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Advanced Reactor Stakeholder Public Meeting

July 15, 2021

Microsoft Teams Meeting
Bridgeline: 301-576-2978
Conference ID: 446 067 450#

Advanced Reactor Program

Time	Agenda	Speaker
10:00 - 10:20 am	Opening Remarks – NRC Advanced Reactor Public Website Updates	NRC
10:20 - 10:45 am	Advanced Reactor Generic Environmental Impact Statement (GEIS) Update	NRC/NMSS
10:45 -11:15 am	Annual Fees for Non-Light-Water Reactors	NRC/OCFO
11:15 am - 12:00 pm	Technology-Inclusive Content of Application Project (TICAP) and Advanced Reactor Content of Application Project (ARCAP) Updates	NRR/DANU
12:00 - 1:00 pm	Break	All
1:00 - 1:30 pm	Applicability of Regulations to Non-Light-Water Reactors	NRR/DANU
1:30 - 2:30 pm	ANL Report for Non-Light-Water Reactor Vessel Cooling Systems	NRR/DANU and ANL
2:30 - 3:30 pm	Best Practices for Conducting Part 50 Reviews and Lessons Learned from the SHINE Application Reviews	NRR/DANU
3:30 - 3:45 pm	Concluding Remarks and Future Meeting Planning	NRC/All

Advanced Reactor Integrated Schedule of Activities

Advanced Reactor - Summary of Integrated Schedule and Regulatory Activities

Summary of Integrated Schedule and Regulatory Activities (updated 11/02/2020)

Advanced Reactor Program - Summary of Integrated Schedule and Regulatory Activities*

Strategy 1	Knowledge, Skills, and Capability
Strategy 2	Computer Codes and Review Tools
Strategy 3	Flexible Review Processes
Strategy 4	Consensus Codes and Standards
Strategy 5	Policy and Key Technical Issues
Strategy 6	Communication

Legend

Concurrence (Division/Interoffice)	• EDO Concurrence Period
Federal Register Publication	Commission Review Period**
Public Comment Period	▼ ACRS SC/FC (Scheduled or Planned)
Draft Issuance of Deliverable	External Stakeholder Interactions
Final Issuance of Deliverable	↓ Public Meeting (Scheduled or Planned)

Version 11/2/20

Present Day

Strategy	Regulatory Activity	Commission Papers	Guidance	Rulemaking	NEIMA	Complete	2020												2021											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Development of non-Light Water Reactor (LWR) Training for Advanced Reactors (Adv. Rxs) (NEIMA Section 103(a)(5))																													
	FAST Reactor Technology				x	x																								
	High Temperature Gas-cooled Reactor (HTGR) Technology				x	x																								
	Molten Salt Reactor (MSR) Technology				x	x																								
	Competency Modeling to ensure adequate workforce skillset					x																								
	Identification and Assessment of Available Codes					x																								
	Development of Non-LWR Computer Models and Analytical Tools																													
	Code Assessment Reports Volumes 1 (Systems Analysis)					x																								
	Reference plant model for Heat Pipe-Cooled Micro Reactor					x																								
	Reference plant model for Sodium-Cooled Fast Reactor					x																								
	Reference plant model for Fluoride-Salt-Cooled High-Temperature Reactor																													
	Reference plant model for Gas-Cooled Pebble Bed Reactor																													
	Reference plant model for Molten Salt Fueled Reactor																													
	Code Assessment Reports Volumes 2 (Fuel Perf. Analysis)					x																								
	FAST code assessment for metallic fuel																													
	FAST code assessment for TRISO fuel																													
	Code Assessment Reports Volumes 3 (Source Term Analysis)					x																								

https://www.nrc.gov/reactors/new-reactors/advanced/details#advSumISRA

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Updates to the NRC Public Webpage on Pre-application Activities

Advanced Reactor Licensing Branch
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
U.S. Nuclear Regulatory Commission

Updated Webpage on Pre-application Activities

- The NRC staff has updated public webpages on advanced reactors:

  https://www.nrc.gov/reactors/new-reactors/advanced.html

- New information on pre-application activities

  https://www.nrc.gov/reactors/new-reactors/advanced/ongoing-licensing-activities/pre-application-activities.html

  – Design
  – Activities
  – NRC project manager

- Draft White Paper on Pre-Application Engagement

  Draft Pre-application Engagement to Optimize Advanced Reactors Application Reviews

Questions?

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Advanced Reactor Generic Environmental Impact Statement and Rulemaking

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Environmental Center of Expertise, U.S. NRC

Current Status

- On September 21, 2020, the Commission approved development of the ANR GEIS and directed the staff to codify the results through rulemaking (SRM-SECY-20-0020, ADAMS Accession No. ML20265A112).

- Scoping Summary Report issued on September 25, 2020 (ADAMS Accession No. ML20260H180).

- Staff has completed writing sections of the draft ANR GEIS.

- Staff is developing the proposed rule package, which includes: proposed rule language, revisions to guidance documents, regulatory analysis, and other related rulemaking documents.

- Proposed rule package due to the Commission in November 2021.

Key Framework

- The ANR GEIS uses a technology neutral, performance-based approach that utilizes a plant and site parameter envelope (PPE/SPE).
- Most environmental issues are decoupled from reactor power level.
- The PPE/SPE values and assumptions were developed to bound a maximum number of designs and sites.
- Category 1 issues are environmental issues that are generically resolved as SMALL; while Category 2 issues impacts cannot be determined and are not analyzed in the ANR GEIS because they are project-specific.
- It is anticipated that an applicant for any advanced reactor would be able to use the ANR GEIS (LWRs, Non-LWRs, SMRs, fusion reactors).
- The ANR GEIS evaluates both construction and operation for 16 “resource areas” such as land use, visual, ecology, air quality, water use, socioeconomics, noise, decommissioning, fuel cycle, transportation of fuel, and continued storage.

Implementation

- ANR applicants may use GEIS findings in the Environmental Report provided:
  - reactor and site meet the plant and site parameter envelope (PPE/SPE) values and assumptions used in the GEIS, and
  - there is no new and significant information between the time the GEIS is finalized and when the applicant submits their application.

- NRC Staff would:
  - verify the PPE/SPE demonstration for Category 1 issues,
  - audit the applicant's new and significant process,
  - produce a Supplemental EIS that focuses on Category 2 issues and issues that could not meet the PPE/SPE values and assumptions while incorporating the demonstrated ANR GEIS findings.

PPE/SPE Values and Assumptions

- The PPE and SPE values and assumptions were developed by an interdisciplinary team of Subject Matter Experts assigned to prepare the GEIS. The SMEs developed the values and assumptions based on one or more of the following:

  - regulatory limits and permitting requirements relevant to the resource as established by Federal, State, or local agencies;
  - relevant information obtained from other NRC GEISs, including the License Renewal GEIS and the Continued Storage GEIS;
  - empirical knowledge gained from conducting evaluations and analyses for past new reactor EISs;
  - values and assumptions derived from other documents applying a PPE/SPE approach (such as the National Reactor Innovation Center PPE Report); and
  - subject matter expertise and/or development of calculations and formulas based upon education and experience with the resource.

- PPE and SPE values and assumptions were set broadly enough to make the GEIS a useful licensing tool, while still ensuring that project-specific analyses evaluate and document **significant** environmental impacts for the public and decision-makers and ensure that NRC's NEPA requirements (and related laws, rules, and regulations) are met.

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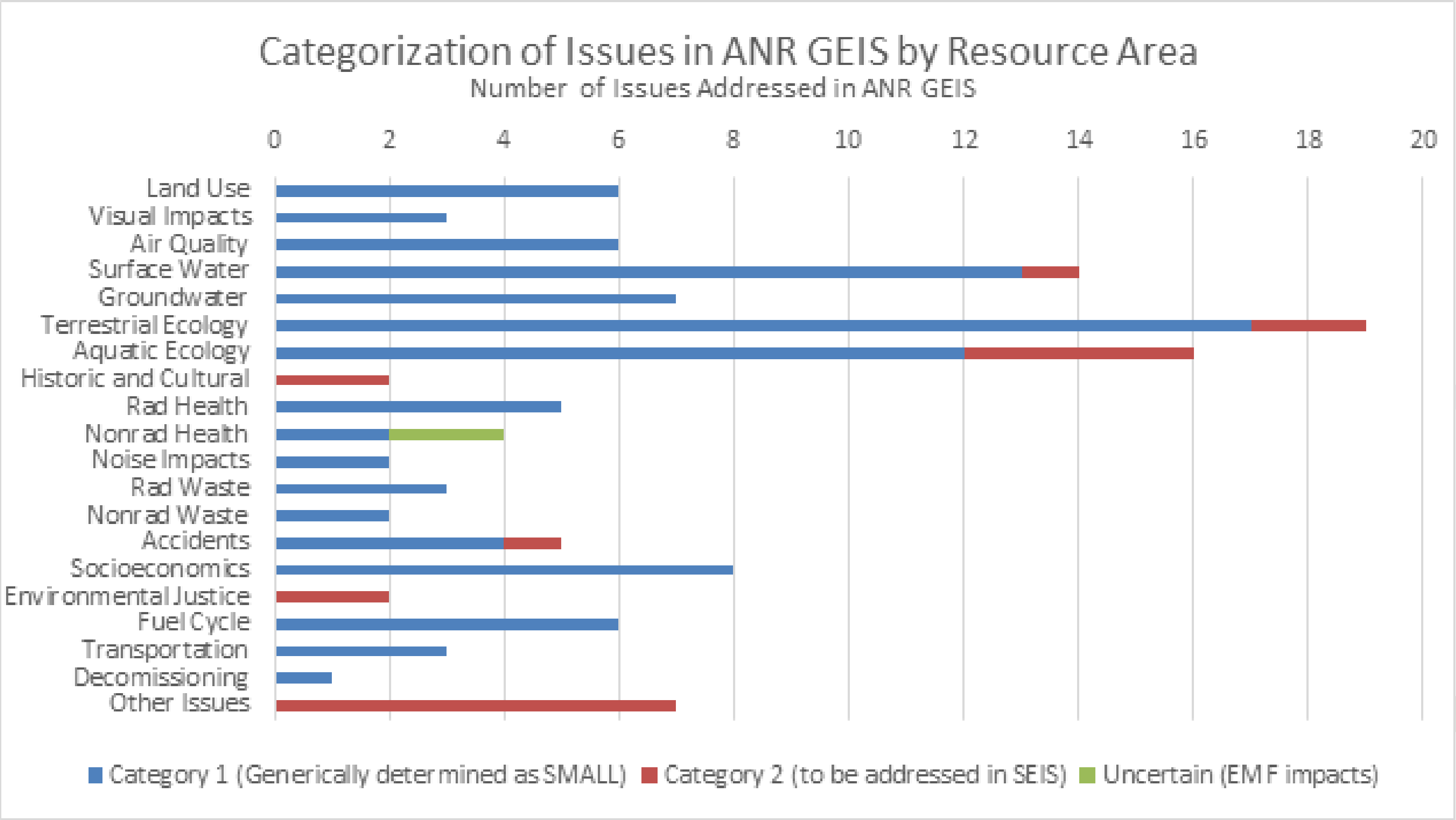
PPE/SPE Values and Assumptions

PPE/SPE Values and Assumptions Table includes parameters applicable to the resource area issues can be found at ML21189A176.

DRAFT – PRELIMINARY TEXT		
Parameter	**Values and Assumptions**	**Basis/Methodology**
Cooling Towers	1. No natural draft cooling towers 2. Would be equipped with drift eliminators 3. Makeup water would be fresh (salinity less than 1 ppt)	Various past new reactor EISs indicate that natural draft cooling towers are tall structures over 200 ft in height that may be visible from substantial distances and from which salt drift and fogging may affect substantial areas of offsite land.
Other Cooling Features	1. No once-through cooling 2. No new cooling ponds 3. No new reservoirs 4. No spray irrigation ponds	Once-through cooling systems have a substantial potential for significant impacts on aquatic biota from entrainment and impingement and are essentially not possible due to Section 316(b) of the Clean Water Act (33 U.S.C. § 1326-TN4823). Operation of cooling ponds can have potentially significant effects on aquatic and terrestrial biota. Building reservoirs can affect large areas of aquatic and terrestrial habitats, including sensitive wetland, floodplain, and riparian habitats.

Environmental Issues

- A complete list of Environmental Issues for Each Resource Area are in the background slides.



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Category 2 Issues

- Staff determined 19 resource area issues require a site or project specific analysis.
  - Surface Water Quality Degradation Due to Chemical and Thermal Discharges (Operation)
  - Terrestrial and Aquatic Endangered Species and Habitats (Construction and Operation)
  - Aquatic Thermal Impacts on Aquatic Biota (Operation)
  - Other Effects of Cooling-water Discharges on Aquatic Biota (Operation)
  - Historic and Cultural Resources (Construction and Operation)
  - Severe Accidents (Operation)
  - Environmental Justice (Construction and Operation)
  - Cross Cutting Issues- Climate Change and Cumulative
  - Non-Resource Related Issues
    - Purpose and Need
    - Need for Power
    - Site, Energy and System Design Alternatives

Air Quality Example

- Emissions of Criteria Pollutants and Dust During Construction
  - PPE/SPE values and assumptions
    - The site size is 100 ac or less.
    - The permanent footprint of disturbance is 30 ac or less of vegetated land and the temporary footprint of disturbance is an additional 20 ac or less of vegetated land.
    - New offsite ROWs for transmission lines, pipelines, or access roads would be no longer than 1 mi and have a maximum ROW width of 100 ft.
    - Criteria pollutants emitted from vehicles and standby power equipment during construction are less than Clean Air Act de minimis levels set by the EPA if the site is located in a nonattainment or maintenance area, or the site is located in an attainment area.
    - The site is not located within 1 mi of a mandatory Class I Federal area where visibility is an important value.
    - The level of service determination for affected roadways does not change.
    - Mitigation necessary to rely on the generic analysis includes implementation of BMPs for dust control.
    - Compliance with air permits under State and Federal laws that address the impact of air emissions during construction.

Fuel Cycle Example

- Summary of PPE values and assumptions
  - Table S-3 is expected to bound the impacts for ANR fuels, because of changes since WASH-1248, including:
    - Increasing use of in situ leach uranium mining
    - Current light-water reactors are using nuclear fuel more efficiently
    - Less reliance on coal-fired electrical generation plants
    - Transitioning of U.S. uranium enrichment technology from gaseous diffusion to gas centrifugation
  - Reprocessing capacity up to 900 MTU/yr
  - Waste and spent fuel inventories, as well as their associated certified spent fuel shipping and storage containers, are not significantly different from NUREG-2157
  - Must satisfy the regulatory requirements of 10 CFR Parts 40, 70, 71, and 73

Regulatory Guide 4.2 Revisions

- Regulatory Guide 4.2 provides guidance to applicants on the preparation of environmental reports
  - Guidance for ANR applicants mostly contained in Appendix C of RG 4.2.
    - General guidance for ERs referencing the ANR GEIS
    - Additional guidance for ANR applications
    - Demonstration method of PPE/SPE values and assumptions
  - If PPE/SPE value or assumption not met, then follow guidance in RG 4.2 Main Body

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Regulatory Guide 4.2 – Air Quality Demonstration

- The site size is 100 ac or less.
  - Document site acreage and include a scaled map or drawing outlining the site boundaries. Demonstrate that the site is large enough to accommodate the proposed reactor and supporting facilities, the exclusion area as defined in 10 CFR Part 100, and any lands (other than offsite ROWs) permanently or temporarily needed for construction and operation of the proposed reactor and supporting facilities.
- Criteria pollutants emitted from vehicles and standby power equipment during construction are less than Clean Air Act de minimis levels set by the EPA if the site is located in a nonattainment or maintenance area, or the site is located in an attainment area.
  - Provide the attainment status in the region for all the criteria pollutants. If the proposed project is in an attainment area, then the applicant does not need to provide estimates of criteria pollutants emitted for the project. Applicants should provide an applicability analysis that contains the estimates of potential emissions of criteria pollutants to demonstrate emissions would be below *de minimis* level thresholds provided in 40 CFR 93.153(b) for non-attainment & maintenance areas.

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Regulatory Guide 4.2 – Fuel Cycle Demonstration

- Verify the following:
  - Use of in situ uranium recovery
  - Use of gas centrifuges for enrichment
  - Anticipated levels of fuel burnup
  - Less reliance on coal fired electrical generation plants
  - Planned reprocessing capacity less than or equal to 900 MTU/yr
  - Waste and spent fuel inventories, as well as their associated certified spent fuel shipping and storage containers, are not significantly different from NUREG-2157
  - Meet 10 CFR Parts 40, 50, 70, 71, 72, and 73
- If not bounded by the GEIS, provide information
  - PNNL-29367 Rev. 2, Non-LWR Fuel Cycle Environmental Data (ML20267A217)

Rulemaking Schedule

November 2021
- Proposed rule submitted to Commission

May 2022 (estimated)
- Proposed rule publication for 60-day comment period

May 2023 (estimated)
- Final rule submitted to Commission

Jan 2024 (estimated)
- Final rule publication

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Questions?

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Background Slides

Environmental Issues

DRAFT – PRELIMINARY TEXT	
Issue	**Category**
Land Use Impacts	
Construction	
Onsite Land Use	1
Offsite Land Use	1
Impacts to Prime and Unique Farmland	1
Coastal Zone and Compliance with the Coastal Zone Management Act	1
Operation	
Onsite Land Use	1
Offsite Land Use	1
Visual Impacts	
Construction	
Visual Impacts in Site and Vicinity	1
Visual Impacts from Transmission Lines	1
Operation	
Visual Impacts During Operations	1
Air Quality Impacts	
Construction	
Emissions of Criteria Pollutants and Dust During Construction	1
Greenhouse Gas Emissions During Construction	1
Operation	
Emissions of Criteria and Hazardous Air Pollutants during Operation	1
Greenhouse Gas Emissions During Operation	1
Cooling System Emissions	1
Emissions of Ozone and NOx during Transmission Line Operation	1

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Environmental Issues (Cont'd)

DRAFT – PRELIMINARY TEXT	
Issue	**Category**
Water Resource Impacts	
Construction	
Surface Water Use Conflicts during Construction	1
Groundwater Use Conflicts due to Excavation Dewatering	1
Groundwater Use Conflicts due to Construction-Related Groundwater Withdrawals	1
Water Quality Degradation due to Construction-Related Discharges	1
Water Quality Degradation due to Inadvertent Spills during Construction	1
Water Quality Degradation due to Groundwater Withdrawal	1
Water Quality Degradation due to Offshore or In-Water Construction Activities	1
Water Use Conflict Due to Plant Municipal Water Demand	1
Degradation of Water Quality from Plant Effluent Discharges to Municipal Systems	1
Operation	
Surface Water Use Conflicts during Operation due to Water Withdrawal from Flowing Water Bodies	1
Surface Water Use Conflicts during Operation due to Water Withdrawal from Non-flowing Water Bodies	1
Groundwater Use Conflicts Due to Building Foundation Dewatering	1
Groundwater Use Conflicts Due to Groundwater Withdrawals for Plant Uses	1
Surface Water Quality Degradation Due to Physical Effects from Operation of Intake and Discharge Structures	1
Surface Water Quality Degradation Due to Changes in Salinity Gradients Resulting from Withdrawals	1
Surface Water Quality Degradation Due to Chemical and Thermal Discharges	2
Groundwater Quality Degradation Due to Plant Discharges	1
Water Quality Degradation due to Inadvertent Spills and Leaks during Operation	1
Water Quality Degradation due to Groundwater Withdrawals	1
Water Use Conflict from Plant Municipal Water Demand	1
Degradation of Water Quality from Plant Effluent Discharges to Municipal Systems	1

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Environmental Issues (Cont'd)

DRAFT – PRELIMINARY TEXT	
Issue	**Category**
Terrestrial Ecology Impacts	
Construction	
Permanent and Temporary Loss, Conversion, Fragmentation, and Degradation of Habitats	1
Permanent and Temporary Loss and Degradation of Wetlands	1
Effects of Building Noise on Wildlife	1
Effects of Vehicular Collisions on Wildlife	1
Bird Collisions and Injury from Structures and Transmission Lines	1
Important Species and Habitats – Resources Regulated under the Endangered Species Act of 1973	2
Important Species and Habitats – Other Important Species and Habitats	1
Operation	
Permanent and Temporary Loss or Disturbance of Habitats	1
Effects of Operational Noise on Wildlife	1
Effects of Vehicular Collisions on Wildlife	1
Exposure of Terrestrial Organisms to Radionuclides	1
Cooling Tower Operational Impacts on Vegetation	1
Bird Collisions and Injury from Structures and Transmission Lines	1
Bird Electrocutions from Transmission Lines	1
Water Use Conflicts with Terrestrial Resources	1
Effects of Transmission Line ROW Management on Terrestrial Resources	1
Effects of Electromagnetic Fields on Flora and Fauna	1
Important Species and Habitats – Resources Regulated under the ESA of 1973	2
Important Species and Habitats – Other Important Species and Habitats	1

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Environmental Issues (Cont'd)

