NATRIUM

Fuel Cycle: Environmental Impacts

a TerraPower & GE-Hitachi technology

NATD-LIC-PRSNT-0027

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Objectives

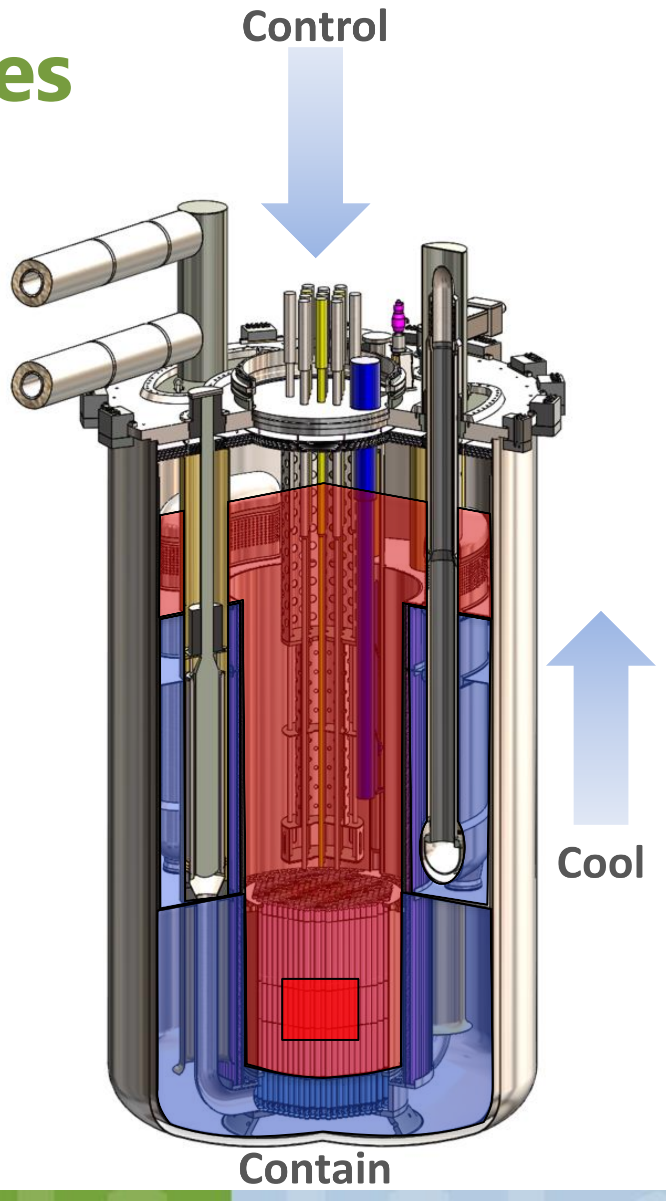
- Natrium™ reactor overview
- Fuel cycle review
- Regulatory requirements and guidance
- Natrium approach to fuel cycle and transportation environmental impacts

Natrium Reactor Overview

- Regulatory Engagement Plan was submitted 6/8/2021
- Construction Permit Application submittal planned for 8/2023
- Pre-application interactions are ongoing, intended to reduce regulatory uncertainty and facilitate the NRC's understanding of the Natrium advanced reactor and its safety case
- The Natrium reactor is demonstrating the ability to design, license, construct, startup and operate the Natrium reactor within a seven-year timeframe

Natrium Safety Features

- Pool-type Metal Fuel SFR with Molten Salt Energy Island
  - Metallic fuel and sodium have high compatibility
  - No sodium-water reaction in steam generator
  - Large thermal inertia enables simplified response to abnormal events
- Simplified Response to Abnormal Events
  - Reliable reactor shutdown
  - Transition to coolant natural circulation
  - Indefinite passive emergency decay heat removal
  - Low pressure functional containment
  - No reliance on Energy Island for safety functions
- No Safety-Related Operator Actions or AC power
- Technology Based on U.S. SFR Experience
  - EBR-I, EBR-II, FFTF, TREAT
  - SFR inherent safety characteristics demonstrated through testing in EBR-II and FFTF



Control

- Motor-driven control rod runback
- Gravity-driven control rod scram
- Inherently stable with increased power or temperature

