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Assessment of Lessons Learned from the Fukushima Dai-ichi Nuclear Accident to Research and Test Reactors in the United States

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Introduction to Licensing Methodology

- Thirty-one research and test reactors (RTRs) used for commercial activities, medical therapy, or research and development
- Licensed thermal power ranges from 5 watts to 20 megawatts (MW)
- Licensed using defense-in-depth concept to compensate for design, operation, and radiological consequence uncertainties associated with potential accidents
- Deterministic analysis methods, including highly conservative safety margins, described in U.S. Nuclear Regulatory Commission (NRC) RTR standard review plan, NUREG-1537

Characteristics of Research and Test Reactors

- Potential accident consequences for RTRs significantly less than nuclear power reactors due to differences in operating characteristics

- Nuclear material inventories, accident source terms, and demand for active decay heat removal limited by:
  - Low operating power levels, temperatures, and pressures
  - Reduced hours of operation
  - Minimal onsite spent fuel

Approach to Accident Analysis

- Each RTR licensed to protect workers and public from radiological hazards based on set of licensing-basis events

- Based on conservative assumptions, an incredible maximum hypothetical accident (MHA) analyzed to assess potential dose to public
  - MHA must bound all credible hazards from postulated accidents resulting in the release of fission products and design basis external event scenarios
  - Since not expected to occur, only potential consequences analyzed
  - For operating RTRs, MHA assumes fuel or fueled experiment failure

- Research reactor radiological consequences bounded by Title 10 of the *Code of Federal Regulations* (10 CFR) Part 20 occupational and public dose limits

- One NRC-licensed test reactor must meet 10 CFR Part 100 accident dose criteria

Consideration of External Events

- Average and extreme natural event conditions considered during licensing
- Licensee safety analysis reports include information on geographical, geological, seismological, hydrological, and meteorological characteristics of reactor site
- NRC staff determines whether structures, systems, and components capable of performing safety functions during and after postulated events

Prompt Post-Fukushima Assessments

- NRC staff collected information relative to accident to determine whether immediate regulatory action needed to address safety at RTRs

- The prompt assessment of RTRs considered
  - Natural events
  - Electrical power
  - Decay heat removal
  - Spent fuel cooling
  - Combustible gas control
  - Confinement and containment

Results of Prompt Assessments

- No safety concerns revealed requiring immediate action
- No new information that would contradict or invalidate licensing basis at NRC-licensed RTRs

Assessment of Near-Term Task Force Report

- Near-Term Task Force (NTTF) established to evaluate need for NRC action at nuclear power plants

- In July 2011, NTTF issued report with recommendations related to:
  - Clarifying NRC's regulatory framework
  - Ensuring protection
  - Enhancing mitigation
  - Strengthening emergency preparedness
  - Improving regulatory efficiency

- NRC staff based assessment of RTRs on applicable NTTF recommendations and postulated beyond-design-basis external events

- Assessment included review of licensing documents and guidance, security assessments, and other facility-specific analyses

- Thirty-one RTRs grouped into two categories based on power level:
  - Less than or equal to 2 MW_t (28 research reactors)
  - Greater than 2 MW_t (3 research and test reactors)

Assessment of Research and Test Reactors

- NRC staff assessed facility resilience to loss of active decay heat removal capability, loss of electrical power, and loss of coolant as a result of a beyond-design-basis external event

- Review of external events, included:
  - Reevaluation of all hazards, with focus on seismic and flooding events
  - Assessment of concurrent adverse events
  - Assumed exceedance of design-basis external events

- The potential for fuel cladding failure and fission product radiological release exceeding MHA considered in assessment

- Results of assessment used to determine whether additional evaluation needed

Category 1 Research Reactors

- Assessment of twenty-eight research reactors operating at 2 MW_t or lower found:
  - Decay heat adequately removed via air cooling to prevent cladding failure
  - Facilities are resilient to loss of all power, reactor coolant, and active decay heat removal
- Therefore, no significant increase in risk of radiological consequences as a result of a beyond-design-basis external event
- Low risk of release of radioactive material driven by several factors, including:
  - Low thermal power ratings
  - Low fission product inventory
  - Low decay heat generation
  - Capability of air cooling adequately prevent fuel overheating and cladding failure
- NRC staff found no additional assessment or action necessary for Category 1 research reactors