DRAFT – PRELIMINARY TEXT	
Issue	Category
Aquatic Ecology Impacts	
Construction	
Runoff and sedimentation from construction areas	1
Dredging and filling aquatic habitats to build intake and discharge structures	1
Building transmission lines, pipelines, and access roads across surface water bodies	1
Important Species and Habitats – Resources Regulated under the ESA and Magnuson-Stevens Fishery Conservation and Management Act	2
Important species and habitats – Other Important Species and Habitats	1
Operation	
Stormwater runoff	1
Exposure of aquatic organisms to radionuclides	1
Effects of refurbishment on aquatic biota	1
Effects of maintenance dredging on aquatic biota	1
Impacts of transmission line ROW management on aquatic resources	1
Impingement and entrainment of aquatic organisms	1
Thermal impacts on aquatic biota	2
Other effects of cooling-water discharges on aquatic biota	2
Water use conflicts with aquatic resources	1
Important Species and Habitats – Resources Regulated under the ESA and Magnuson-Stevens Act	2
Important species and habitats – Other Important Species and Habitats	1

Environmental Issues (Cont'd)

DRAFT – PRELIMINARY TEXT	
Issue	**Category**
Historic and Cultural Resources Impacts	
Construction	
Construction impacts on historic and cultural resources	2
Operation	
Operation impacts on historic and cultural resources	2
Radiological Environment Impacts	
Construction	
Radiological dose to construction workers	1
Operation	
Occupational doses to workers	1
Maximally exposed individual annual doses	1
Total population annual doses	1
Nonhuman biota doses	1
Nonradiological Environment Impacts	
Construction	
Building impacts of chemical, biological, and physical nonradiological hazards	1
Building impacts of Electromagnetic Fields	N/A
Operation	
Operation impacts of chemical, biological, and physical nonradiological hazards	1
Operation impacts of Electromagnetic Fields	N/A
Noise Impacts	
Construction	
Construction-related noise	1
Operation	
Operation-related noise	1

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Environmental Issues (Cont'd)

DRAFT – PRELIMINARY TEXT	
Issue	**Category**
Radiological Waste Management Impacts	
Operation	
Low-level radioactive waste	1
Onsite spent nuclear fuel management	1
Mixed waste	1
Nonradiological Waste Management Impacts	
Construction	
Construction nonradiological waste	1
Operation	
Operation nonradiological waste	1
Postulated Accidents Impacts	
Operation	
Design Basis Accidents Involving Radiological Releases	1
Accidents Involving Releases of Hazardous Chemicals	1
Severe Accidents	2
Severe Accident Mitigation Design Alternatives	1
Acts of Terrorism	1
Socioeconomics Impacts	
Construction	
Community Services and Infrastructure	1
Transportation Systems and Traffic	1
Economic Impacts	1
Tax Revenue Impacts	1
Operation	
Community Services and Infrastructure	1
Transportation Systems and Traffic	1
Economic Impacts	1
Tax Revenue Impacts	1

Environmental Issues (Cont'd)

DRAFT – PRELIMINARY TEXT	
Issue	**Category**
Environmental Justice Impacts	
Construction	
Construction Environmental Justice Impacts	2
Operation	
Operation Environmental Justice Impacts	2
Fuel Cycle Impacts	
Operation	
Uranium Recovery	1
Uranium Conversion	1
Enrichment	1
Fuel Fabrication[a]	1
Reprocessing	1
Storage and Disposal of Radiological Wastes	1
Transportation of Fuel and Waste Impacts	
Operation	
Transportation of Unirradiated ANR Fuel	1
Transportation of Radioactive Waste from ANRs	1
Transportation of Irradiated Fuel from ANRs	1
Decommissioning Impacts	
Decommissioning	1
Issues Applying Across All Resources	
Climate Change	2
Cumulative Impacts	2
Non-Resource Related Issues	
Purpose and Need	2
Need for Power/Project	2
Site Alternatives	2
Energy Alternatives	2
System Design Alternatives	2

ROW = right-of-way.

(a) Fuel fabrication impacts for metal fuel and liquid fueled molten salt are not included in the staff's generic analysis

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Annual Fees for Non-Light-Water Reactors

July 15, 2021

Annual Fee Alternatives for Non-LWRs including Micro-reactors

- The Alternatives described herein were developed at the NRC staff level participating in a multi-discipline work group with stakeholder input obtained through public meetings

- The Alternatives have not been presented to the Commission for review, comment, or decision

Annual Fee Alternatives for Non-LWRs including Micro-reactors

- **Alternative 1:**
  - Change the SMR definition to include non-LWRs
  - Micro reactors pay the minimum SMR fee if the bundled units have a total licensed thermal power rating ≤ 250 MWt
  - The bundled units concept would apply

- **Alternative 2:**
  - Change the SMR definition to include non-LWRs
  - Include a separate minimum fee in the SMR variable fee structure for power reactors ≤ 20 MWt
  - The bundled units concept would apply

Annual Fee Alternatives for Non-LWRs including Micro-reactors

- **Alternative 3:**
  - Change the SMR definition to include non-LWRs and to exclude power reactors ≤ 20 MWt
  - Add definition of micro-reactors ≤ 20 MWt for the purpose of annual fees
  - Include a set fee for power reactors ≤ 20 MWt
  - The bundled units concept would not apply to power reactors ≤ 20 MWt

- **Alternative 4:**
  - Change the SMR definition to include non-LWRs
  - Include a separate minimum fee in the SMR variable fee structure for power reactors ≤ 20 MWt
  - Apply a revised variable fee formula to the >20 MWt ≤250 MWt thermal power level
  - The bundled units concept would apply

Annual Fee Alternative 1

Bundled Unit Thermal Power Rating	Minimum Fee *	Variable Fee *	Maximum Fee *
First Bundled Unit - cumulative MWt			
0 MWt ≤ 250 MWt	$158.5K (a)	N/A	N/A
>250 MWt ≤ 2,000 MWt	$158.5K (a)	Variable Rate 2 (c)	N/A
>2,000 MWt ≤ 4,500 MWt	N/A	N/A	$4,986K (b)
Additional Bundled Units – cumulative MWt (above the first bundled unit of 4,500 MWt)			
0 MWt ≤ 2,000 MWt	N/A	Variable Rate 3 (d)	N/A
>2,000 MWt ≤ 4,500 MWt	N/A	N/A	$4,986K (b)

* FY 2021 Final Annual Fees used as an Illustration.

>>> Expands the SMR variable annual fee rule, which was first published in 2016; the bundled units concept applies.

a) *Micro Reactors Maximum Fee*: Equals the average of the annual fees for Spent Fuel Storage/Reactor Decommissioning (SFS/RD) and Non-Power Production or Utilization Facilities (NPUFs)
b) *OR Maximum Fee*: Equals the annual fee paid by the Operating Power Reactor Fee Class
c) *Variable Rate 2*: Equals [(OR Max Fee - Micro Reactors Max Fee) /1,750] x the difference between 250 MWt for the first bundled unit(s) and the actual cumulative MWt rating up to 2,000 MWt
d) *Variable Rate 3*: Equals [(OR Max Fee - Micro Reactors Max Fee) /2,000] x the difference between 4,500 MWt for the first bundled unit(s) and the total actual cumulative MWt rating up to 2,000 MWt

Annual Fee Alternative 2

Bundled Unit Thermal Power Rating	Minimum Fee *	Variable Fee *	Maximum Fee *
First Bundled Unit - cumulative MWt			
0 MWt ≤ 20 MWt	$80K (a)	N/A	N/A
>20 MWt ≤ 250 MWt	$158.5K (b)	N/A	N/A
>250 MWt ≤ 2,000 MWt	$158.5K (b)	Variable Rate 2 (d)	N/A
>2,000 MWt ≤ 4,500 MWt	N/A	N/A	$4,986K (c)
Additional Bundled Units – cumulative MWt (above the first bundled unit of 4,500 MWt)			
0 MWt ≤ 2,000 MWt	N/A	Variable Rate 3 (e)	N/A
>2,000 MWt ≤ 4,500 MWt	N/A	N/A	$4,986K (c)

* FY 2021 Final Annual Fees used as an Illustration

>>> Adds a Thermal Power Level and fee for 0 MWt ≤20 MWt; the bundled units concept applies.

a) *Micro Reactors Minimum Fee*: Equals annual fee paid by NPUF Fee Class
b) *Micro Reactors Maximum Fee*: Equals the average of the annual fees for Spent Fuel Storage/Reactor Decommissioning (SFS/RD) and Non-Power Production or Utilization Facilities (NPUFs)
c) *OR Maximum Fee*: Equals the annual fee paid by the Operating Power Reactor Fee Class
d) *Variable Rate 2*: Equals [(OR Max Fee - Micro Reactors Max Fee) /1,750] x the difference between 250 MWt for the first bundled unit(s) and the actual cumulative MWt rating up to 2,000 MWt
e) *Variable Rate 3*: Equals [(OR Max Fee - Micro Reactors Max Fee) /2,000] x the difference between 4,500 MWt for the first bundled unit(s) and the total actual cumulative MWt rating up to 2,000 MWt

Annual Fee Alternative 3

- Define micro-reactors, for the purpose of annual fees, as power reactors with thermal power ratings of less than or equal to 20 MWt
- Modify the SMR variable fee structure to be technology inclusive and to begin with **> 20 MWt ≤ 250 MWt**
- Under this alternative, the bundled unit concept applied to small modular reactors would not be applied to micro-reactors

Thermal Power Rating for Each Unit	Fee for Each Unit *
0 MWt ≤ 20 MWt	$ 80K (a)

* FY 2021 Final Annual Fees Used as an Illustration

(a) Equals the annual fee paid by the NPUF Fee Class.

Annual Fee Alternative 4

Bundled Unit Thermal Power Rating	Minimum Fee *	Variable Fee *	Maximum Fee *
First Bundled Unit - cumulative MWt			
0 MWt ≤ 20 MWt	$80K (a)	N/A	N/A
>20 MWt ≤ 250 MWt	$80K (a)	Variable Rate 1 (d)	N/A
>250 MWt ≤ 2,000 MWt	$158.5K (b)	Variable Rate 2 (e)	N/A
>2,000 MWt ≤ 4,500 MWt	N/A	N/A	$4,986K (c)
Additional Bundled Units – cumulative MWt (above the first bundled unit of 4,500 MWt)			
0 MWt ≤ 2,000 MWt	N/A	Variable Rate 3 (f)	N/A
>2,000 MWt ≤ 4,500 MWt	N/A	N/A	$4,986K (c)

* FY 2021 Final Annual Fees used as an Illustration

>>> Adds a variable rate for the >20 MWt ≤250 MWt level; the bundled units concept applies.

a) *Micro Reactors Minimum Fee*: Equals annual fee paid by NPUF Fee Class
b) *Micro Reactors Maximum Fee*: Equals the average of the annual fees for Spent Fuel Storage/Reactor Decommissioning (SFS/RD) and Non-Power Production or Utilization Facilities (NPUFs)
c) *OR Maximum Fee*: Equals the annual fee paid by the Operating Power Reactor Fee Class
d) *Variable Rate 1*: Equals [(Micro Reactors Max Fee – Micro Reactors Min Fee) /230] x the difference between 20 MWt for the first bundled unit(s) and the actual cumulative MWt rating up to 250 MWt
e) *Variable Rate 2*: Equals [(OR Max Fee - Micro Reactors Max Fee) /1,750] x the difference between 250 MWt for the first bundled unit(s) and the actual cumulative MWt rating up to 2,000 MWt
f) *Variable Rate 3*: Equals [(OR Max Fee – Micro Reactors Max Fee) /2,000] x the difference between 4,500 MWt for the first bundled unit(s) and the total actual cumulative MWt rating up to 2,000 MWt

Next Steps

- Staff will consider any additional feedback received today and will proceed with next steps

- Staff will present alternatives to management

- Based upon the anticipated schedule for new facilities, the staff is considering proposing the policy to the Commission for FY 2023

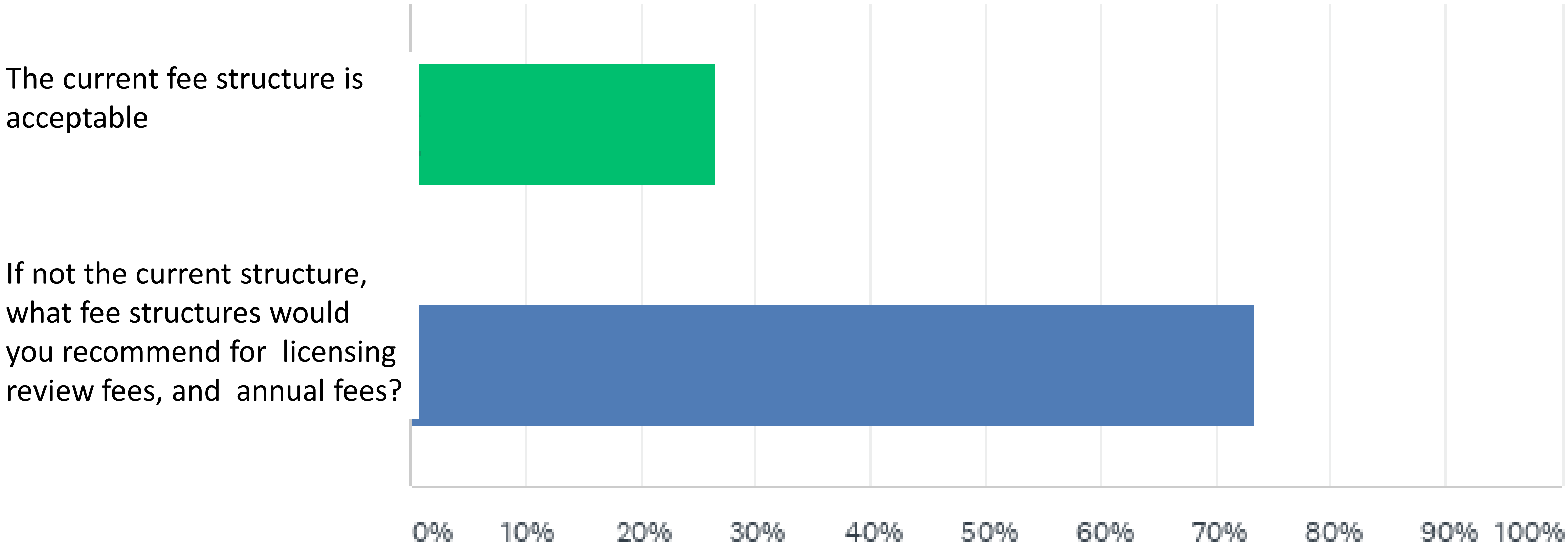
Input on Annual Fees
U.S. Nuclear Industry Council

Cyril W. Draffin, Jr.
Senior Fellow, Advanced Nuclear
U.S. Nuclear Industry Council

15 July 2021

USNIC 2021 Survey question: What is an appropriate Nuclear Regulatory Commission fee?

(for the current regulatory framework and desired future regulatory framework)



United States NIC Nuclear Industry Council

Input on Annual Fees

Annual Fee Comments from 2021 USNIC Advanced Nuclear Survey

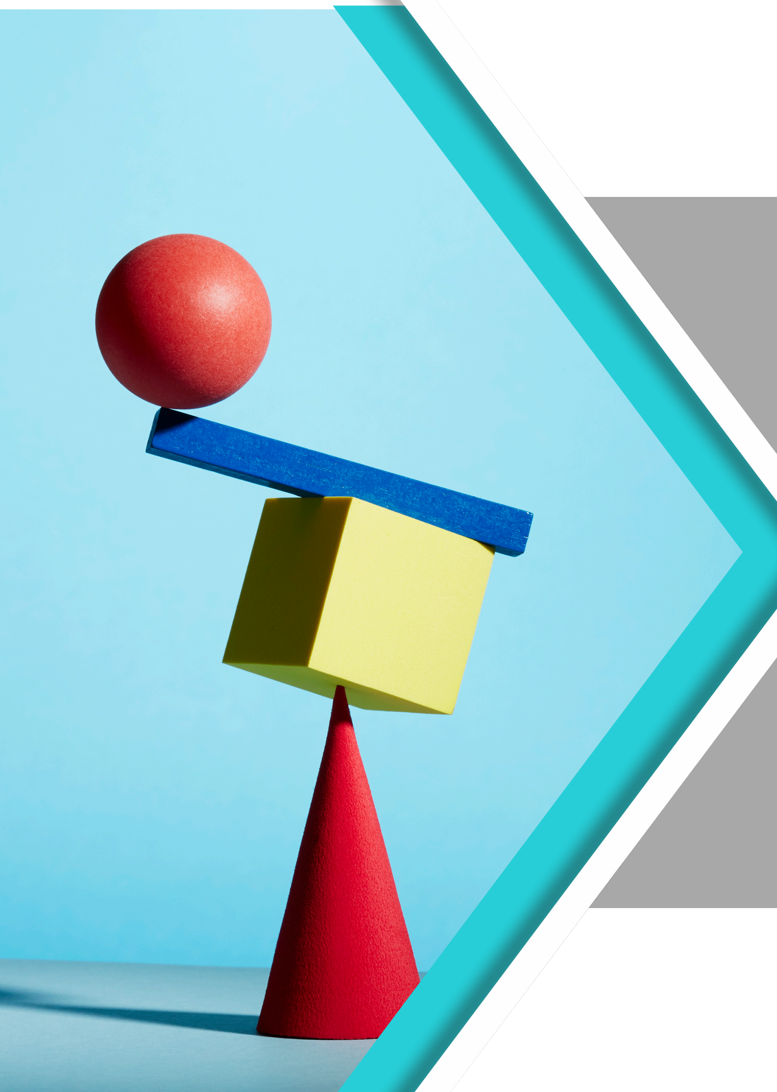
- Under the current structure, microreactor annual fees should be no greater than those applied to research and test reactors
- Fee should be scaled to power level and plant safety profile
- Annual fees should be revisited for whether they are truly necessary. Recent reports suggested alternative fee structures be looked at for applicability, including EPA, FDA, and FAA. These structures recognize the public benefit incurred as a result of the associated reviews, and therefore set the expectation that public share in regulatory costs associated with such activities.
- Legislation should be pursued to recognize the zero carbon societal benefit of nuclear and to make cost recovery commensurate or favorable when compared to carbon producing technologies. Without legislative action, annual fees should reflect the level of staff effort as this is a zero sum game and no licensee should be disproportionately burdened by other licensees.
- Getting a non-LWR fee expectation in place is important to developers ability to effectively make cost estimates and communicate what the on-going costs of a prospective plant are. Some have been using the Light water SMR calculations as a guide, but that’s not going to provide the same confidence as clear rule language.

Input on Annual Fees

<u>From USNIC member made at 15 April 2021 Stakeholders Meeting</u>

- Current annual fee structure with thresholds and tiers is overcomplicated
- Customers care about levelized cost of electricity
- Suggest 0-4500 MW thermal sliding scale
  - Rather electric power because some Advanced Reactor deployments could be for process heat
  - No tiers; avoids discontinuity that penalizes reactors just larger then the threshold (e.g. 300 MW)
  - Fully sliding scale would be predictable and equitable per reactor for every unit
  - Recognize it would be a substantial change that would impact all power reactors; some winners and losers so would need operating fleet stakeholder input

United States NIC Nuclear Industry Council



Advanced Reactors

Overview of ARCAP Roadmap ISG and TICAP DG White Papers

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

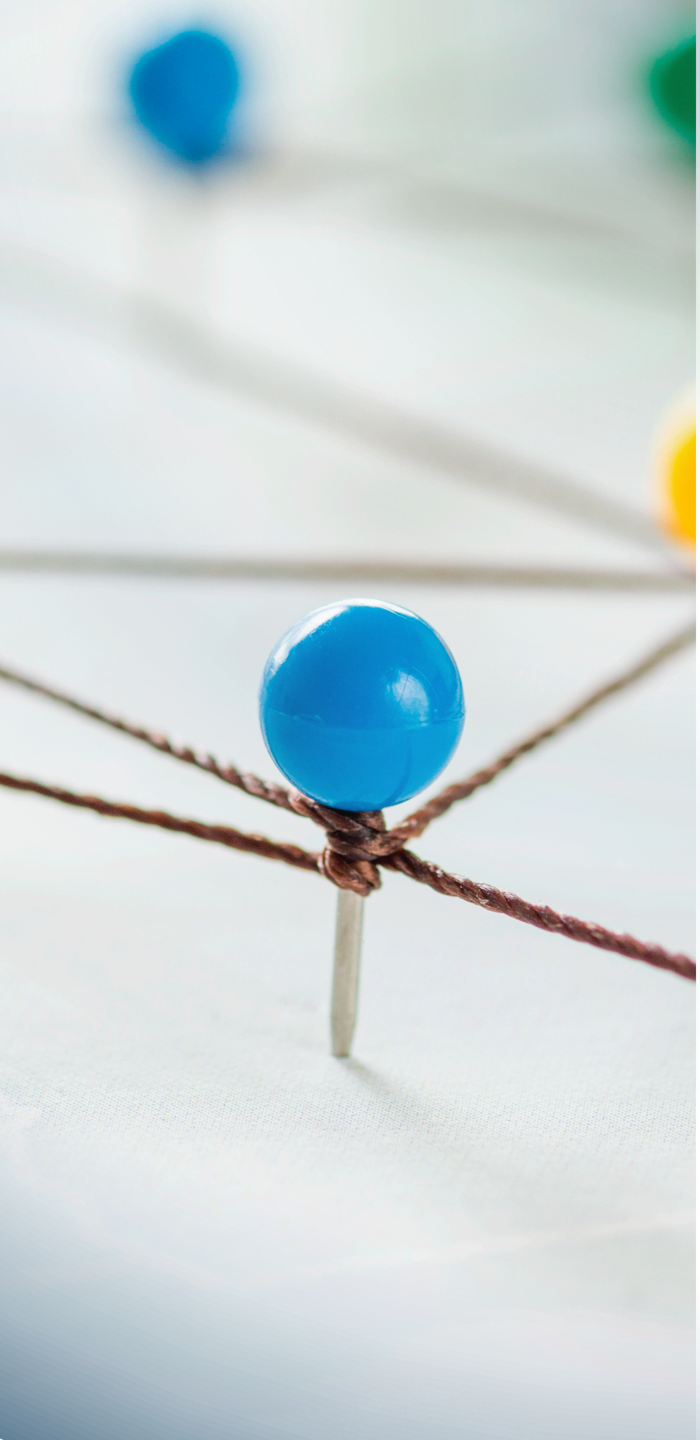
Advanced Reactor Content of Application (ARCAP)

To ensure review readiness to regulate a new generation of advanced reactors, a key element of a flexible regulatory framework is to provide guidance for the development of content of an advanced reactor application.

