, which is then used to generate steam. Various forms of steam generators are used in nuclear reactors. The nuclear reactor itself is the steam generator in the case of boiling water reactors, where the steam is formed directly within the reactor core. The steam generator is fed with water, which is totally or partially evaporated to steam. The steam is then passed through the turbine, which drives the electrical generator. The very low pressure exhaust steam from the turbine is passed to a condenser, where it is converted back into water and recirculated to the steam generator. The removal of energy in the fuel and the production of the energy must be balanced. The situation of either too little coolant flow or too much energy production can result in the fuel overheating and potentially melting. Thermal-hydraulic research involves development of computer codes and data that are used to model the reactor system to ensure that a balance is achieved and to assess the consequences of such an imbalance and mitigating actions taken if an imbalance occurs.



An illustration of a Boiling Water Reactor

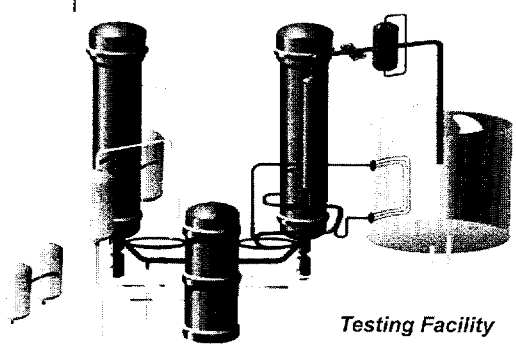
Additionally, RES maintains and continues to improve the usefulness of computer codes that are used to analyze reactor operations and functions. These codes are used in analyzing many types of information about reactors. For example, they also are used to resolve fuel behavior technical issues.

Severe accidents: Severe accidents are that highly improbable group of accidents that involve serious, prolonged overheating of most of the nuclear fuel which then results in the release of large amounts of radiation and radioactive material. For some of these severe accidents, the radiation may escape from the nuclear power plant and be carried by the wind exposing people in the surrounding area. Severe accident research studies the detailed behavior of reactors and the radiation released during such accidents and examines means to prevent such accidents and protect the public.

Probabilistic Risk Analysis:

Probabilistic risk analysis is a systematic process for estimating the potential risk associated with the design and operation of nuclear power plants. The analysis helps produce estimates of core damage frequency and its consequences. These can be defined in terms of early and delayed health effects, loss of habitability of areas close to nuclear power plants and economic ramifications.

Information on risks and risk analysis are considered in all phases of the agency's regulatory process. RES has several



Testing Facility

The NRC's Office of Regulatory Research works closely with universities nationwide.

programs in the area of probabilistic risk assessment to evaluate the risks, however small, of accidents or events that may occur. These programs are expected to result in regulations that enhance safety for nuclear facilities, as well as reduce the burden of unnecessary regulations and requirements on those NRC regulates.

New Reactor Designs:
There is a real possibility that in the next five to 10 years orders for new nuclear power plants will become a reality. However, for such orders to be realized, future reactor designs must be attractive from an economic and safety perspective.

Many of these designs will propose features very different than current reactor designs. Since safety and licensing are major considerations for any future designs, it is most efficient, timely, and in the national interest for NRC to prepare for licensing future designs by having early interactions with the designers and developers as encouraged by the Nuclear Regulatory Commission's Policy Statement on Advanced Reactors. Early interaction would be to:

- Understand reactor designs
- Identify safety issues and plans for their resolution
- Establish a framework for licensing that recognizes the unique features of these designs.

One major concern for new plant designs will be reducing capital costs by 30-35 percent. That will lead to novel designs, the search for new, less costly materials, the use of commercial components, and revised design and construction codes and standards. It will likely require additional research on issues such as piping design (higher allowable seismic stresses that lead to fewer and less massive supports and to fewer snubbers), pipe break criteria, and inspection and testing requirements. It is also anticipated that new plant designs will make use of on-line monitoring techniques to supplement advanced nondestructive examination and inspection techniques.

These new plant designs can be anticipated to introduce concepts, such as seismic base-isolation, advanced energy-absorbing supports, and advanced construction techniques and materials to reduce the costs of earthquake resistant designs. To implement these advances, the site-specific modeling of the propagation of strong ground motions will have to be refined, as well as staying abreast with the advances in geological information pertinent to seismic hazard and risk assessment. It should be noted that similar siting considerations impact new fuel fabrication facilities, dry storage sites, as well as nuclear power plant sites.

Wide use of digital technology is expected. New research will likely be needed to evaluate some of the commercial-grade components, the advanced technologies (new materials, digital systems, etc.), and to support staff evaluation of revised codes and standards. Finally, research will be needed to evaluate the long-term aging of new materials, designs, and commercial components. The use of on-line monitoring techniques is expected to supplement advanced non-destructive examination and inspection techniques.