Category 2 Research and Test Reactors

- Assessment of two high-powered research reactors (6 MW_t and 10 MW_t) and one test reactor (20 MW_t) during beyond-design-basis external event found:
  - Air cooling no longer sufficient for adequate decay heat removal
  - Availability of reactor coolant, heat sink, and electrical power more important than at lower-powered reactors

- For two research reactors at Massachusetts Institute of Technology (MITR) and University of Missouri-Columbia (MURR):
  - Adequate decay heat can be removed through natural convection flow of reactor coolant if integrity of reactor pool maintained or sufficient make up coolant available
  - With adequate availability of reactor coolant, reactors not reliant on electrical power or active decay heat removal systems to prevent cladding failure

- For test reactor at the National Institute of Standards and Technology (NBSR):
  - Natural convection of reactor coolant and passive makeup system initially provide adequate decay heat removal
  - Reactor reliant on source of primary coolant make up or electrical power and active decay heat removal systems to prevent fuel cladding failure

- Additional assessment of seismic and other beyond-design-basis events that could result in a loss-of-coolant accident (LOCA) concurrent with loss of electrical power needed

Additional Assessments for MITR and MURR

- NRC staff performed probabilistic seismic hazard analysis (PSHA) to assess safety of facilities
  - For MITR, peak ground acceleration (PGA) values between 0.2 g and 0.225 g approximate previously analyzed Safe Shutdown Earthquake (SSE)
  - For MURR, ground motion response spectra enveloped by previously analyzed SSE in the 1 to 16 hertz (Hz) range
  - For both facilities, seismic-induced sloshing would not create additional hazard
- NRC staff assessed potential effects of high-wind-driven missiles
  - Both MITR and MURR have containments that protect cores with reinforced concrete
  - Rigid large tornado missile (e.g., Schedule 40 pipe) selected for analysis
  - For MITR, missile would be unable to penetrate steel plates of containment structure
  - For MURR, missile would lose substantial kinetic energy upon impact and be unlikely to reach biological shield
- Therefore, NRC staff concluded that no further assessment was needed for either seismic- or high-wind-related hazards at MITR and MURR

Additional Assessments for NBSR

- NRC staff performed PSHA to assess safety of facility
  - Calculated PGA of 0.07 g compared well with 0.1 PGA used in facility design-basis
  - Seismic-induced sloshing would not create additional hazard
  - Passive coolant make up system, natural convection of cooling, and availability of portable equipment adequate for protecting against consequences of seismic event
- NRC staff assessed potential effects of flooding
  - Facility located above 500-year flood plain and not near any major bodies of water
  - Only potential flooding from rivers, streams, and local intense precipitation (LIP) events
  - Since facility is above flood plain, no credible hazard from rivers or streams
  - In rare instance of LIP event, no adverse impact on availability of coolant water
- NRC staff assessed potential effects of high-wind-driven missiles
  - NBSR surrounded by concrete biological shield inside a confinement building
  - Rigid large tornado missile (e.g., Schedule 40 pipe) selected for analysis
  - Because exterior wall of confinement building 0.6 meters [2 feet] thick, missile unable to reach biological shield
- Therefore, NRC staff concluded that no further assessment was needed for seismic-, flooding-, or high-wind-related hazards at NBSR

Conclusions

- Category 1 research reactors
  - Even if LOCA occurs concurrently with an external event, decay heat could be sufficiently removed by air cooling of the core
  - Confinement or containment structures not challenged by energetic releases from cooling systems or hydrogen generation during accidents
  - Minimal quantities of spent fuel can be adequately cooled by air
- Category 2 research and test reactors
  - Existing design bases adequately protect against cladding failures and release of radioactive material during an external event that could result in failure of primary coolant system integrity
  - Confinement or containment structures not challenged by energetic releases from cooling systems or hydrogen generation during accidents
  - Minimal quantities of spent fuel can be adequately cooled by air
- All NRC-licensed research and test reactors present minimal radiological hazards to the public health and safety
- No additional protective or mitigating strategies necessary