- Ensures consistency of staff reviews,
- Presents a well-defined base for scope and requirements of reviews.

- Makes information about regulatory matters widely available,
- Improves communication and understanding of the staff review process by interested members of the public and the nuclear power industry.

- Apply lessons learned from LWR application reviews,
- Technology Inclusive,
- Risk-Informed Performance-Based.



ARCAP
Background

Purpose
Provides a roadmap for developing a tech-inclusive, risk-informed application. Leverages existing guidance or guidance that is under development.

Broad
Encompasses industry-led technology-inclusive content of application project (TICAP).

Need for Additional Guidance
Roadmap also identifies areas where additional guidance is needed (i.e.: Technical Specifications).

Regulatory Applicability (As applicable)
10 CFR Parts 50, 52, and informs 53.

Streamlined Review Process
ARCAP guidance document not intended to replicate NUREG-0800, "Standard Review Plan for LWRs."

Previous Discussions
ARCAP overview discussed at August 2020, October 2020, and February 2021 public meetings.

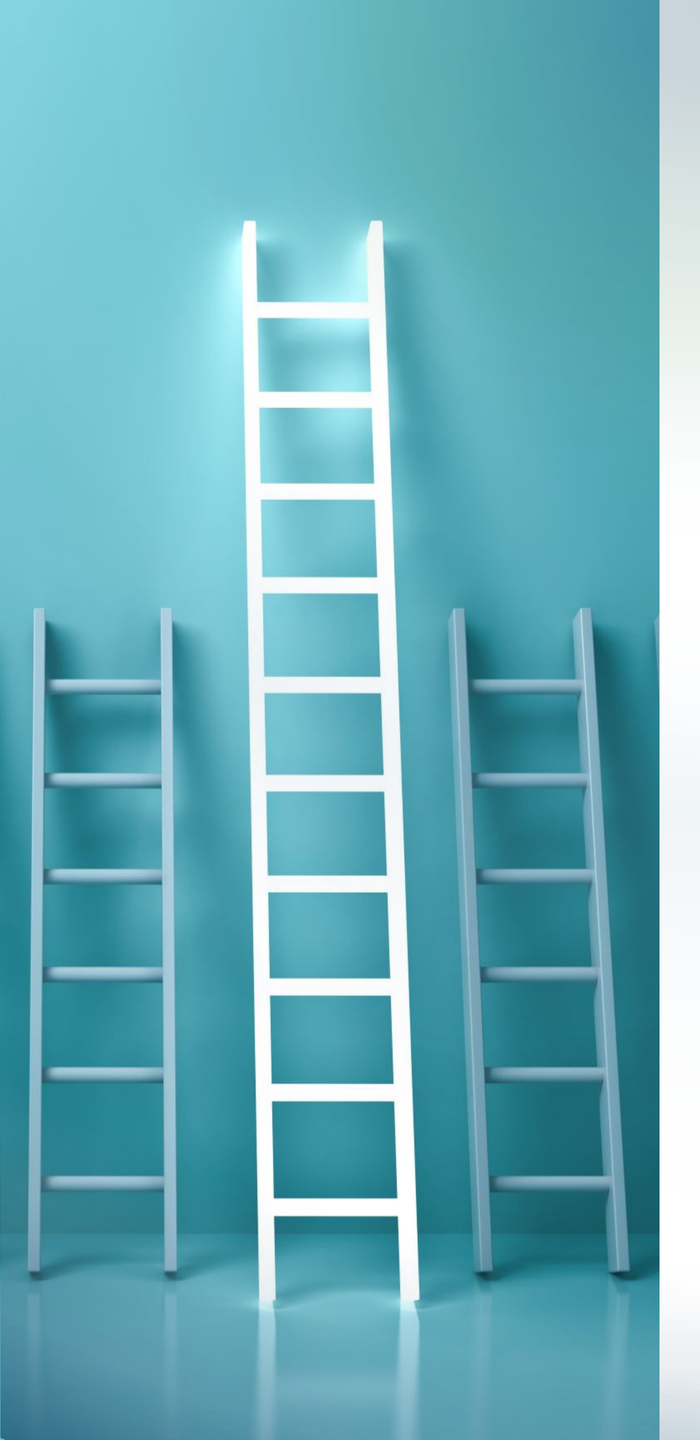
ARCAP Roadmap ISG – **Outline**

Identifies all Adv. Rx application topics.

Provides background and overview of expected information for each topic.

Provides endorsements, clarifications, supplements info, or points of emphasis.

Provides pointers to key guidance in support of application topic.



TICAP
Background

Purpose

- TICAP is industry-led guidance focused on describing the scope and level of detail for portions of an application consistent with the LMP.
- LMP is described in NEI18-04, as endorsed by RG 1.233.
- Industry-led TICAP guidance only applicable to portions of first 8 SAR chapters.
- Aims to minimize burden of generating and supplying non-safety significant information.

Regulatory Applicability (As applicable)
10 CFR Parts 50, 52, and informs 53.

Methodology
Scope is governed by the LMP-based safety case. LMP process is one approach to select licensing basis events, develop SSC categorization and ensures defense-in-depth is considered.

TICAP draft DG– **Outline**

Endorses LMP-based NEI 21-xx TICAP document.

Provides additional clarifications, exceptions, points of emphasis from information described in NEI 21-xx.

Provides further information needed outside of LMP-based affirmative safety case for first 8 chapters.

Includes appendices to key guidance in support of FSAR development for first 8 chapters.

ARCAP and TICAP – **Nexus**

<u>Outline Safety Analysis Report (SAR) – Based on TICAP Guidance</u>

1. General Plant Information, Site Description, and Overview of the Safety Case
2. Methodologies and Analyses
3. Licensing Basis Events (LBEs)
4. Integrated Evaluations
5. Safety Functions, Design Criteria, and SSC Categorization
6. Safety Related SSC Criteria and Capabilities
7. Non-safety related with special treatment SSC Criteria and Capabilities
8. Plant Programs

Additional SAR Content –Outside the Scope of TICAP

9. Routine Plant Radioactive Effluents, Plant Contamination, and Solid Waste
10. Control of Occupational Doses
11. Organization
12. Initial Startup Programs

Audit/inspection of Applicant Records

- Calculations
- Analyses
- P&IDs
- System Descriptions
- Design Drawings
- Design Specs
- Procurement Specs

<u>Additional Portions of Application</u>

- Technical Specifications
- Technical Requirements Manual
- Quality Assurance Plan (design)
- Fire Protection Program (design)
- PRA
- Quality Assurance Plan (construction and operations)
- Emergency Plan
- Physical Security Plan
- SNM physical protection program
- SNM material control and accounting plan
- Cyber Security Plan
- Fire Protection Program (operational)
- Radiation Protection Program
- Offsite Dose Calculation Manual
- Inservice inspection/Inservice testing (ISI/IST) Program
- Environmental Report
- Site Redress Plan
- Exemptions, Departures, and Variances
- Facility Safety Program (under consideration for Part 53 applications)

- Safety Analysis Report (SAR) structure based on clean sheet approach

*Additional contents of application outside of SAR are still under discussion. The above list is draft and for illustration purposes only.

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NRC ARCAP/TICAP Guidance

Other Insights

1. **Efficiency**
NRC ARCAP/TICAP guidance being developed in parallel to industry,

2. **Openness**
Main purpose of releasing draft documents is to solicit stakeholder feedback on proposal,

3. **Initial Thoughts**
The guidance structure, not detailed content, is the focus of stakeholder interactions,

4. **Adaptable**
ARCAP guidance includes placeholders for guidance under development (e.g., Applicability of Regs),

5. **Endorsement**
NRC TICAP white paper endorses, as appropriate, industry's TICAP document,

6. **Supplements**
NRC TICAP white paper supplements, as appropriate, information not addressed in industry's TICAP document (i.e.: Fuel Qual and ASME Sec III, Div 5).

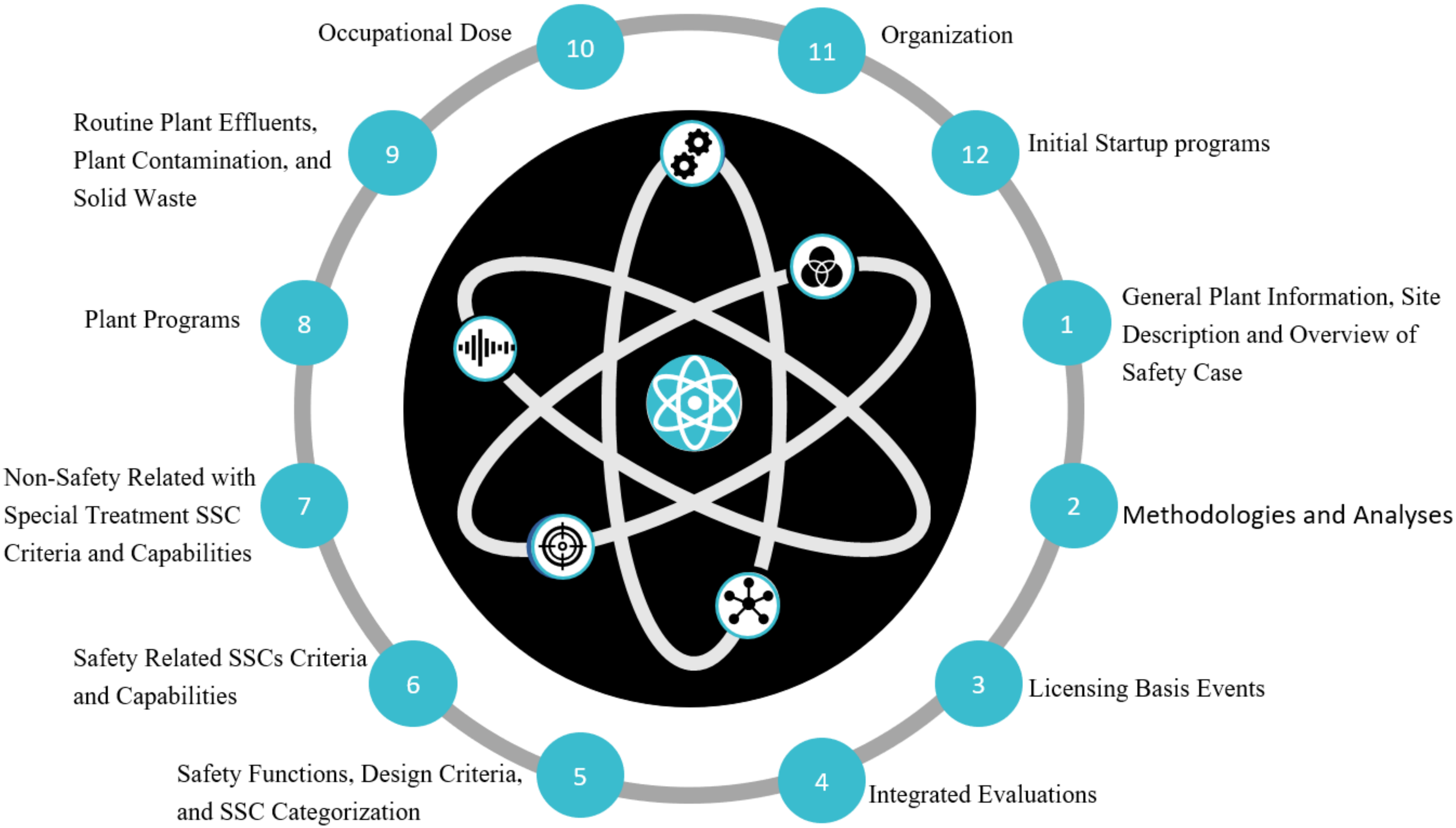
ARCAP Roadmap ISG – **Example 1**

- FSAR structure developed as a result of extensive stakeholder engagement.
- Consists of 12 main chapters.
- Provides the most safety-significant information at the forefront (ASC).
- Focus on the most relevant safety information while removing unnecessary details.
- Additional information/background is available for audit/inspection by NRC.

Contents of an Advanced Reactor Application*

- Safety Analysis Report
- Technical Specifications
- Technical Requirements Manual
- Quality Assurance Plan (Design, Construction, and Operation)
- Fire Protection Program (Design and Operation)
- Probabilistic Risk Assessment
- Environmental Report/Redress Plan
- Emergency Plan
- Physical Security Plan
- Radiation Protection Program
- Offsite Dose Calculation Manual
- Special Nuclear MC&A
- ITAAC
- Cyber Security Plan
- ISI/IST
- Financial Qualification/Liability
- Facility Safety Program

*Contents of application are still under discussion. List represents a draft outline



Note: SAR Chapters 1-8 addressed by TICAP. SAR Chapters 9-12 addressed by ARCAP.

Ch. 1- General Plant Information, site description, and overview of safety case (TICAP)

Information should provide an understanding of the overall facility (type of application, the number of plant units, a brief description of the proposed plant location, and the type of advanced reactor being proposed). The site description should provide an overview of the actual physical, environmental and demographic features of a site, and how they relate to the affirmative safety case.

Clarifies	Endorses	Key Guidance	Supplements
• Roadmap clarifies that guidance applicable to chapter 1 is described in NEI 21-xx – TICAP document.	• RG 1.2xx "Guidance For A Technology-inclusive Content Of Application Methodology To Inform The Licensing Basis And Content Of Applications For Licenses, Certifications, And Approvals For Advanced Reactors."	• Chapter 1 of NEI 21-xx (TICAP) as one acceptable method.	• Construction Permit Information in NEI 21-xx by including Appendix A for info outside LMP for first 8 chapters.*

Note: CP information for all other portions of the application are described in Appendix E of the ARCAP roadmap ISG)

Ch. 2- Methodologies and Analyses (TICAP)

Certain analyses are common to several licensing-basis event analyses. Information should describe the process and methods used to develop baseline information related to the probabilistic risk assessment (overview of the PRA), source-term analysis, and design-basis accidents (DBAs) analytical methods.

Clarifies

- Roadmap clarifies that guidance applicable to chapter 2 is described in NEI 21-xx – TICAP document.

Endorses

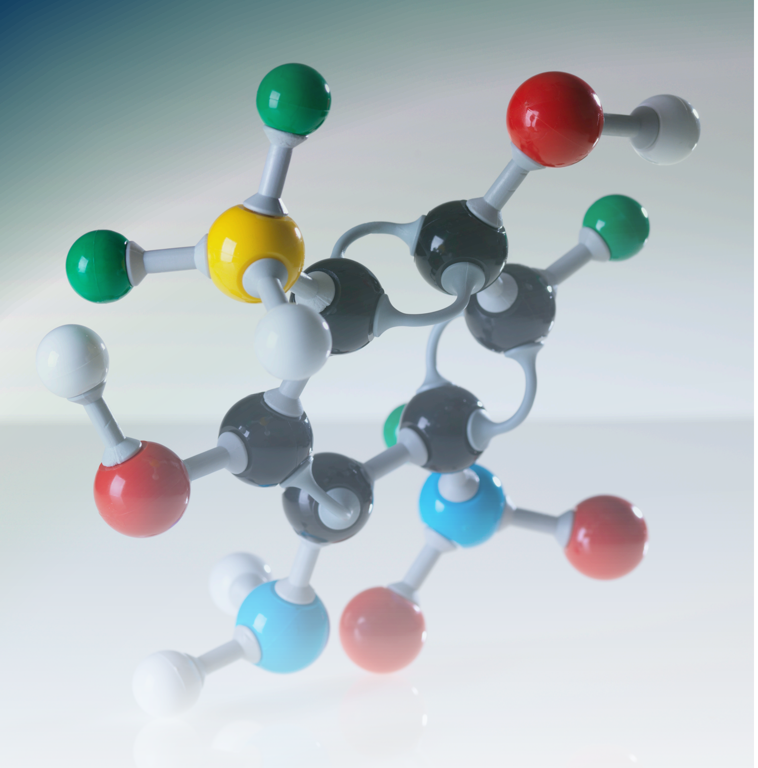
- RG 1.2xx "Guidance For A Technology-inclusive Content Of Application Methodology To Inform The Licensing Basis And Content Of Applications For Licenses, Certifications, And Approvals For Advanced Reactors."

Key Guidance

- Chapter 2 of NEI 21-xx (TICAP) as one acceptable method.

Supplements

- "Site Information" draft ISG previously released.
- Staff positions on additional considerations to document information.



Ch. 10 – Control of Occupational Dose

Information should include facility and equipment design, radiation sources, and operational programs that are necessary to ensure that the occupational radiation protection standards set forth in 10 CFR Part 20 are met. The information should also include any commitments made by the applicant to develop the management policy and organizational structure necessary to ensure occupational radiation exposures are as low as (is) reasonably achievable (ALARA).

Clarifies	Endorses	Key Guidance	Supplements
• Guidance is included for chapters 9-12.	• DANU-ISG-2021-XX, "Control of Occupational Dose." • Released on prior ARCAP/TICAP public meeting.	• RG 8.8 • RG 8.10 • ANSI/ANS 18.1-1999 • NEI 07-08A • Draft list released in prior public meeting. Expected to evolve. (MLxyz123).	

ARCAP Roadmap ISG – **Example 2**

- Ongoing "Emergency Preparedness Requirements for Small Modular Reactors and Other New Technologies" rulemaking.

- Rule would amend the NRC's regulations to add new emergency preparedness requirements for small modular reactors, non-light-water reactors and non-power production or utilization facilities.

- Rule would adopt a scalable plume exposure pathway emergency planning zone approach that is performance-based, consequence-oriented, and technology-inclusive.

Contents of an Advanced Reactor Application*

- Safety Analysis Report
- Technical Specifications
- Technical Requirements Manual
- Quality Assurance Plan (Design, Construction, and Operation)
- Fire Protection Program (Design and Operation)
- Probabilistic Risk Assessment
- Environmental Report/Redress Plan
- Emergency Plan
- Physical Security Plan
- Radiation Protection Program
- Offsite Dose Calculation Manual
- Special Nuclear MC&A
- ITAAC
- Cyber Security Plan
- ISI/IST
- Financial Qualification/Liability
- Facility Safety Program

*Contents of application are still under discussion. List represents a draft outline

Emergency Preparedness Plan

This rulemaking would develop a dose-based, consequence-oriented framework for future SMR applicants and licensees with respect to offsite EP that would reduce the need for exemptions related to regulations associated with large LWRs.
- SECY-16-0069 (ML21007A330)

Clarifies	Endorses	Key Guidance	Supplements
• Ongoing rulemaking.		• DG-1357, "Emergency Response Planning and Preparedness for Nuclear Power Reactors." • SECY-18-0103	

Key Messages

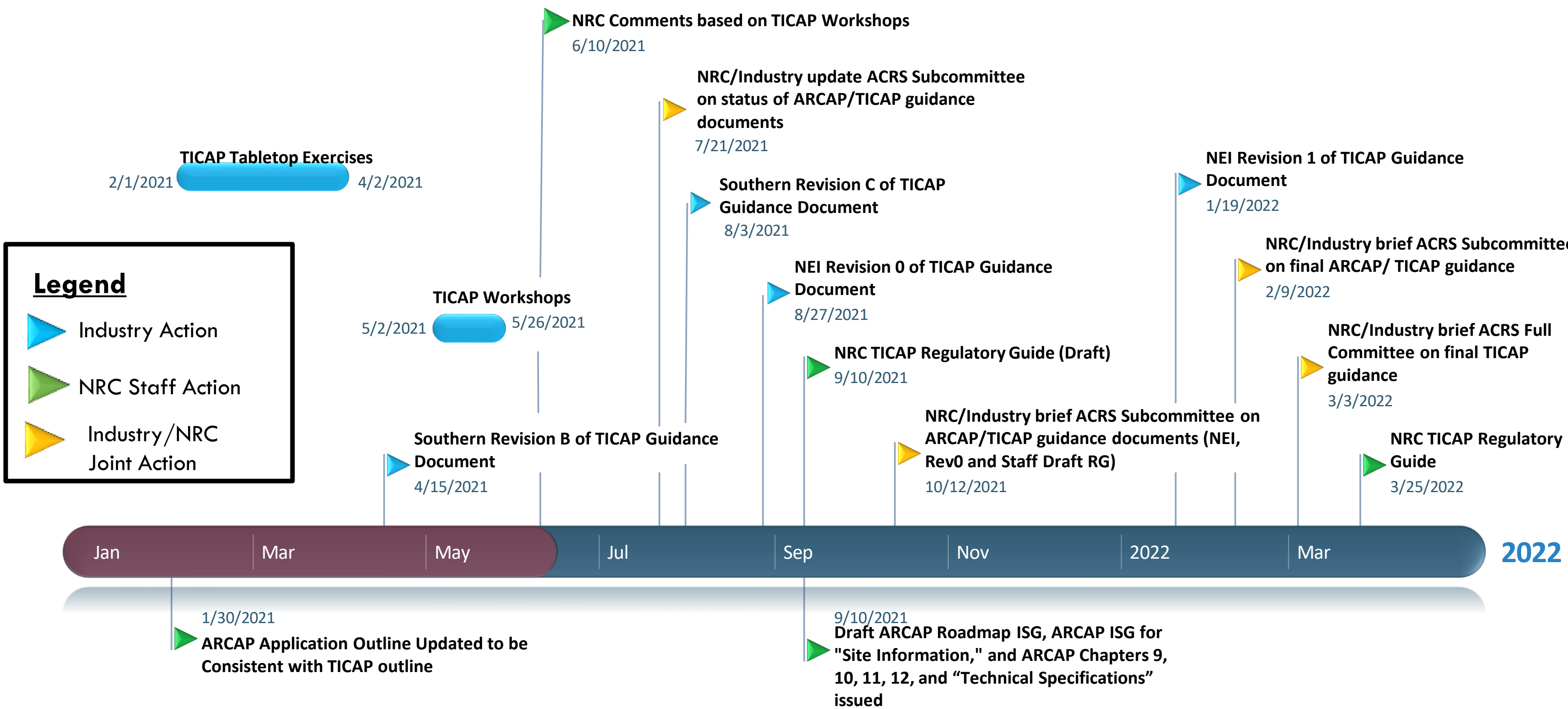
What's Next?