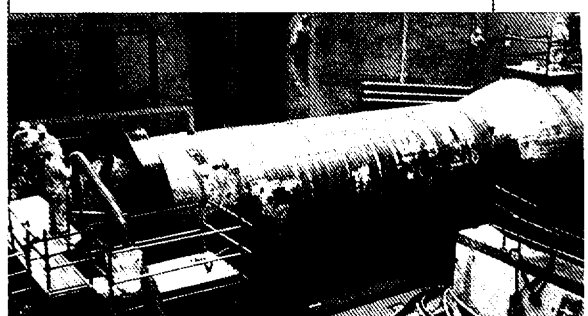
Radiation Protection:

Working with others in the agency, RES studies radionuclide transport, or the movement of radioactive materials in the environment. It examines sites that have been environmentally contaminated with radioactive materials. To protect the public from adverse effects of such contamination, the location and future transport of these materials must be assessed with the most advanced scientific tools available. The research program develops and improves these scientific tools for use by the agency regulatory staff to assist it with clean-up and long-term control of sites formerly used for nuclear operations, such as a nuclear power plant.

With regard to the NRC's current regulations on radiation exposure based on risk estimates, RES accumulates data on the effects of radiation on the human body through several types of studies. RES uses this data to re-evaluate the current health effects of computer models and to evaluate health effects caused by long-term exposures to low levels of radiation.

Decommissioning:

For reactors and other facilities that are nearing the end of their productivity, RES has initiated studies on safe and effective means of decommissioning

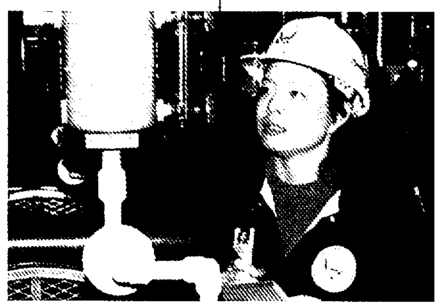


Dismantlement of the Trojan Nuclear Power Plant in Oregon.

nuclear power plants and other nuclear facilities. Decommissioning is the process of safely removing a facility from service followed by reducing residual radioactivity to a level that permits the release of the property for unrestricted use and, under certain conditions, restricted use. This includes removal of all intact radioactive materials and the clean-up of any residual contamination to acceptable regulatory levels. RES examines environmental contamination associated with a nuclear facility in terms of potential off-site transport of radioactive material and compliance with any standards for termination of the operating license.

Operational Data Assessment:

Data from operating reactors is continually assessed to learn more about operating reactor safety. RES collects, analyzes, and disseminates data accumulated during operations and assesses trends in performance from these data. It evaluates operating experience to provide insights into and to improve the understanding of the risk significance of events that have occurred at licensed facilities. The evaluation may disclose risk-significant interactions, phenomena, and behaviors at power reactors that have not previously been recognized or analyzed. For example, data accumulated from many operating reactors can show trends in aging of the reactors. Examinations of individual plants and events at nuclear plants is also used to develop guidance and standards on the use of risk assessments that are needed for the agency's reactor oversight program.



An NRC inspector collects data at a licensed facility.

Human Performance:

Human Performance research activities at the NRC focus on the interaction of people with the systems and the environments in which they work. The importance of these interactions is that they can strongly affect personnel performance and thus overall system safety at a nuclear facility. Indeed there is considerable operational evidence that poor human performance has been a factor in more than 50% of the incidents at nuclear power plants and an even greater percentage of incidents involving the use of nuclear materials for medical and industrial applications.

At NRC we look at the performance of people in normal and abnormal conditions, and at the effects of the work environment, including physical and cognitive effects, on both individual and team performance. This includes human-system interfaces, training, procedures, shift working hours, and a safety conscious work environment. In addition, human performance research addresses human characteristics, such as knowledge, skills, and abilities, fatigue, and fitness for duty. It is important that human performance is supported by an organizational environment that promotes a culture of safety and provides its personnel with the programs, support, staffing, and tools necessary to perform the jobs safely and comfortably.

NRC's research program in human performance is anticipatory in that it addresses emerging technology's potential effect on human performance. In addition, human performance research develops and establishes the technical bases for NRC initiatives, such as, inspection guidance for evaluating emergency operating procedures, a systems approach to training, human system interface design for current and advanced control station design, human performance contributors in events, communications-related corrective action plans, shift working hours and fatigue management programs.

Use of Technical Standards and Computer Codes:

RES coordinates the development of consensus and voluntary standards for agency use. Consensus standards are technical standards that support regulatory needs pertaining to materials, components, and processes. They are developed by experts from industry, universities, or government agencies. The agency serves on committees of the national and international organizations (i.e., American Society of Mechanical Engineers, the American National Standard Institute, the International Commission on Radiation Units and Measurements, and the National Council on Radiation Protection) that develop these standards. The NRC frequently endorses these standards as guidance or adopts them into its regulations.

In short, the NRC's Office of Regulatory Research goals are to maintain safety, increase public confidence, make NRC activities and decisions more effective, efficient, and realistic, and reduce unnecessary regulatory burden on stakeholders. It carries out the agency's research program to provide independent information and expertise needed to support the Commission's decision-making process and to identify and characterize technical questions in anticipation of safety issues that may arise in the future.

FOR ADDITIONAL INFORMATION CONTACT:

Office of Public Affairs
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
(301) 415-8200

http://www.nrc.gov/OPA

Notes

NUREG/BR-0282

Office of Nuclear Regulatory Research

U.S. Nuclear Regulatory Commission