- TICAP draft RG, ARCAP Draft roadmap ISG, and ARCAP selected chapters (e.g., site information, technical specifications) released as white-paper to solicit stakeholder feedback. Further iterations expected.

- Draft documents provided in Table 2 of ARCAP/TICAP public webpage https://www.nrc.gov/reactors/new-reactors/advanced/details.html#advRxContentAppProj

- Some sections are primarily aligned with the Licensing Modernization Project (LMP), however:
  - the concepts and general information may be used to inform the review of an application submitted using other methodologies (as applicable) such as a maximum hypothetical accident, or deterministic approaches.

Timeline for Technology Inclusive Content of Application Project (TICAP) Guidance and Advanced Reactor Content of Application Project (ARCAP) Guidance (rev 7/13/2021)

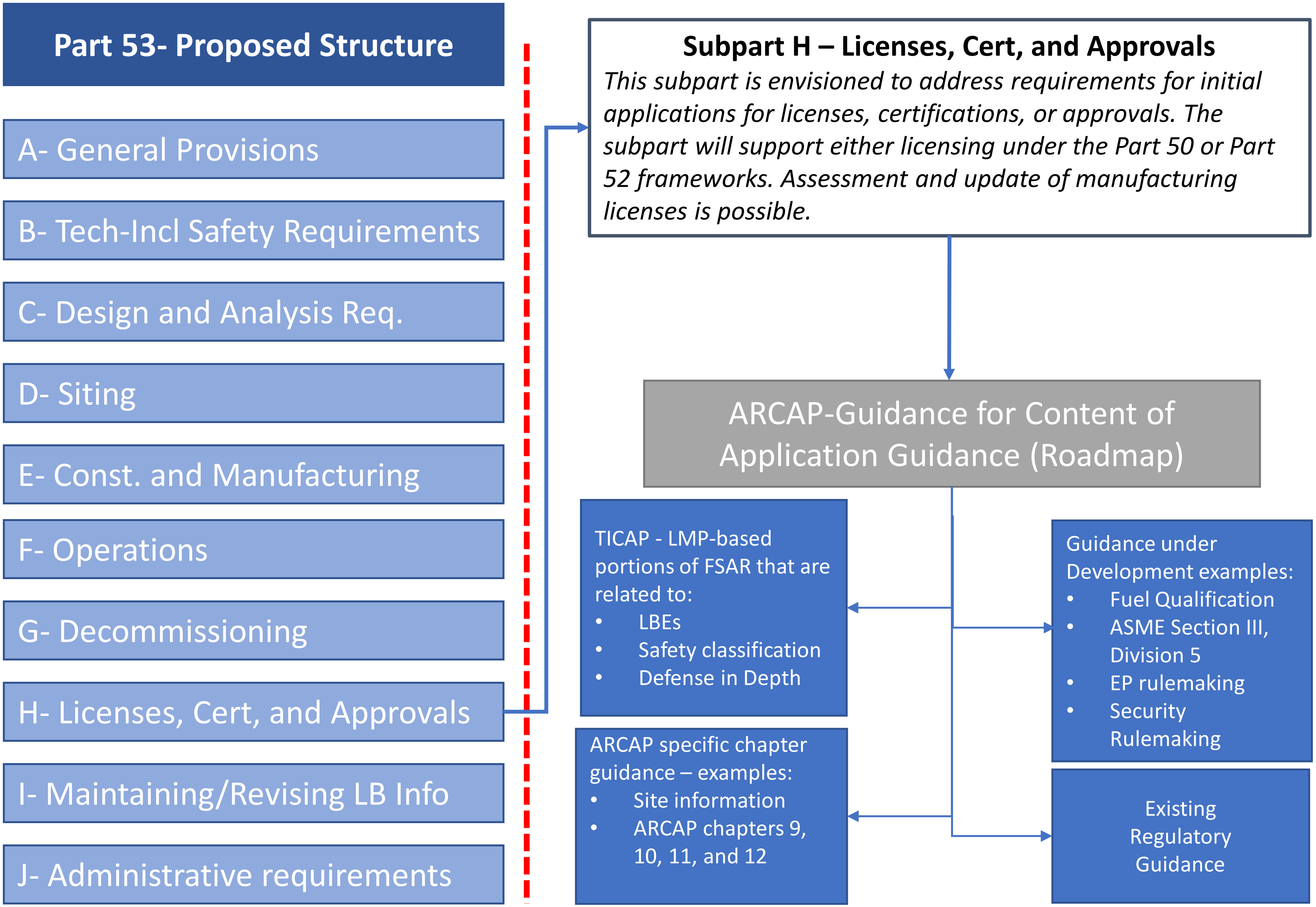


Next Steps – Future Milestones

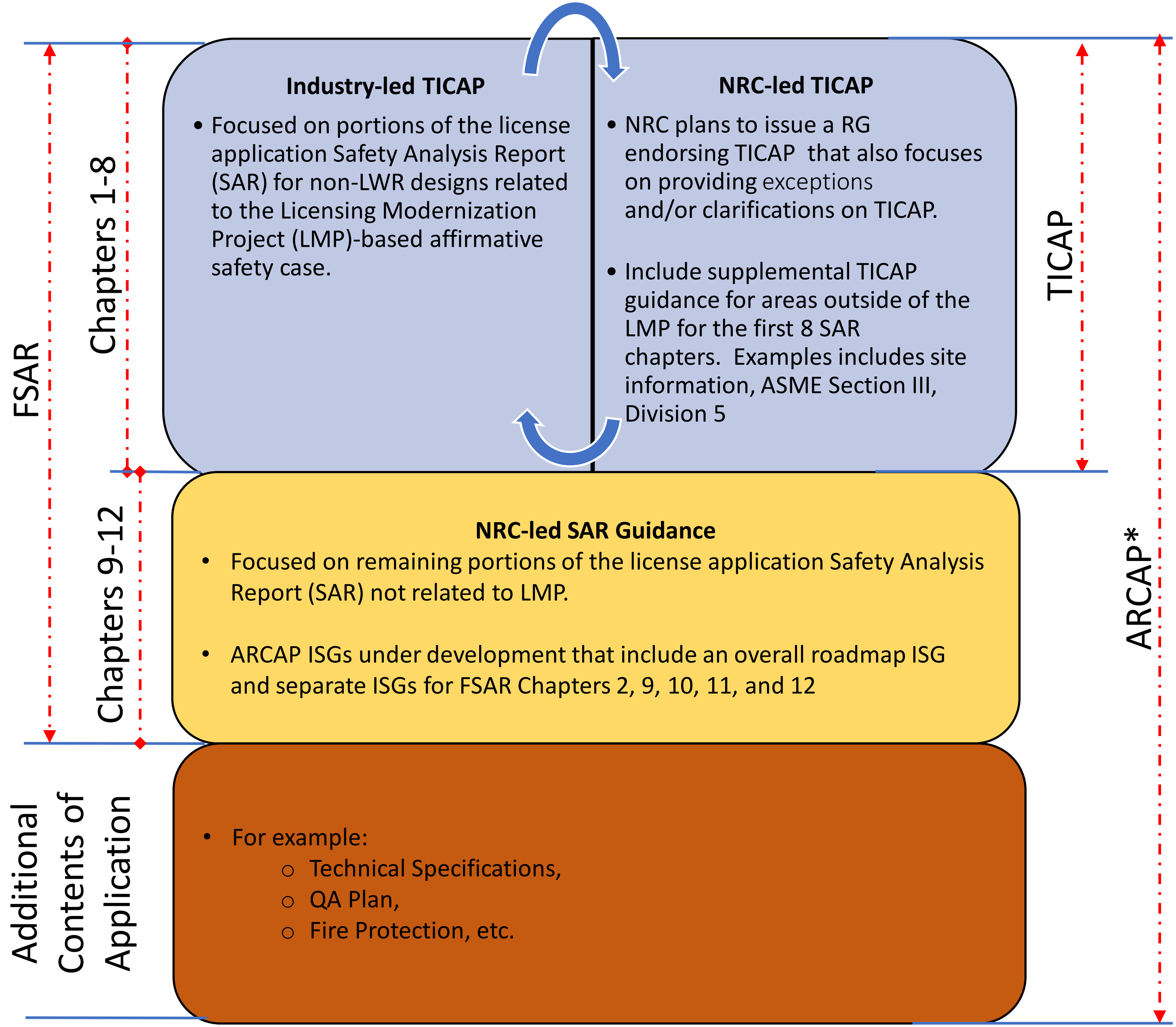
TICAP Near-Term Milestones	Target Date
Southern Revision C to TICAP Guidance Document	Early August 2021
NEI Revision 0 of TICAP Guidance Document	Late August 2021
Update of NRC Draft Guidance Documents	September 2021
ACRS Future Plant Subcommittee Meeting on ARCAP/TICAP Guidance Documents	October 2021

Backup Slides

Technology-Inclusive Content of Application (TICAP) and Advanced Reactors Content of Application (ARCAP)- Nexus to Part 53



Note: The illustrated content structure for Part 53 (including Subpart H) is part of ongoing work and subject to change.



*Staff plans to issue an ARCAP Roadmap ISG that would provide pointers to various guidance documents developed/issued.

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Key Part 53 Guidance by Subpart

Existing / Ongoing Guidance	Additional Guidance
Subpart A: General Provisions	
Existing / Ongoing Guidance	Additional Guidance
N/A	
Subpart B: Safety Criteria	
Existing / Ongoing Guidance	Additional Guidance
N/A	▪ Further explanation of criteria and structure in the Statements of Consideration
Subpart C: Design and Analysis	
Existing / Ongoing Guidance	Additional Guidance
▪ NEI 18-04 & RG 1.233 (LMP) ▪ ANS/ASME-RA-S-1.4 (Non-LWR PRA Standard) ▪ Industry PRA Peer Review Guidance for Non-LWRs (NEI 20-09) ▪ ANS/ASME Standards ▪ Fuel Qualification ▪ RG 1.232 (ARDCs)	▪ ISG on PRA for Initial Licensing ▪ RG 1.247 Endorsing Non-LWR PRA Standard and NEI Peer Review Guidance ▪ Application of Analytical Margins ▪ Treatment of Chemical Hazards
Subpart D: Siting Requirements	
Existing / Ongoing Guidance	Additional Guidance
▪ SECY-20-0045/RG 4.7 ▪ External Hazard Updates ▪ Risk-Informed Seismic Design; ANS 2.26	N/A

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Key Part 53 Guidance by Subpart

Subpart E: Construction and Manufacturing	
<u>Existing / Ongoing Guidance</u>	<u>Additional Guidance</u>
N/A	▪ Manufacturing Guidance ▪ QA Alternatives
Subpart F: Operations	
SSCs	
<u>Existing / Ongoing Guidance</u>	<u>Additional Guidance</u>
▪ NEI 18-04 & RG 1.233 (LMP)	▪ Technical Specifications ▪ Special Treatment ▪ Maintenance, Repair & Inspection ▪ Facility Safety Program
Personnel	
<u>Existing / Ongoing Guidance</u>	<u>Additional Guidance</u>
▪ DRO Paper/preliminary ISG	▪ Concept of Operations
Programs	
<u>Existing / Ongoing Guidance</u>	<u>Additional Guidance</u>
▪ EPZ Draft Final Rule, RG 1.242 ▪ Radiation Protection (ARCAP)	▪ Emergency Preparedness ▪ Security Programs ▪ Integrity Assessment Program

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Key Part 53 Guidance by Subpart

Subpart G: Decommissioning	
Existing / Ongoing Guidance	Additional Guidance
N/A	N/A
Subpart H: Licensing	
Existing / Ongoing Guidance	Additional Guidance
▪ TICAP ▪ ARCAP	▪ Manufacturing Licenses
Subpart I: Maintaining Licensing Basis	
Existing / Ongoing Guidance	Additional Guidance
N/A	▪ 50.59 Equivalent ▪ FSAR/PRA Updates
Subpart J: Administrative/Misc.	
Existing / Ongoing Guidance	Additional Guidance
N/A	▪ Reporting Requirements ▪ Financial/Liability

Break

Meeting will resume at 1pm EST

Microsoft Teams Meeting
Bridgeline: 301-576-2978
Conference ID: 446 067 450#

NRC Staff Draft White Paper - Analysis of Applicability of NRC Regulations for Non-Light Water Reactors

July 2021

Purpose

- Discuss "Updated NRC Staff Draft White Paper - Analysis of Applicability of NRC Regulations for Non-Light Water Reactors"

- Outline high level changes to the white paper since the last released version

- Describe path forward for final paper

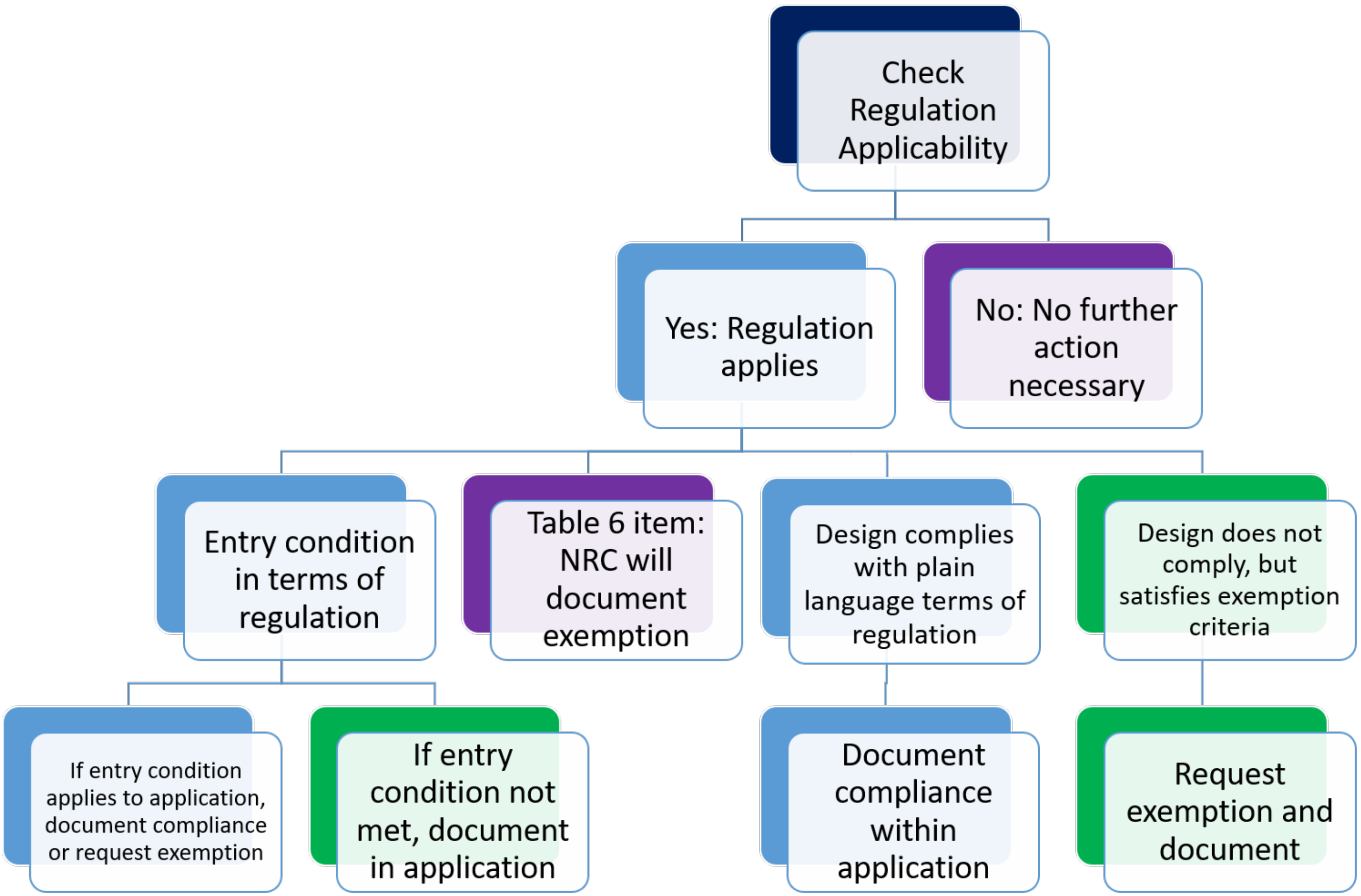
Background

- Will discuss revisions to “Updated NRC Staff Draft White Paper - Analysis of Applicability of NRC Regulations for Non-Light Water Reactors”, first issued in 9/2020

- Stakeholders provided feedback regarding the NRC draft white paper in correspondence and public meetings; NRC staff has considered the feedback and made changes to improve clarity

- Paper layout has been reworked, a flowchart has been added for additional clarity, tables have been renumbered and additional context has been added on some items

Flowchart



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New Table Flow

- Table 1: 10 CFR Part 50 Requirements, as applicable to applications under Part 50 for non-LWRs
- Table 2: Selected 10 CFR Part 52 Requirements, as applicable to non-LWR Standard Design Certifications, Combined Licenses and Standard Design Approvals applications
- Table 3: Other regulations that may apply to non-LWRs
- Table 4: Applicability of 10 CFR 50.34(f) "TMI Requirements" to non-LWRs under Part 52
- Table 5: Areas with anticipated exemptions
- Table 6: Part 52 Regulations Referencing Part 50 Regulations Limited to LWRs

- Tables contain additional footnotes clarifying various items based on feedback

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Appendix: Examples - Regulatory Compliance and Exemptions

- The revised Appendix content now contains examples (some new) related to regulatory compliance and requesting exemptions.
- Content related to the concept of compliance and specifics related to exemption request content have been moved to the main body of the white paper.
- Exemption examples are provided as a starting point; NRC staff expects that specific applications will further explore these areas. NRC encourages early engagement on these topics.

Issuance of White Paper and Final Guidance

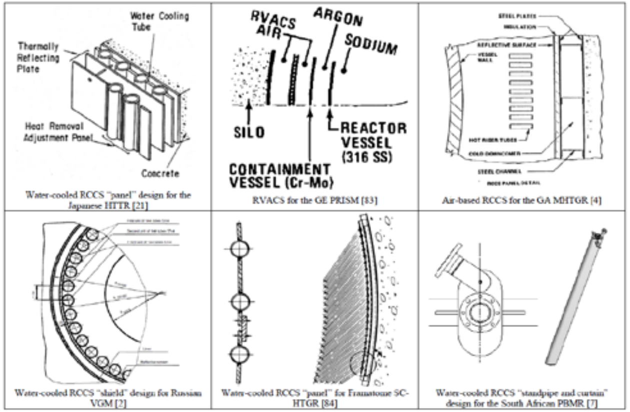
- The version issued in support of this meeting represents the final content expected as part of the staff white paper to support regulatory applicability for non-LWRs

- Plan for final issuance of the white paper content involves integrating the paper as an appendix to the planned TICAP/ARCAP interim staff guidance

Questions/Discussion

United States Nuclear Regulatory Commission
Protecting People and the Environment

AN OVERVIEW OF NON-LWR VESSEL COOLING SYSTEMS FOR PASSIVE DECAY HEAT REMOVAL



Author / Speaker: **Darius Lisowski**
Co-Authors: Qiuping Lv, Bogdan Alexandreanu, Yiren Chen, Rui Hu, and Tanju Sofu

Imtiaz Madni, NRC Senior Reactor Systems Engineer; Task Lead
Maryam Khan, NRC Project Manager; Contracting Officer's Representative
Joseph Sebrosky, NRC Senior Project Manager; Alternate Contracting Officer's Representative

NRC Periodic Advanced Reactor Stakeholder Meeting
July 15th 2021

UNITED STATES NUCLEAR REGULATORY COMMISSION

Argonne NATIONAL LABORATORY

INTRODUCTION AND OBJECTIVES

MOTIVATION

- One of the leading focus areas in the development of advanced reactor concepts is the use of passive safety systems as a primary means for decay heat removal.
- The design and use of such technologies date to the earliest high-temperature gas-cooled reactors, which were built and operated in the 1950s.
  - With the introduction of new and alternative reactor types, these systems have been adapted to meet specific operational and safety needs
- For any vessel cooling system to serve as a viable feature for safety basis reactor licensing, vendors will have to defend their ability to maintain the intended safety function throughout the operating life of the reactor

MOTIVATION, CONT'D

- To answer this question, there is a need to conduct a technical review to provide an assessment of the maturity, performance, and viability of reactor vessel cooling systems for decay heat removal in advanced non-LWR reactor concepts

- This review should focus on air- and water-based reactor vessel cooling systems, such as Reactor Vessel Auxiliary Cooling System (RVACS) and Reactor Cavity Cooling Systems (RCCS)
  - In-vessel decay heat removal such as the Direct Reactor Auxiliary Cooling System (DRACS) not included in the scope
  - Focus on future advanced, non-LWR concepts

- Ultimately, the question to be addressed is how such systems are designed to perform and how degraded conditions can impact their safety function

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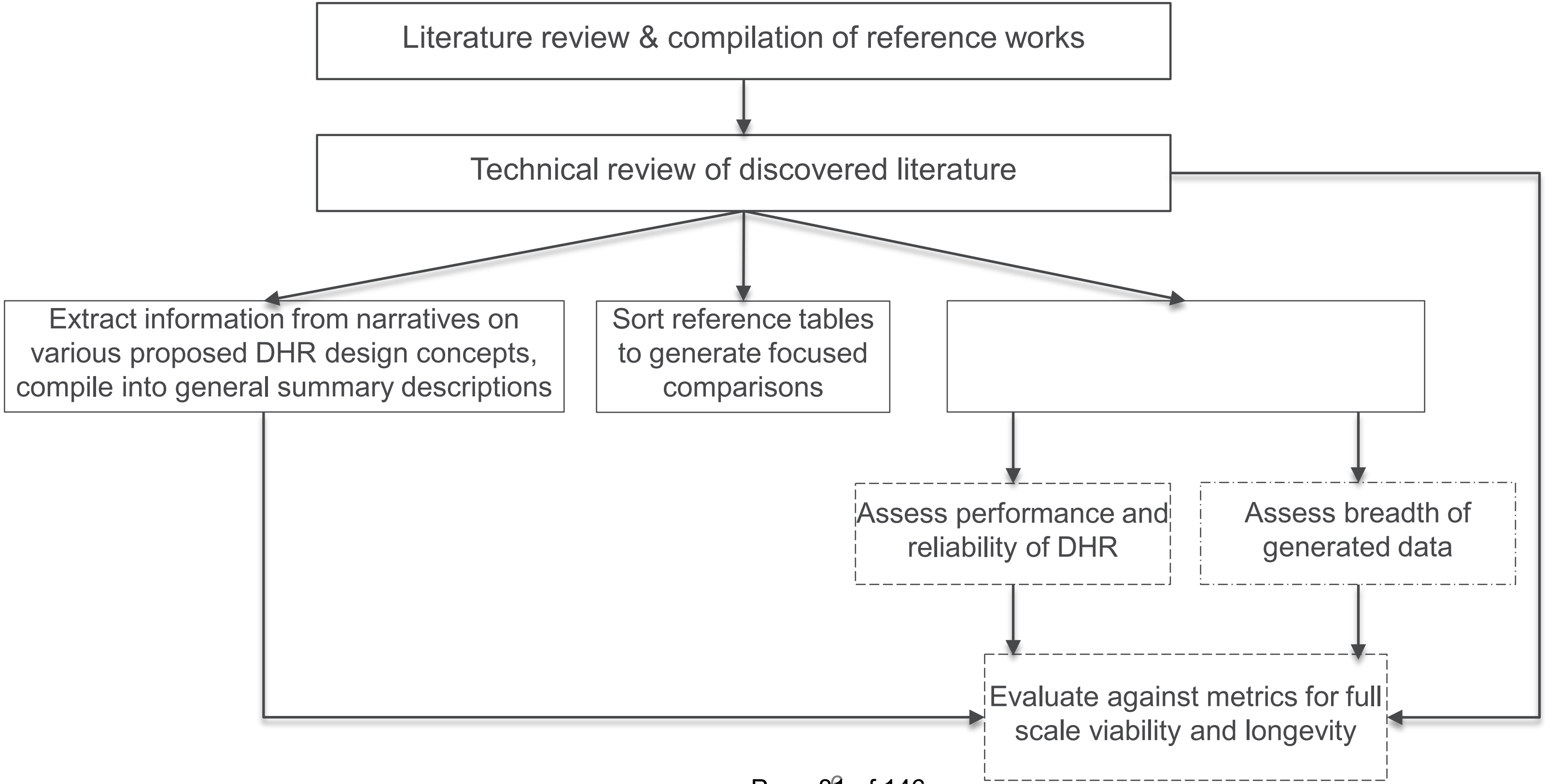
PROJECT OBJECTIVES

- Interagency agreement with the Nuclear Regulatory Commission (NRC) and Argonne National Laboratory (Argonne), performance period spanning 12-mo.

- Technical review of design concepts for vessel cooling systems
  - Summary of vessel cooling design options
  - Design history and maturity
  - Applicability to various reactor types

- Evaluation and Assessment
  - Operating characteristics during normal operation and accident conditions
  - Performance during degraded operation and impact on design function
  - Discovery of available data

APPROACH & METHODOLOGY



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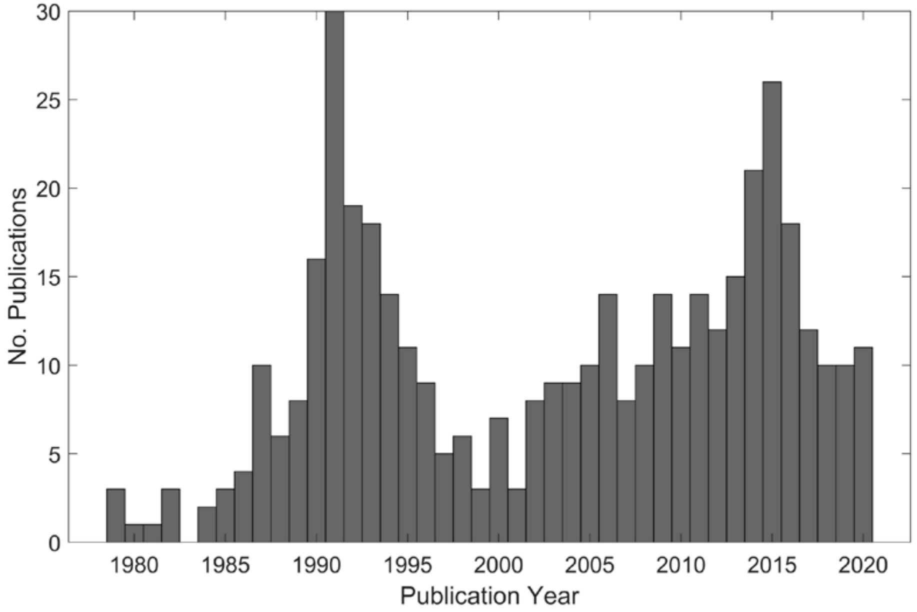
LITERATURE SEARCH

- Database was generated from openly available publications related to the design, analysis, testing, and optimization of decay heat removal systems
- Sources included:
  - OSTI
  - ResearchGate
  - ScienceDirect
  - Society conferences (ANS, etc.)
  - IAEA
  - US National Laboratory reports



- Earliest available publication dating back to 1979 and the most recent publication from ~~2020~~ 2021
- Zotero was used as database manager, allowing access and searching of ~500 collected records

zotero

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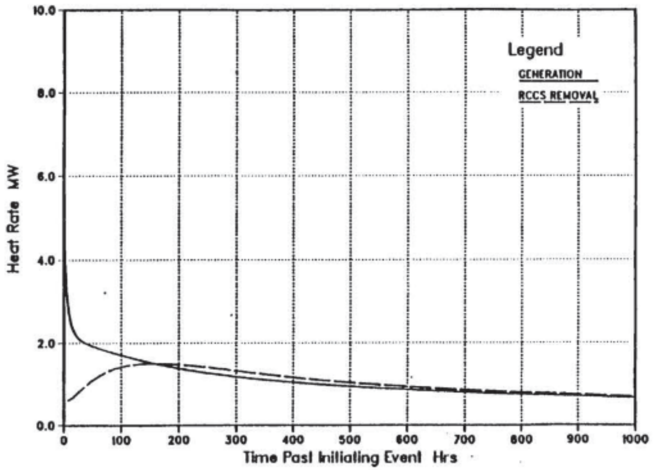
DECAY HEAT REMOVAL OVERVIEW

SAFETY GRADE DECAY HEAT REMOVAL

- Role of decay heat removal systems is to remove core afterheat in the case of failure or unavailability of primary cooling systems
- The decay heat removal system designs feature any number of passive, highly-reliable, and/or redundant features to accomplish their heat removal function
- When inherent hazards cannot be eliminated, engineered safety systems help to establish sufficient confidence in the reliability and performance of these safety systems decay heat removal function across normal and accident conditions

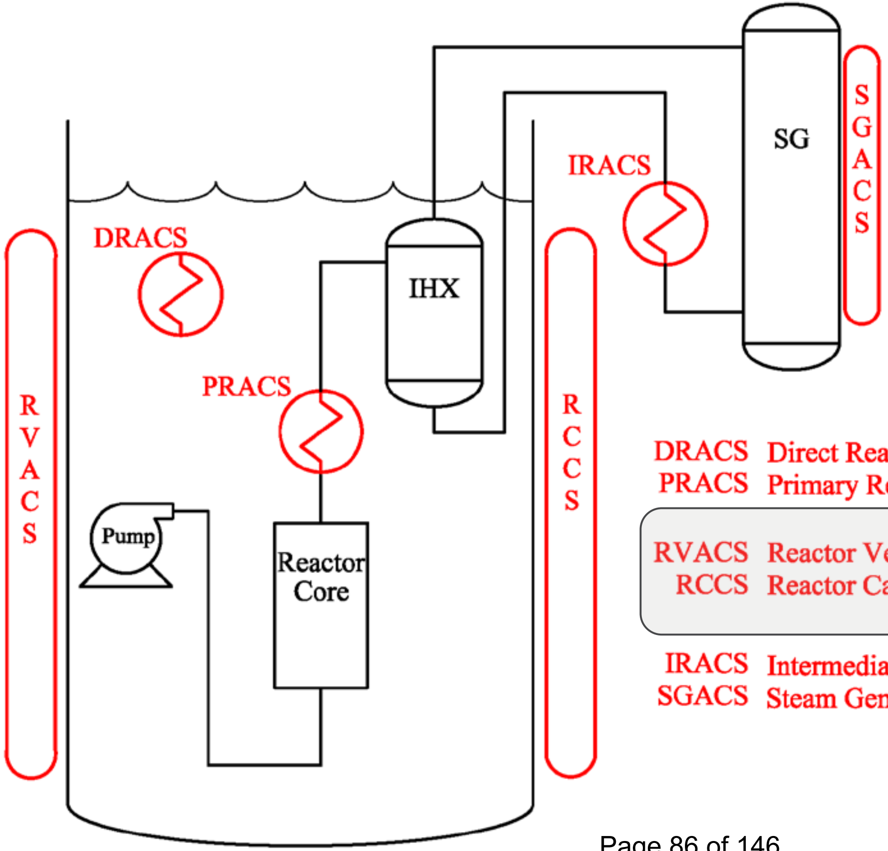


[4] Preliminary Safety Information Document for the Standard MHTGR (No. HTGR-86-024), 1992

SAFETY GRADE DECAY HEAT REMOVAL, CONT'D

- Maintain fuel and reactor vessel temperatures within safe limits
- Passive mode of operation during safety-related accident conditions
- Reliable operation during both accident transients and over the course of plant life
- Heat removal rate commensurate with rate of decay

OVERVIEW OF DHR CONCEPTS

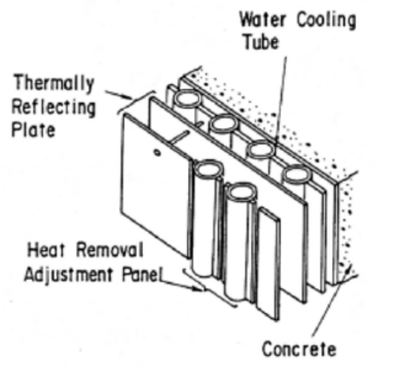


DRACS	Direct Reactor Auxiliary Cooling System	
PRACS	Primary Reactor Auxiliary Cooling System	
RVACS	Reactor Vessel Auxiliary Cooling System	Ex-vessel
RCCS	Reactor Cavity Cooling System	Ex-vessel
IRACS	Intermediate Reactor Aux Cooling System	Secondary
SGACS	Steam Generator Auxiliary Cooling System	Secondary

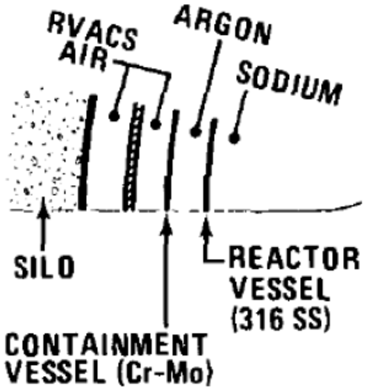
EX-VESSEL COOLING SYSTEMS (VCS)

- The design of these systems, including the RCCS, RVACS, and their hybrid variations, share a commonality in the use of conductive, radiative and convective cooling from the walls of an reactor vessel (RV) to a network of cooling channels
- In addition to design choices of air or water as the primary coolant, geometry and design of the individual cooling channels such dimensions of air or water pipes, vary widely across reactor designs

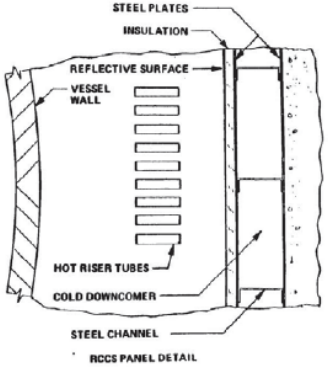
EXAMPLES OF VARIOUS VCS CONCEPTS



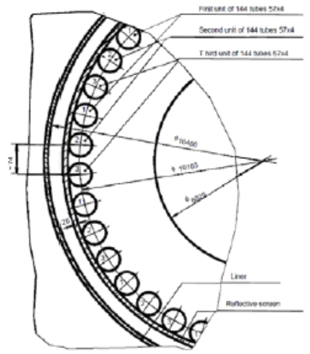
Water-cooled RCCS "panel" design for the Japanese HTTR [21]



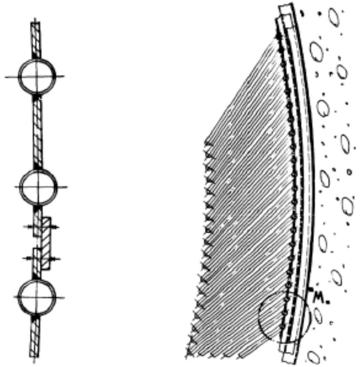
RVACS for the GE PRISM [83]



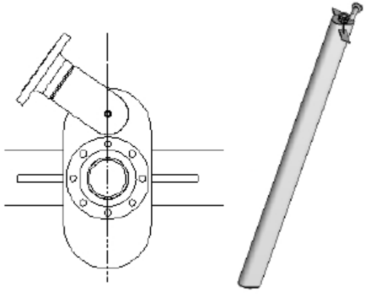
Air-based RCCS for the GA MHTGR [4]



Water-cooled RCCS "shield" design for Russian VGM [2]



Water-cooled RCCS "panel" for Framatome SC-HTGR [84]



Water-cooled RCCS "standpipe and curtain" design for the South African PBMR [7]

RCCS DESIGN OVERVIEW

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RCCS DESIGN OVERVIEW

- RCCS is a passive safety system that has been proposed for use in high-temperature gas reactors and their variants, and have been included as a primary design choice in concepts dating back to the 1950s
- Different RCCS concepts have been proposed for the range of reactor designs, with primary differences in their working fluid and passive mode of operation
  - The air-based RCCS features unlimited supply of the ambient air cooling but may be susceptible to certain ambient effects, e.g., strong winds
  - The water-based RCCS exhibits a superior efficiency in heat transfer due to two-phase boiling, but its cooling capability is limited by the capacity of the water inventory tank

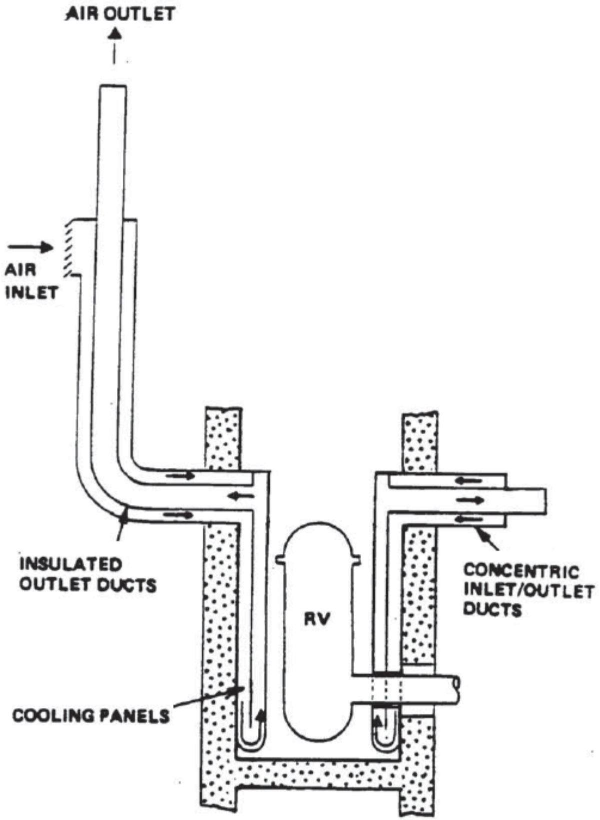

Fig. Generic water-based RCCS operating principal [72]

[4] Preliminary Safety Information Document for the Standard MHTGR (No. HTGR-86-024), 1992
[72] Lisowski, D., 2013. Thermal Hydraulic Analysis of an Experimental Reactor Cavity Cooling System with Water: Performance and Stability (Thesis). University of Wisconsin - Madison,

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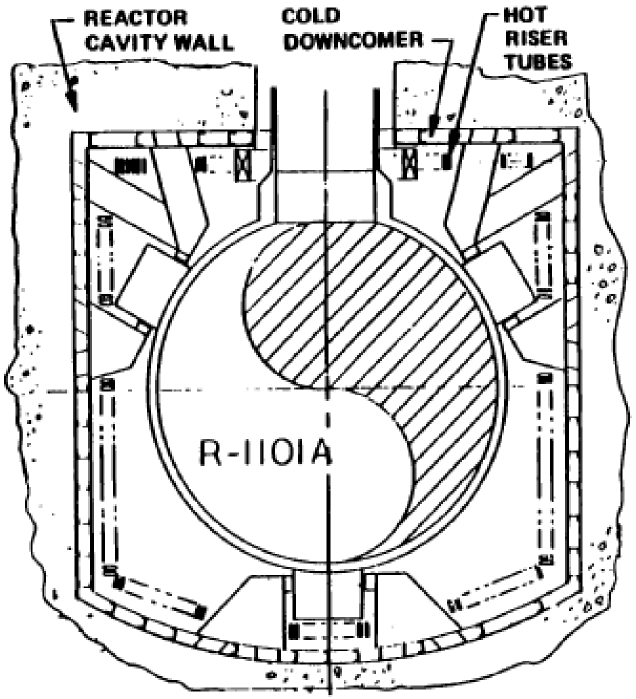
GA-MHTGR AIR-COOLED RCCS

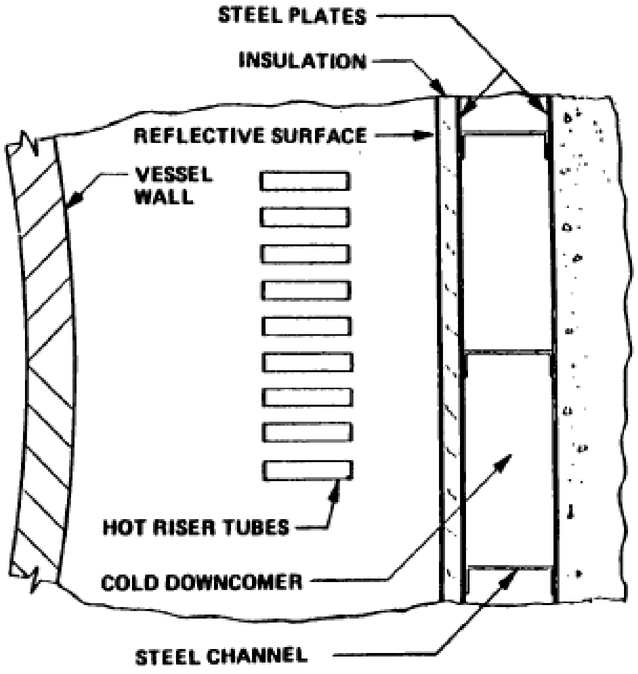
- The GA-MTHGR employs an air-based RCCS which draws cold air from the ambient environment and into channels within the cavity by natural circulation
- Decay heat is rejected from the RV to the RCCS cooling channels by thermal radiation and natural convection
- This RCCS design is always on, and it is completely passive with no valves or active components

Reactor	GA-MHTGR	**Reactor Power**	140 MW_e / 350 MW_t
Reactor Coolant	He	**DHR Concept**	RCCS
Number of Units	4	**Working Fluid**	Air
Heat Removal Capacity	**Power**	**Scenario**	
	718 kW_t	Normal operation	
	1.75 MW_t	Pressurized conduction cooldown, control rod withdraw	
	1.50 MW_t	Depressurized conduction cooldown, small primary leak	

GA-MHTGR AIR-COOLED RCCS, CONT'D

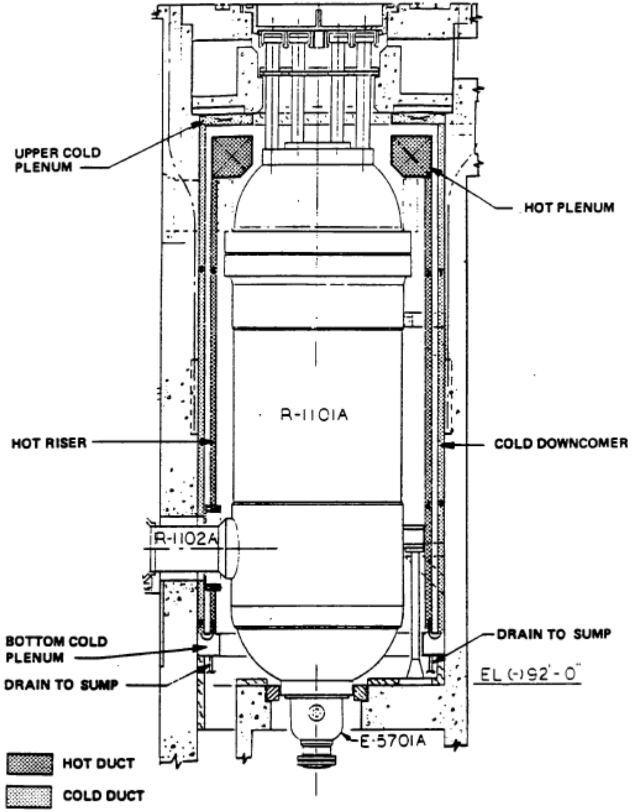


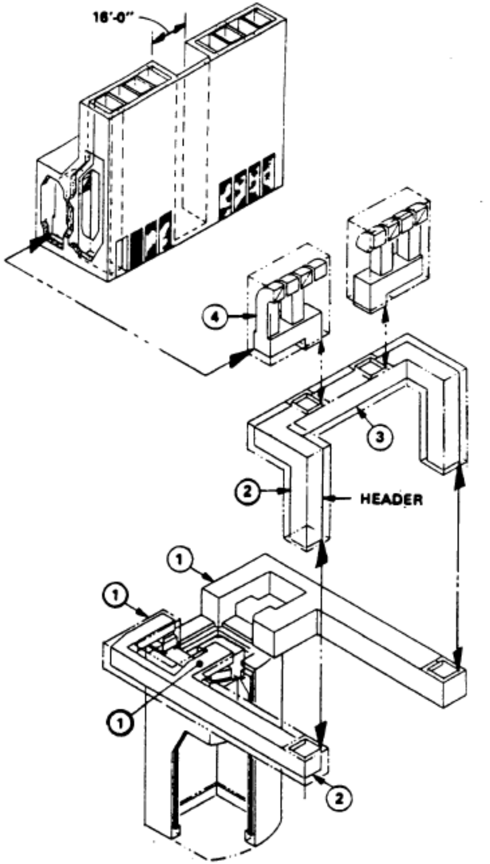
PLAN



RCCS PANEL DETAIL

GA-MHTGR AIR-COOLED RCCS, CONT'D





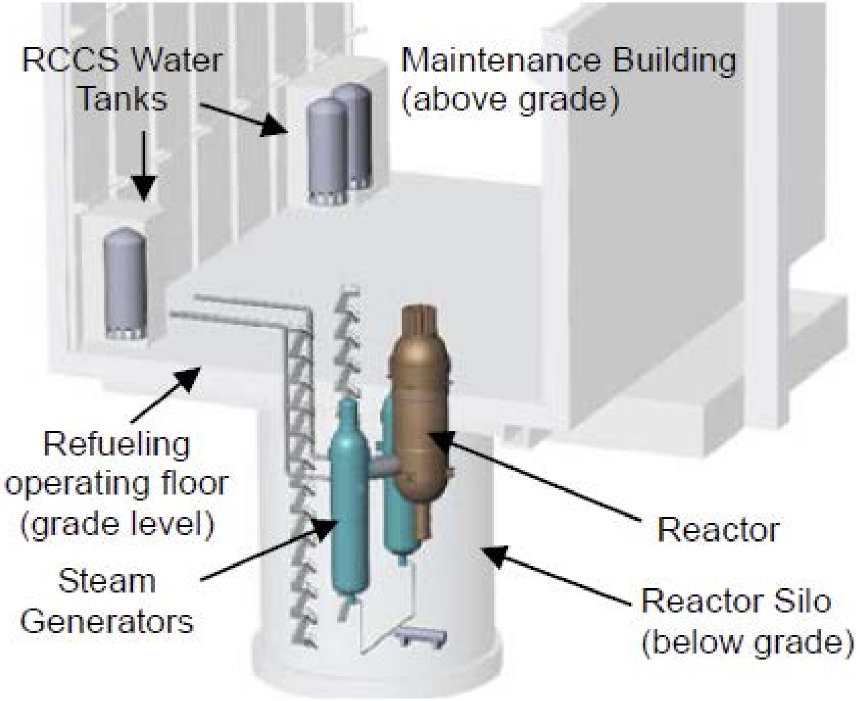
[4] Preliminary Safety Information Document for the Standard MHTGR (No. HTGR-86-024), 1992

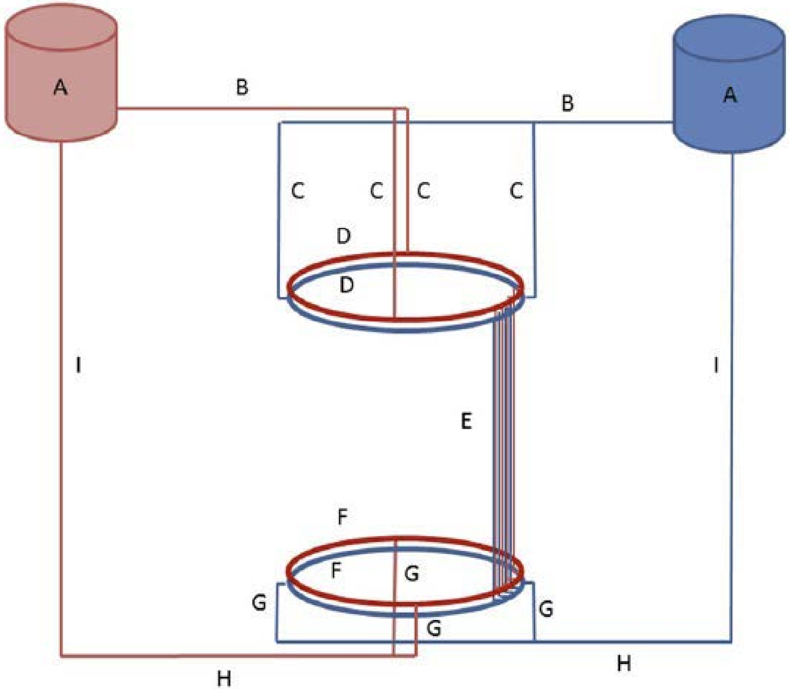
FRAMATOME SC-HTGR WATER-COOLED RCCS

- The SC-HTGR RCCS comprises many water tubes joined to form a single cooling panel which surround the reactor vessel
- These tubes are connected to multiple water storage tanks at higher elevations
- Power from the reactor vessel heats up the water inside the cooling panel and establishes natural circulation flow across the network of piping
- This RCCS design is always on, with active cooling during normal operation and passive heat-up with boil-off during accident scenarios

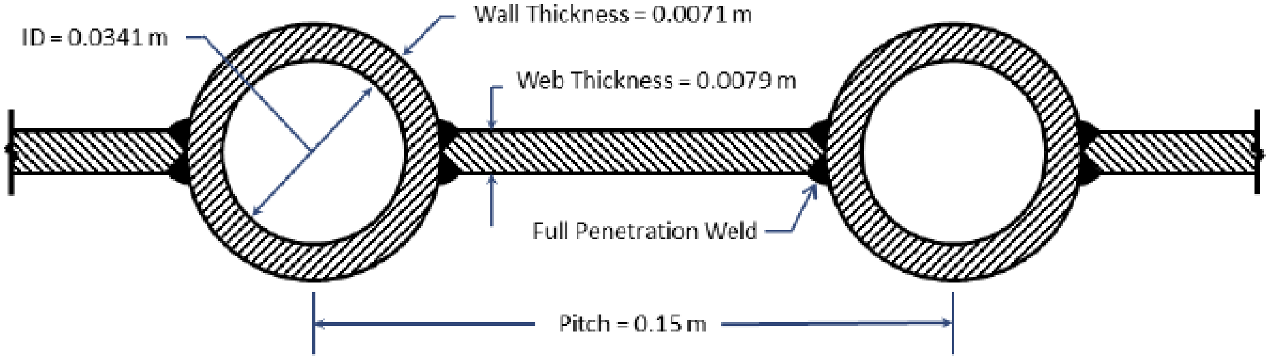
Reactor	SC-HTGR	**Reactor Power**	272 MW_e / 625 MW_t
Reactor Coolant	He	**DHR Concept**	RCCS
Number of Units	2	**Working Fluid**	Water
Heat Removal Capacity	**Power**	**Scenario**	
	1.4 MW_t	Normal operation	
	2.1 MW_t	Normal DLOFC operation, active cooling	
	2.1 MW_t	Passive DLOFC operation, design basis accident	

FRAMATOME SC-HTGR WATER-COOLED RCCS





FRAMATOME SC-HTGR WATER-COOLED RCCS



[6] Lommers, L., Shahrokhi, F., Iii, J.M., Southworth, F., 2014. AREVA Modular Steam Cycle – High Temperature Gas-Cooled Reactor Development Progress 10.

REACTOR DESIGNS FEATURING RCCS

Reactor	Year	Reactor				Decay Heat Removal System					Ref.
		Country	Vendor	Power	Coolant	Decay heat removal approach	Capacity	Fluid	Circulation	UHS	
Peach Bottom 1	1967		Philadelphia Electric	115 MW$_t$	Helium	Reactor-vessel cooling panels, secondary system	*n/a*	*n/a*	*n/a*	*n/a*	[113]
MHTGR	1986		General Atomics	560 MW$_t$	Helium	Reactor cavity cooling system with air	1.5 MW	Air	Natural	Atmosphere	[4]
VGM	1989		OKMB	200 MW$_t$	Helium	Radiation heat transfer from vessel to cooling tubes with back mounted fins	1.3 MW	Water	Natural	Atmosphere	[100]
HTR Module	1993		Siempelkamp/ Siemens	200 MW$_t$	Helium	Radiation heat transfer from vessel to cooling tubes, natural to atmosphere, dry air cooling	890 kW	Water	Natural	Atmosphere	[23]
HTTR	1998		JAEA	30 MW$_t$	Helium	Radiation heat transfer from reactor vessel to cooling tubes, forced convection to water	0.3 MW	Water	Forced	Cooling water	[12]
NPR-MHTGR	1998		General Atomics	350 MW$_t$	Helium	Water-cooled panels surrounding reactor vessel, cooled by HXG above grade	*n/a*	Water	Natural and forced	Atmosphere	[115]
HTR-10	2000-		Tsinghua University	10 MW$_t$	Helium	Radiation heat transfer from reactor vessel to cooling tubes, forced convection to water	200 kW	Water	Natural	Atmosphere	[103]
PBMR	2009		PBMR (Pty)	265 MW$_t$	Helium	Radiation heat transfer from RV to water pool, forced air circulation, evaporation or boiling	3.1 MW	Water	Forced air circulation	Atmosphere	[13]
SC-HTGR	2010		Framatome	625 MW$_t$	Helium	Radiation heat transfer from RV to cooling panel with natural circulation of water inside	2.1 MW	Water	Natural	Atmosphere	[22]
GT-MHR	2010		GA & MINATOM	600 MW$_t$	Helium	Liquid metal filled reactor cavity to cool reactor vessel, and passive air from reactor cavity.	1.5 MW	Air	Natural	Atmosphere	[101]
HTR-PM	*under cont.*		Huaneng Group	458 MW$_t$	Helium	Radiation heat transfer from reactor vessel to cooling tubes, forced convection to water	1.1 MW	Water	Natural	Atmosphere	[102]

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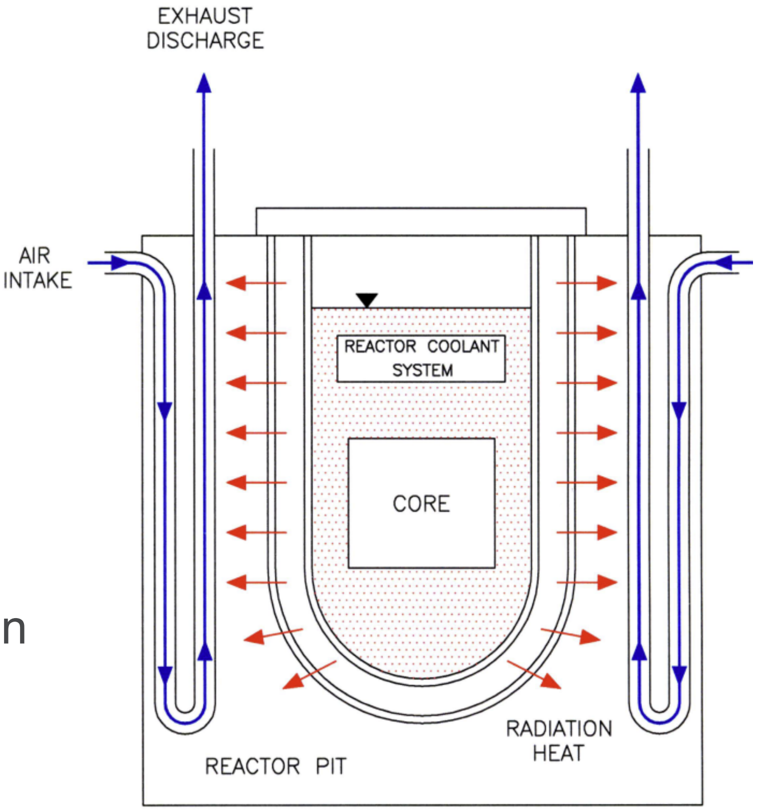
RVACS DESIGN OVERVIEW

RVACS DESIGN OVERVIEW

- The RVACS is designed to remove decay heat by radiative and convective cooling to natural circulation driven airflow across a guard vessel
- Unlike the RCCS concept, air travels directly within the containment and requires special design constraints for potential fission product release and material activation
- The design is uniquely tailored toward the design of advanced liquid metal cooled reactors because the high conductivity of the coolant allows for effective heat transmission to the vessel and guard walls



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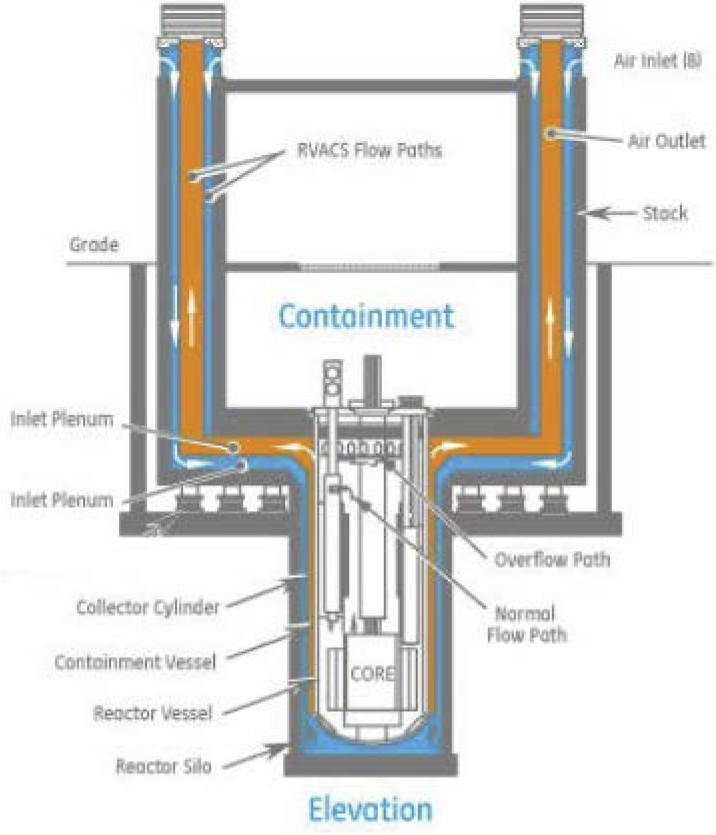
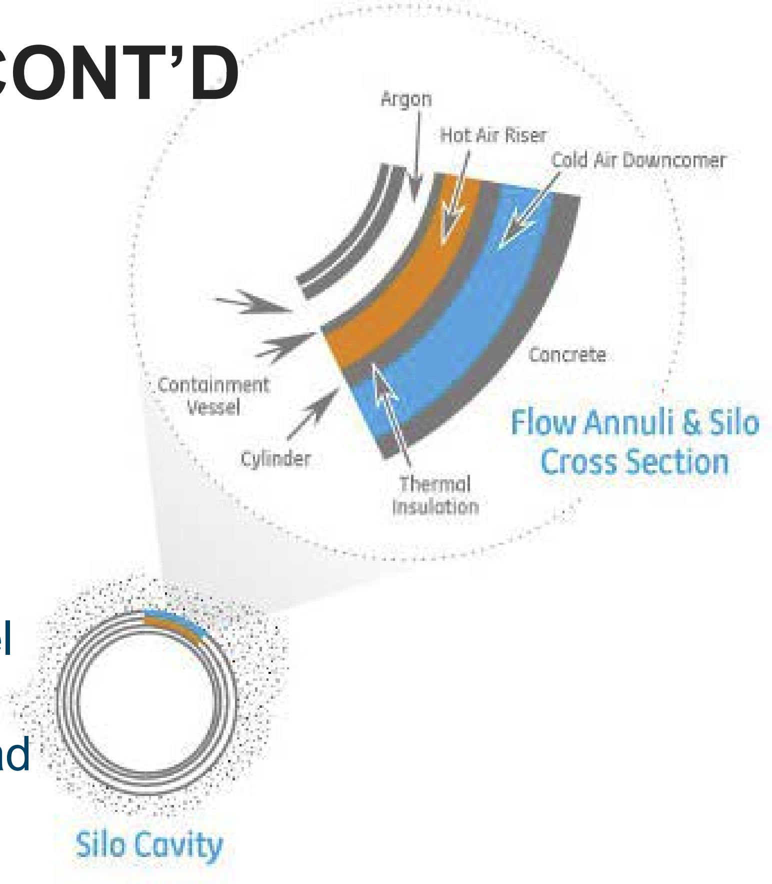
GE-HITACHI PRISM RVACS

- The GE PRISM RVACS is designed to maintain reactor temperatures well below design limits using only air-based natural circulation to remove heat from the reactor guard vessel
  - Atmospheric air is drawn into the reactor building and flows over the outside of the containment vessel. The warm air then returns to the stack and is exhausted
- Heat loss to the RVACS during normal full power conditions, with the associated lower temperatures, is <0.2% because thermal radiation between the reactor and containment vessels controls the heat transfer rate



GE-HITACHI PRISM RVACS, CONT'D

- Similar to the air-based RCCS, the RVACS is..
  - Always on and operating
  - Requires no actuations
  - Sized to remove the full decay heat load
  - Employs redundant chimney networks
    - x8 inlets, x4 outlets
- Differences are primarily
  - Surface of heat transfer from the internal fuel (guard vessel vs reactor vessel)
  - Single continuous flow area for hot air instead of multiple individual channels



REACTOR DESIGNS FEATURING RVACS

Name	Year	Reactor				Decay Heat Removal System				Ref.
		Country	Vendor	Power	Coolant	DHR Approach	Capacity, % Full Power	Mode	Fluid	
Phenix	1973		CEM	840 MW_t	Sodium	Radiation heat transfer across safety vessel by natural convection of atmospheric air; in 2002 was converted to air	0.4 (0.7)	Forced	Water, Air	[36]
Super Phenix	1985		Novatome	3000 MW_t	Sodium	Radiation heat transfer across safety vessel by natural convection of atmospheric air	0.2	Forced	Water	[36]
SAFR	1988		Rockwell	900 MW_t	Sodium	Radiation heat transfer across safety vessel by natural convection of atmospheric air	0.6	Natural	Air	[31]
PEACER	2000		SNU	850 MW_t	Lead	Radiation heat transfer across safety vessel by natural convection of atmospheric air in tubes	*unknown*	Natural	Air	[111]
SSTAR	2004		LLNL	45 MW_t	Lead	Radiation heat transfer across safety vessel by natural convection of atmospheric air in tubes	*unknown*	Natural	Air	[107]
AHTR	2004		ORNL	2400 MW_t	Molten Salt	Radiation heat transfer across safety vessel by natural convection of near atmospheric air channel	*unknown*	Natural	Air	[33]
ELSY	2006		Euratom	600 MW_t	Lead	Radiation heat transfer from safety vessel by natural convection of atmospheric air in tubes	*unknown*	Natural	Air	[50]
PRISM	2010		General Electric	840 MW_t	Sodium	Radiation heat transfer across guard vessel to a free convecting atmospheric air stream (air channel)	0.7	Natural	Air	[47]
ASTRID	2014		CEA	1500 MW_t	Sodium	Radiation heat transfer across safety vessel by natural convection of oil	*unknown*	Natural	Oil	[27]
CLEAR-I	2014		CAS	45 MW_t	Lead	Radiation heat transfer from safety vessel by natural convection of atmospheric air in four independent loops of U-shaped tubes	0.2	Natural	Air	[49]
W LFR	2018		Westinghouse	400 MW_t	Lead	Radiation heat transfer across guard vessel by natural convection of atmospheric air channel	*unknown*	Natural	Air	[98]
IMSR	2019		Terrestrial	400 MW_t	Molten Salt	"Internal" RVACS, heat transfer by a closed cycle flow of nitrogen to a false roof acting as a heat exchanger above the structural roof	*unknown*	Natural	Nitrogen	[35]
Natrium	2021		Terrapower	345 MW_t	Sodium	Radiation heat transfer across safety vessel by natural convection of atmospheric air channel	*unknown*	Natural	Air	[114]

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EVALUATION OF AVAILABLE DATA

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KNOWN ANALYTICAL TOOLS FOR RCCS/RVACS

Modeling Tool	Code Dimension	Developer	Country	Initial Release	Use in DHR analysis		
					Concept	Fluid	Studies
RELAP5-3D	1D system	INL / US NRC	USA	1975	RCCS	Air, Water	[96]
TAC2D	2D system	General Atomics	USA	1976	RCCS	Air	[65]
COMMIX – 1A	3D system	Argonne	USA	1980	RVACS	Air	[51]
COMMIX – 1A	3D system	Argonne	USA	1980	RCCS	Air	[65]
FLUENT	3D system	ANSYS, Inc.	USA	1983	RCCS	Water	[118]
TAC-NC	2D system	JAERI	Japan	1989	RCCS	Water	[12]
MORECA	1D system	ORNL	USA	1991	RCCS	Air	[64]
CERES	unknown	CRIEPI	Japan	1991	RVACS	Air	[57]
SAS4A/SASSYS-1	3D system	Argonne	USA	1991†	RVACS	Air	[53]
RECENT	unknown	MIT*	USA	1991†	RCCS	Air	[66]
RELAP5/Mod3D	*pseudo* 3D system	INL / US DOE	USA	1997	RCCS	Air, Water	[96]
THANPACST2	3D system	JAERI	Japan	1997	RCCS	Water	[25]
MARS-GCR	3D system*	KAERI	Korea	2003	RCCS	Air, Water	[93]
Star-CCM+	3D CFD	CD-adapco	USA	2004	RCCS	Air, Water	[96]
Star-CCM+	3D CFD	CD-adapco	USA	2004	RCCS	Air, Water	[67]
CFX-5	3D CFD	Ansys	USA	2004	RCCS	Air, Water	[13]
Star-CD	3D CFD	CD-adapco	USA	2004	RCCS	Water	[22]
WCOBRA/TRAC – TF2	3D system	Westinghouse	USA	2011	RVACS	Air	[98]
MELCOR	2D system	SNL / US NRC	USA	2016	RCCS	Air, Water	[97]
SAM	1D transient	Argonne	USA	2017	RCCS	Water	[117]
GAMMA+	3D CFD	KAERI	Korea	*unknown*	RCCS	Air, Water	[80]

†estimated based on published information

KNOWN EXPERIMENTAL EFFORTS ON RCCS/RVACS

DHR Concept	Prototype Reactor	Test Facility	Working Fluid	Peak Heat Flux	Heated Length	No. Channels	Institution	Year	Ref.
RVACS	ALMR	IDS	Air	*unknown*	13.1 m	1	Hanford	1985	[119]
RVACS	GE PRISM	NSTF (*legacy*)	Air	21.5 kW/m²	6.7 m	1	Argonne	1986	[51]
RVACS	LMFBR	*unnamed*	Air	10 kW/m²	3.5 m	1	CRIEPI	1991	[57]
RCCS	GA-MHTGR	*unnamed*	Air	2.4 kW/m²	8.6 m	1	MIT	1991	[66]
RCCS	PB-MHTGR	INWA (*legacy*)	Water	*unknown*	2 m	1	Batelle Europe	1992	[23]
RCCS	Siemens	SANA/SANA-II	Water	*unknown*	1 m	4	Sinempelkamp	1992	[95]
RVACS	FBR	*unnamed (legacy)*	Air	~15kW/m²†	2 m	1	Kawasaki	1993	[90]
RCCS	HTGR, VHTR	SCALE	Air	7kW/m²	0.38 m	1	JAERI/Kyushu	2004	[94]
RCCS	PMR200	NACEF	Air	15 kW/m²	4.05 m	6	KAERI	2006	[80]
RCCS	PBMR	RCCS-SNU IET	Air + Water	10 kW/m²†	~2 m†	6	KAERI	2006	[93]
RCCS	PBMR	*unnamed*	Air + Water	10 kW/m²†	2 m	6	INL	2009	[14]
RCCS	HTGR	*unnamed*	Water	*unknown*	0.2 m	1	TAMU	2010	[67]
RCCS	Hybrid	*unnamed*	Water	25 kW/m²	5 m	3	UW – Madison	2013	[89]
RCCS	GA-MHTGR	NSTF (*modern*)	Air	21.5 kW/m²	6.7 m	12	Argonne	2016	[88]
RVACS	PGSFR	SINCRO-V	Air	*unknown*	~1.2 m	1	UNIST	2020	[91]
RVACS	PGSFR	SINCRO-3D	Air	*unknown*	~1.2 m†	1	UNIST	2020	[92]

†estimated based on published information

BEHAVIOR DURING OFF-NORMAL AND DEGRADED CONDITIONS

PARTIAL BLOCKAGES OF RVACS

- In the early 1990’s GE Nuclear Energy, Advance Reactor Programs division, used COMMIX to analyze the RVACS performance during varying degrees of flow area blockage
  - Blocking each of the four air inlet openings 75% and each of the four air outlets also by 75% causes an increase in the maximum core outlet temperature of 32°F

Case	Maximum Avg. Core Outlet Temperature and	
	Tempature Increase Above Nominal Peak (°C/°F)	
75% Area Blockage of Each Air Inelt Opening	614/1137	7/12*
75% Area Blockage of Each Air Outlet Opening	619/1146	12/21
75% Area Blockage of Each Air Inlet and Outlet	625/1157	18/32
One Stack Inoperative	611/1132	4/7
Two Stacks Inoperative	623/1153	16/28
Three Stacks Inoperative	663/1226	56/101

*Increase relative to 607°C/1125°F for normal RVACS operation

[47] Boardman, C.E., Hunsbedt, A., 1991. Performance of ALMR passive decay heat removal system. Presented at the IAEA-IWGFR specialists’ meeting on passive and active safety features of LMFRs, PNC, JAPAN, pp. 113–120.

COMPLETE BLOCKAGE OF RVACS

- More severe postulated events for an operating RVACS were evaluated including complete blockage of all air inlets while the four air outlets remain fully open, and visa-versa
- Several assumptions subject to experimental verification were made in the analysis of this case, with a significant uncertainty of 100% to reflect the lack of experimental information about the air-side flow distribution and the adequacy of the assumed U-flow model
- Block inlets
  - The maximum core sodium outlet temperature increases to 1168°F (631°C), only 43°F (24°C) higher than that expected for the normal RVACS event
- Block outlets
  - Results of the transient analysis for the blocked outlets case show that the maximum core outlet temperature reached exceeds the service level D limit and is unacceptable from a structural point of view

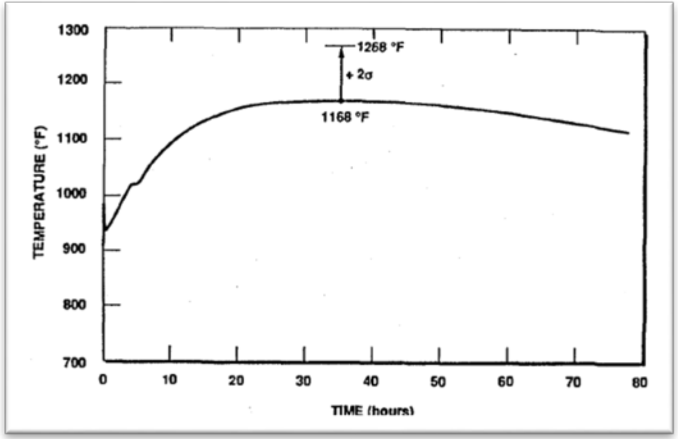
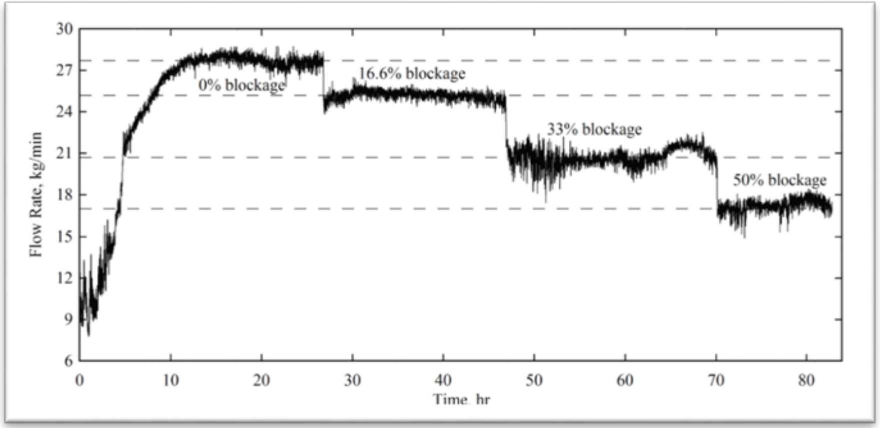


Fig. Core sodium outlet temperature for blocked inlets [47]

PARTIAL BLOCKAGE OF RCCS RISERS

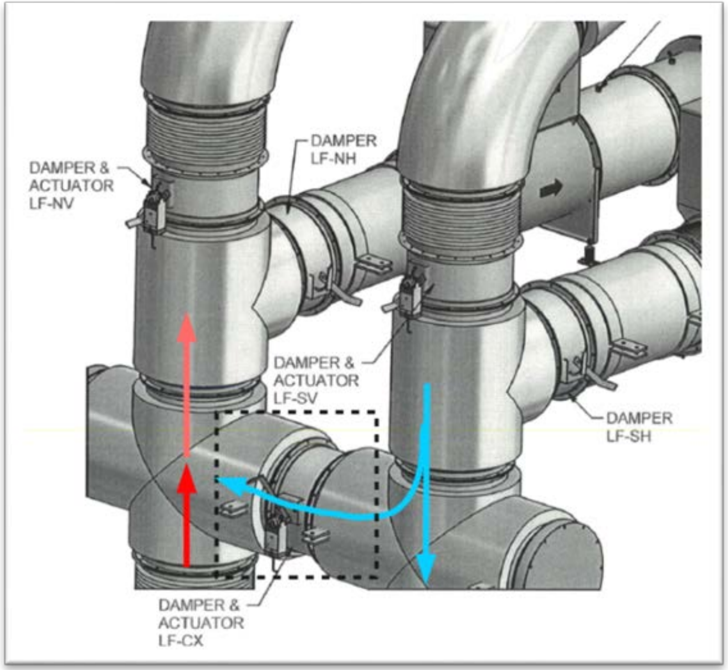


	Stage #0	Stage #1	Stage #2	Stage #3
Riser Blockage, %	0%	16.60%	33.30%	50%
Risers Blocked	-	2,3	(2,3) + 10,12	(2,3,10,12) + 5,8
Span, run time hr	20 - 26	32 - 46	52 - 65	74 - 80
Electric power, kW_e	42	42	41.99	42
Test sect. power, kW_t	24.78	26.68	26.16	25.17
Sys. flow rate, kg/s	0.459	0.42	0.342	0.287
Riser ΔT, °C	53.6	54.92	59.41	63.49
Front heated plate, °C	278.93	282.32	288.17	291.96
Ceramic heaters, °C	405.96	408.27	412.34	414.88

- The heated plate temperature, representing the walls of an RV, averaged 279°C for the normal, fully open operation
- Increased to 282°C, 288°C, and 292°C at 16%, 33%, and 50% blockage flow areas

[58] Lisowski, D., Lee, T., et al., 2016. Final Project Report on RCCS Testing with the Air-based Natural convection Shutdown heat removal Test Facility, ANL-ART-47, Argonne National Laboratory

SHORT CIRCUIT OF RCCS INLET / OUTLET



Break size	Run Time *hour*	Total Inlet *kg/s*	Heated Region *kg/s*	Break Region *kg/s*
0%	28.7	0.365	0.365	≤0.001
0%	57.5	0.384	0.382	0.002
33%	57.85	0.566	0.308	0.258

[58] Lisowski, D., Lee, T., et al., 2016. Final Project Report on RCCS Testing with the Air-based Natural convection Shutdown heat removal Test Facility, ANL-ART-47, Argonne National Laboratory

INGRESS OF NON-AIR GAS

1. System flow rates that quickly fell to nearly zero in about ninety seconds after initiation of the argon ingress sequence
2. Facility experienced near-total flow stagnation for a period of approximately eighteen minutes
3. Due to the cessation of bulk fluid movement and subsequent failure of its heat removal function, fluid and structural temperatures began to rise sharply
4. After approximately eighteen minutes, fluid temperatures in the riser tubes rose to a level sufficient to allow re-establishment of buoyancy-driven system flow

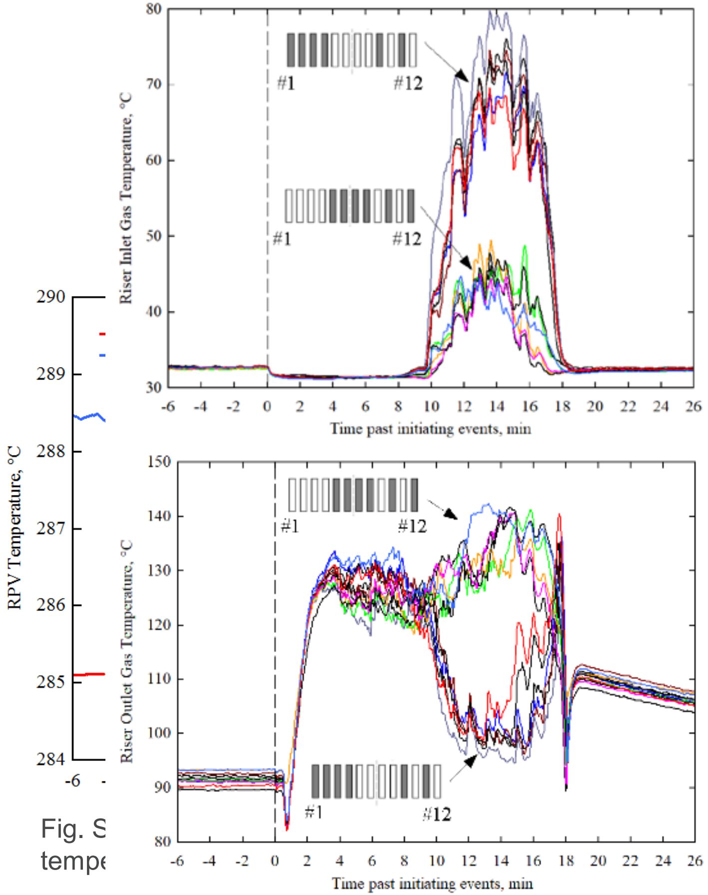


Fig. Riser inlet (top) and outlet (bottom) temperatures during non-air gas event [77]

[77] Lisowski, D., Kraus, A., Lv, Q., Hu, R., 2021. Behavior of an air-cooled thermosiphon during a non-air gas ingress event. International Journal of Heat and Mass Transfer 175, 121155.

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EVALUATION OF RELIABILITY AND PERFORMANCE

SYSTEM LONGEVITY OVER PLANT LIFETIME

- The ability of an ex-vessel VCS installation to maintain intended function throughout the 40- or 60-year life of a commercial reactor could be contingent on the corrosion and structural integrity of material components.

Figure 92: Rust collected from bottom of scaled air-based RCCS test facility over 100-day period [58]

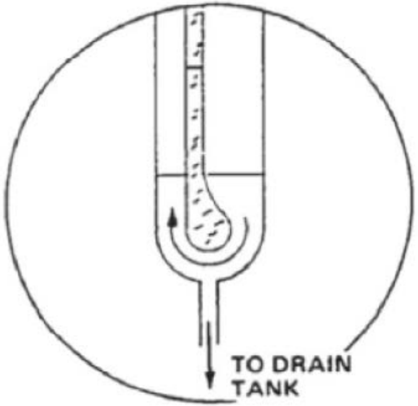

Figure 93: Engineered drain of an air-based RCCS for anticipated water ingress [81]

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METEOROLOGICAL INFLUENCES (AIR-BASED)

- For air-based ex-vessel cooling systems that rely on engineered chimney stacks to provide an intake of ambient air and discharge of heated exhaust, the influence of weather can play a major factor in influencing the behavior of airflow within the channels and cooling system

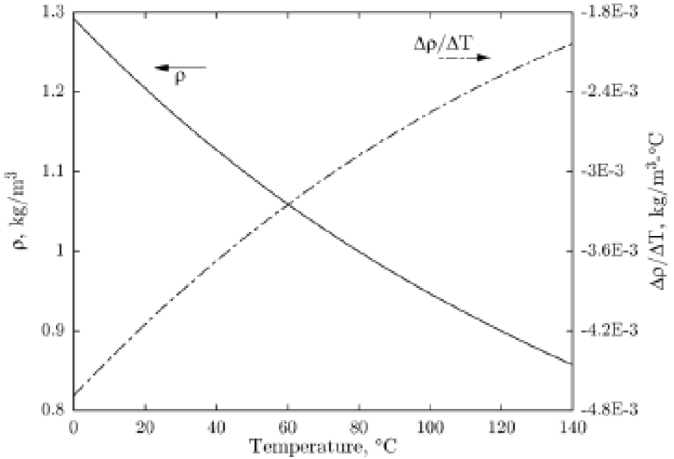

Figure 94: Relationship between standard air temperature and density [79]

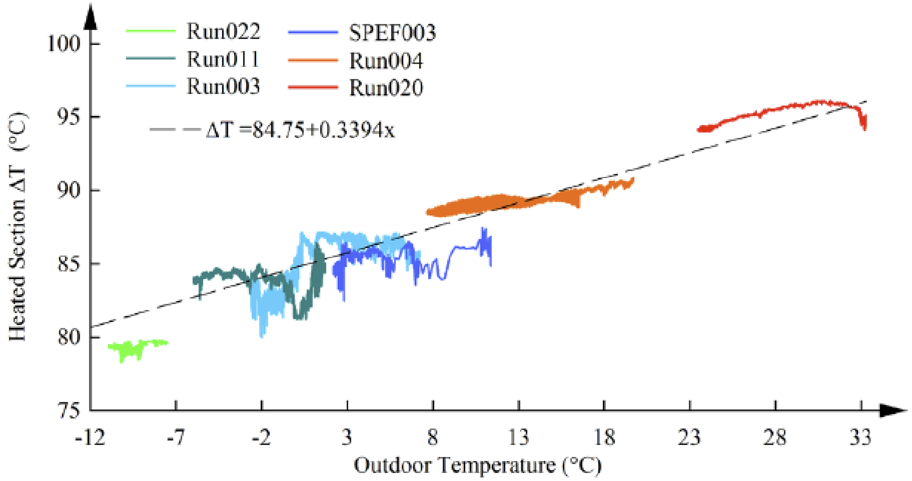

Figure 95: Relation between heated RCCS ΔT and ambient temperature in air-based NSFT [58]

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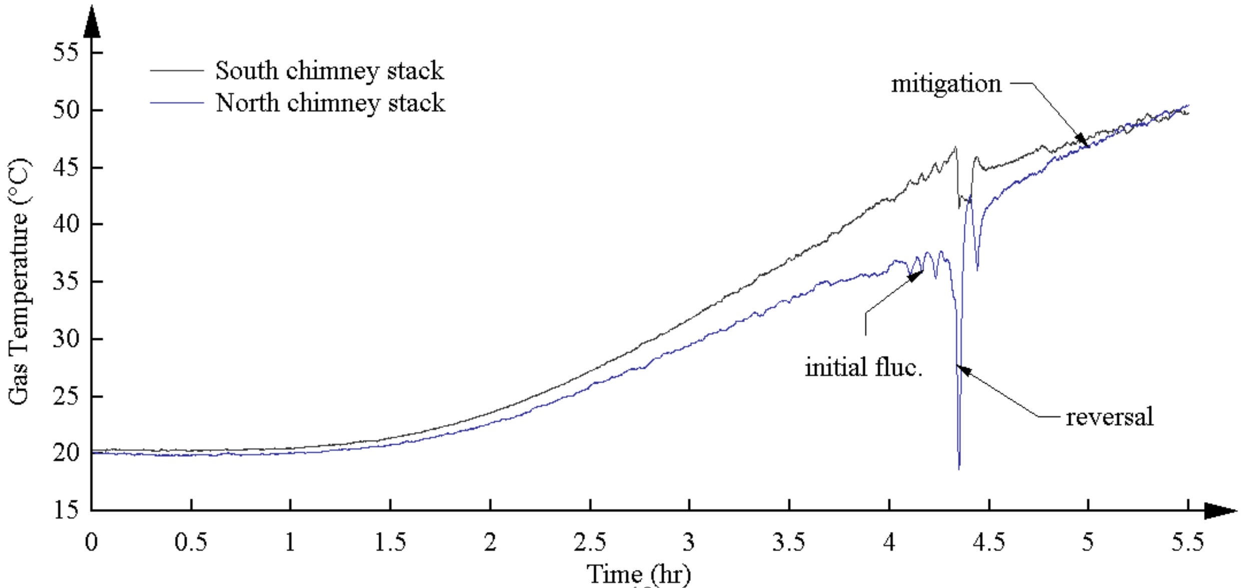
WIND EFFECTS (AIR-BASED)

- Wind direction will likely impact air-based RCCS and RVACS performance
  - May influence flow velocities and/or symmetry across parallel paths
  - Under severe conditions, can cause flow reversals within chimney stacks



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TWO-PHASE PHENOMENA (WATER-BASED)

- Studies suggest the heat removal performance of water-based natural circulation systems may remain unaffected by two-phase and boiling-induced flow instabilities
- Thus, heat is likely to continue being effectively transferred from the core to an ultimate heat sink
- However, given the complexity inherent to a two-phase natural circulation system, there is a need to ensure understanding of all phenomena that may occur in these water loops

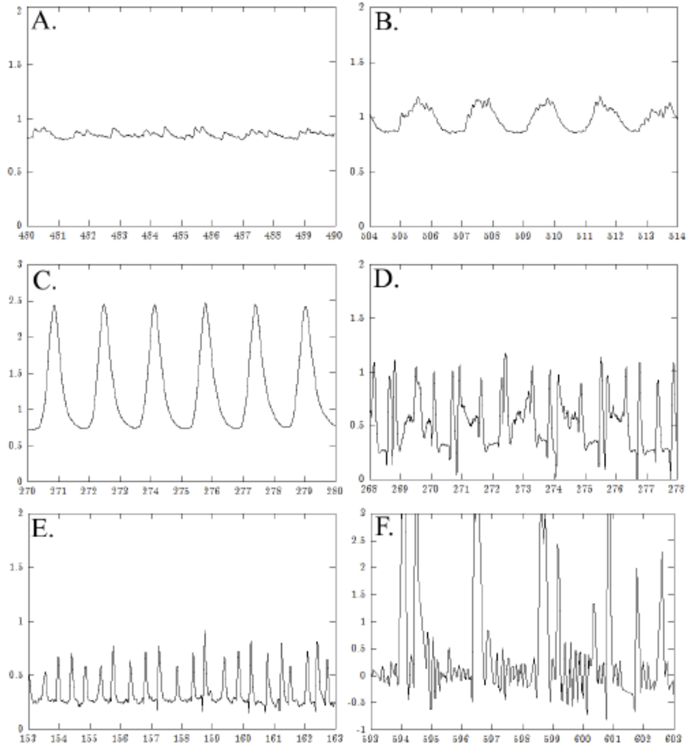

Figure 99: Types of two-phase flow instabilities observed in a 1:4 scale water-based RCCS. A. Nucleate boiling, B. Hydrostatic head fluctuations, C. Pure flashing, D. Parallel channel interaction, E. Density wave oscillation, E. Geysering. [72]

BOILING INSTABILITIES

- Though heat removal performance has been shown to be relatively unaffected by system-wide oscillations, these instabilities do pose unique structural challenges
- If large magnitude vibrations are sustained, piping supports, bolted mating assemblies, loosened securement hardware, etc. are at risk and must be engineered accordingly

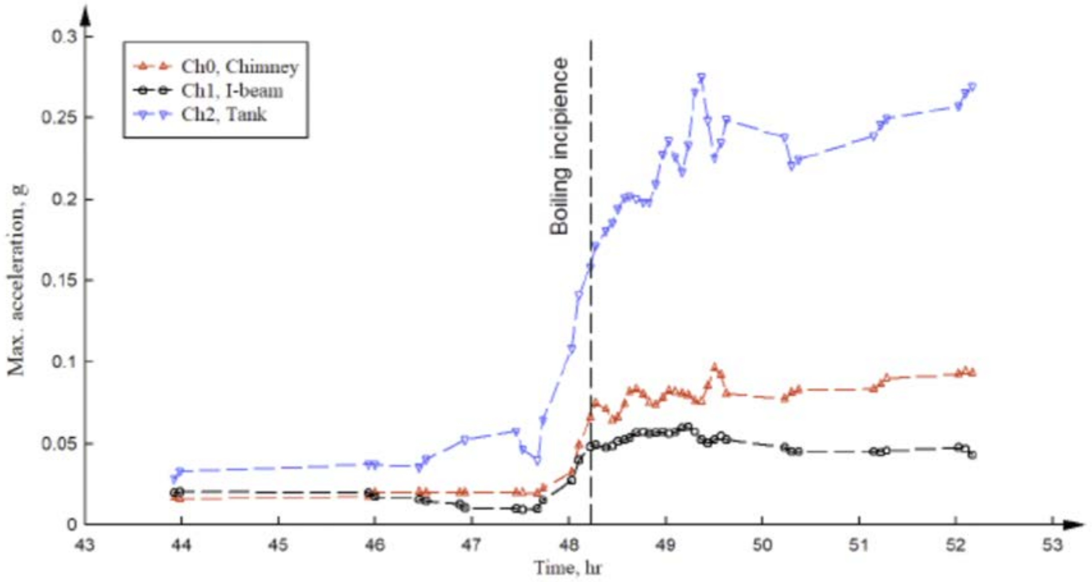

Figure 101: Structural vibration generated by boiling flow in 1:2 scale water-RCCS [87]

SUMMARY

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SUMMARY

- This review included previously published works available in the public domain, focusing on ex-vessel designs such as RCCS, RVACS, and hybrid iterations, using both air and water cooling to achieve their decay heat removal function
- The findings from this review identified a large number of studies that have produced a wide breadth of experimental data and computational tools in support of various ex-vessel cooling designs
- These studies, ranging from 1979 to the present day, have been led by both independent and collaborating institutions and resulted in the construction of several scaled experimental test facilities as well as the availability of numerous validated computational and analytical tools

EVALUATION OF RCCS

- Based on an evaluation of the available data for the RCCS concept, many studies were identified that examined the role of design variations and operating conditions on the performance, heat removal function, and stability of these systems
- These were conducted across several institutions and resulted in the construction of a broad set of test facilities across multiple scales, using both air- and water-based cooling designs
- Computational modeling tools include diverse suite of analytical, system, and CFD level codes
  - Modeling of air systems is mature and able to provide accurate predictions
  - Challenges identified when modeling water-based systems that operate at low pressures and in two-phase or boiling flow regimes

EVALUATION OF RCCS, AIR-BASED

- Studies of air-based RCCS concepts observed stable and adequate levels of heat removal performance when operating under steady conditions at normal or design basis accident levels of decay heat load
- Furthermore, the studies indicate that these systems can maintain their function during many off-normal scenarios, including blocked riser channels, transient chemical ingress, and asymmetries in heated profiles
- However, under start-up, low-power, or strong wind conditions, some studies observed natural circulation phenomena that challenged the system's ability to maintain symmetric flow within parallel channels

EVALUATION OF RCCS, WATER-BASED

- Studies of RCCS systems that used water-based cooling observed a more stable response to external factors that readily degraded the operation of air-based concepts
- However, these water-based designs rely on a finite supply of cooling inventory that must be replenished during extended accident scenarios
- For systems that extend their operation into a boiling flow regime, they exhibit unique sensitivity to complex two-phase flow phenomena, which may induce large amplitude flow oscillations and create vibration concerns for structural components

EVALUATION OF RVACS

- Studies that examined the capacity and heat removal performance of RVACS indicate that a high level of reliability and heat removal function can be expected during normal, accident, and degraded operating conditions
- Analytical predictions of the RVACS performance during unique off-normal scenarios, including partial and total blockage of air inlets and outlets, flooding, etc., yielded results that support the system's high tolerance and robust function
- However, these studies identified the need for additional experimental information about the air-side flow distribution, which authors indicate are necessary to verify the adequacy of the models used to represent these extreme scenarios
- Assessment of current and past experimental data produced for the RVACS design suggests a gap in the availability of multiple-scale test facilities that are similarly designed and share features common to a full prototypic concept

CLOSING REMARKS

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  - **Joseph Sebrosky**, Sr. Project Manager; Atl. Contracting Officer
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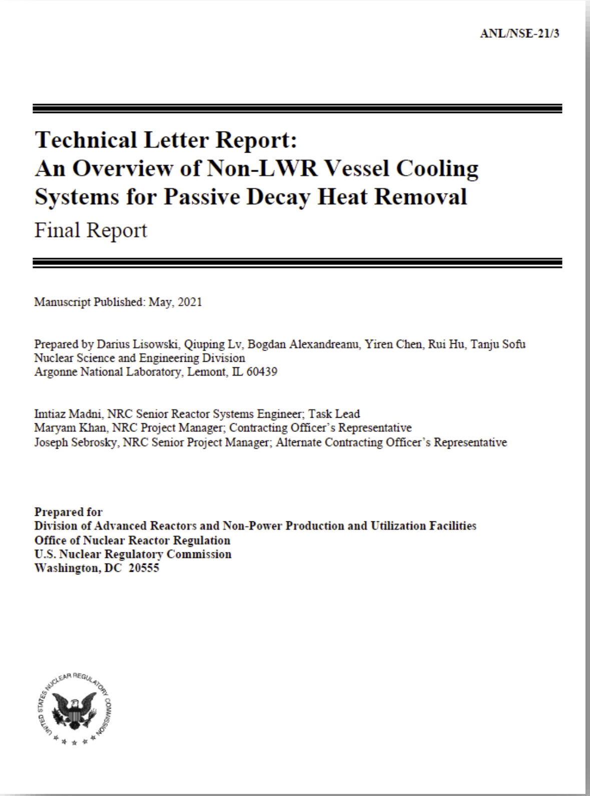
  - Rui Hu
  - Tanju Sofu



ANL/NSE-21/3

Technical Letter Report:
An Overview of Non-LWR Vessel Cooling Systems for Passive Decay Heat Removal

Final Report

Manuscript Published: May, 2021

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U.S. Nuclear Regulatory Commission
Washington, DC 20555

THANK YOU

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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Advanced Reactor Stakeholder Meeting

Insights on Adapting Licensing Frameworks to New Non-Power Technologies

Steven Lynch, Senior Project Manager
Non-Power Production and Utilization Facility Licensing Branch
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
July 2021

Non-Power Facility Licensing and Oversight

- U.S. Nuclear Regulatory Commission (NRC) responsible for 31 non-power reactors
  - Routine licensing actions
  - License renewal reviews
  - Digital instrumentation and control upgrades
  - Highly enriched uranium to low-enriched uranium fuel conversions
  - Inspection and operator licensing
- Licensing infrastructure and policy
  - Guidance development
  - American Nuclear Society standard committee participation
  - Advanced reactor licensing support
  - Rulemaking development and support
- International activities, including International Atomic Energy Agency support
- Initial licensing reviews for medical radioisotope facilities

Status of United States Supply

- Currently, limited domestically-produced molybdenum-99 (^{99}Mo) supply

- The United States ^{99}Mo policy objectives are to:

  1) Ensure a reliable supply of ^{99}Mo

  2) Eliminate highly-enriched uranium use in ^{99}Mo production, and

  3) Eliminate market subsidies

- Production encouraged by cost-sharing cooperative agreements between National Nuclear Security Administration and commercial partners

Supporting ^{99}Mo Production

- NRC staff committed to efficient reviews of applications and inspections in accordance with the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR)

- Licensing and oversight activities support U.S. national security interests and nuclear nonproliferation policy objectives of establishing a domestically-available and reliable supply of ^{99}Mo without the use of highly-enriched uranium

- Applications include initial license and license amendment requests for facilities proposing to manufacture, irradiate, and process low enriched uranium and molybdenum targets

- Oversight activities focused on preparation for construction inspection

Regulated Production Processes

- Target manufacturing
  - Preparation of low enriched uranium (LEU) targets for irradiation
- Target irradiation
  - Nuclear reactors
  - Subcritical operating assemblies
  - Accelerators
- Target processing
  - Hot cell separation of ^{99}Mo from irradiated LEU targets
- Medical uses of byproduct material
  - Generators for extracting technetium-99m from ^{99}Mo

Similarities to Existing Facilities

- Safety considerations comparable to non-power reactors:
  - Fission heat removal
  - Decay heat generation
  - Fission gas release
  - Fission product buildup
  - Accident scenarios
- …and fuel cycle facilities:
  - Target manufacturing
  - Radiation protection
  - Material processing
  - Criticality control
  - Chemical hazards

Non-Power Licensing Process

- Applications contain both general and technical information
- Construction permit application
  - Environmental report
  - Preliminary safety analysis report (PSAR)
- Operating license application
  - Update to environmental report, as necessary
  - Final safety analysis report (FSAR)
- Applications may be submitted separately or together
- Testing facilities and commercial facilities may request limited work authorization to allow certain construction activities prior to the issuance of a construction permit

Regulatory Guidance and Acceptance Criteria

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors”

- Interim Staff Guidance Augmenting NUREG-1537
  - Radioisotope production facilities
  - Incorporates relevant non-reactor guidance from NUREG-1520, “Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility, Rev. 1”

- Other guidance (e.g., regulatory guides and ANSI/ANS standards) and engineering judgement used, as appropriate, to determine what is necessary for construction permit

NUREG-1537 Review Areas

1. The Facility/Introduction
2. Site Characteristics
3. Design of Structures, Systems, and Components
4. Facility Description
5. Coolant Systems
6. Engineered Safety Features
7. Instrumentation and Control
8. Electrical Power Systems
9. Auxiliary Systems
10. Experimental Facilities*
11. Radiation Protection and Waste Management
12. Conduct of Operations
13. Accident Analysis
14. Technical Specifications
15. Financial Qualifications
16. Other License Considerations*
17. Decommissioning*
18. Uranium Conversions*
19. Environmental Review

* May not be applicable to construction permit application for ^{99}Mo facility

NRC Review Methodology

- For a construction permit application review, level of detail needed in application different than for an operating license application
- For the purposes of issuing a construction permit, the facility may be adequately described at a functional or conceptual level in the PSAR
- Applicants may defer providing many design and analysis details until the submission of its final safety analysis report (FSAR) with its operating license application
- Staff's review tailored to unique and novel technology described in construction permit application using appropriate regulatory guidance

Resolving Technical Issues of Preliminary Designs

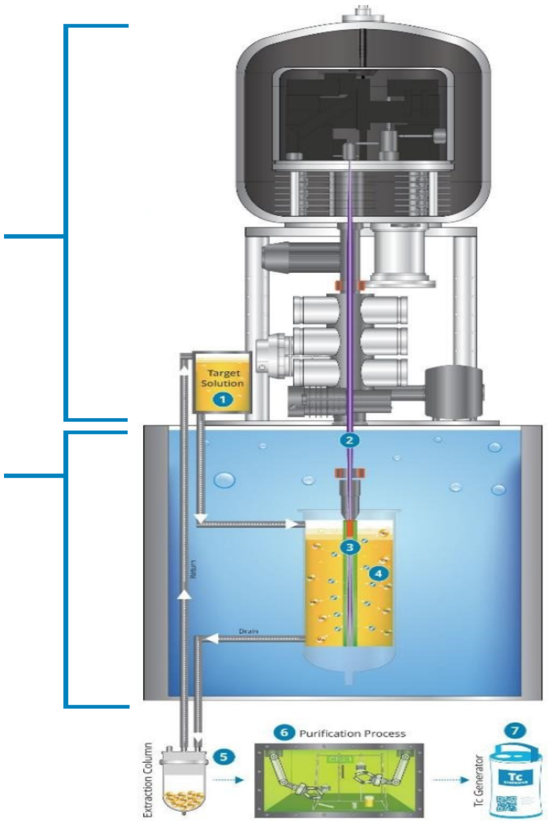
- For technical areas requiring additional information, the staff has several options:
  - The staff may determine that such technical issues must be resolved prior to the issuance of a construction permit
  - The staff may determine that such information may be left until the submission of the FSAR
  - The staff may require that such technical issues be resolved prior to the completion of construction, but after the issuance of the construction permit

- In all cases, staff may issue requests for additional information

- In the second and third options, staff may track regulatory commitments or identify necessary license conditions

SHINE Operating License Application Review

- ^{99}Mo produced by fissioning of low enriched uranium (LEU) solution using eight accelerator-driven subcritical operating assemblies
- ^{99}Mo recovered by processing irradiated solution in three hot cells
- Facility to be located in Janesville, Wisconsin
- Operating license application submitted in July 2019 and accepted for review in October 2019



SHINE
Health. Illuminated.

Northwest Medical Isotopes

- NWMI proposes to manufacture and process LEU targets for ^{99}Mo production
  - Target manufacturing
  - LEU targets irradiated at existing research reactors, including Oregon State University
  - Irradiated targets returned to NWMI for processing

Oregon State University TRIGA Reactor
Source: OSTR Webpage

Prospective Applicants

- Niowave
  - Accelerator-driven subcritical operating assembly, target processing facility, and target fabrication facility
  - Currently conducting proof-of-concept technology demonstrations under an NRC materials license
- Eden Radioisotopes
  - 2-megawatt thermal reactor with hot cell and target fabrication facilities to produce medical radioisotopes
  - Joint construction permit and operating license application, including target fabrication activities, under development
- Atomic Alchemy
  - Four non-power, pool type reactors and processing facility
  - Quality assurance program under review

Licensing Accomplishments

- Issued two construction permits
  - SHINE Medical Technologies (February 2016)
  - Northwest Medical Isotopes (May 2018)
  - Reviews completed in under two years from time of application docketing
- Published guidance in 2018 for medical use applicants and licensees possessing the NorthStar Medical Radioisotopes RadioGenix system
  - Supported first commercial domestic production of ^{99}Mo since Cintichem ceased operations in 1989
- Issued license amendment to OSU in 2016 for demonstration of ^{99}Mo production in small nuclear reactor with experimental uranium targets
- Issued materials license to Niowave in 2015
  - License amendments issued increased LEU possession limit and supported irradiation of natural uranium targets using superconducting linacs for proof of concept

Construction Inspection

- NRC staff developed IMC 2550 in 2015 for construction inspection of new non-power facilities, consisting of three inspection procedures:
  - IP 69020 for safety-related structures, systems, and components (SSCs)
  - IP 69021 for quality assurance program
  - IP 69022 for programmatic inspections

- Inspections commensurate with risk of facility, focusing on most safety-significant SSCs

- Formal construction activities began in October 2019 with the initial pouring of subgrade concrete.

SHINE Construction Site in February 2020

Reflecting Back…

- For novel technologies, early interactions between NRC staff and applicants support efficient application processing and review
- Public pre-application meetings
  - Promote engagement between NRC and potential applicant
  - Inform the development of high-quality applications
  - Inform budgeting and resource allocation
  - Inform public of NRC process
- Best practices from construction permit application reviews:
  - Emphasis on most safety-significant technical aspects
  - Focused requests for additional information
  - Weekly status calls

…And Looking Forward

- Continuing review of SHINE operating license application
- Updating licensing framework
- Anticipating technical and licensing challenges
- Engaging with potential construction permit applicants
- Supporting ongoing activities related to materials and medical use licensees
- Continuing interactions with construction permit holders on facility-specific conditions and annual reports

Impact of Medical Radioisotope Facility Reviews

- Experience gained from reviews supporting a more responsive and efficient technology-inclusive regulatory framework at the NRC
- Considering initial licensing of technologies beyond light water and non-power reactors
- Review of construction permit applications setting example for future advanced reactor reviews
- Success made possible through technical and licensing expertise provided by inter-office working group
- Updates on medical radioisotope facility activities available through NRC public website:
  - http://www.nrc.gov/reactors/medical-radioisotopes.html

Future Meeting Planning

- The next periodic stakeholder meeting is scheduled for August 26, 2021
- If you have suggested topics, please reach out to Margaret.O'Banion@nrc.gov