Cool

- In-vessel primary sodium heat transport (limited penetrations)
- Intermediate air cooling natural draft flow
- Reactor air cooling natural draft flow – always on

Contain

- Low primary and secondary pressure
- Sodium affinity for radionuclides
- Multiple radionuclides retention boundaries

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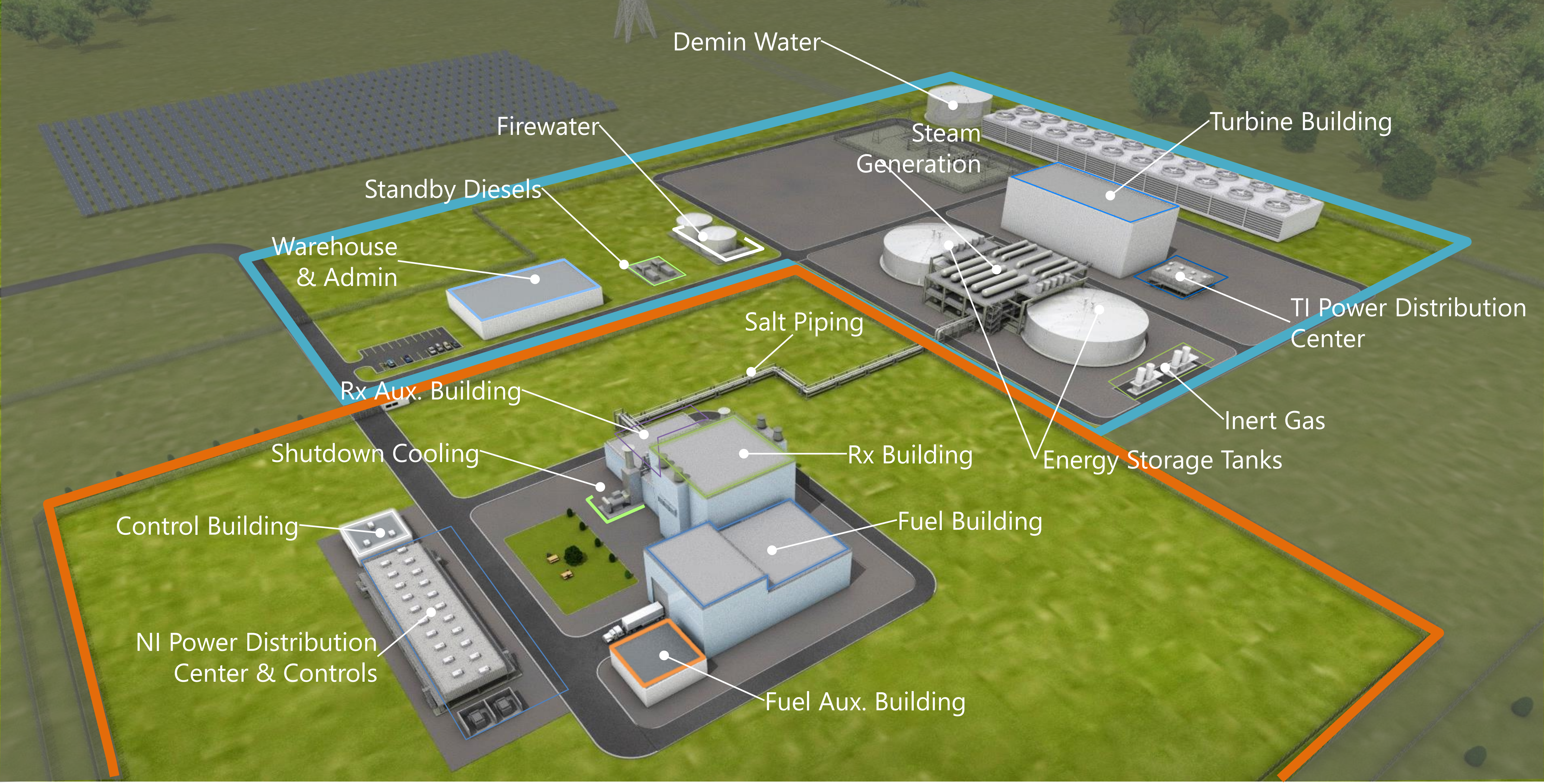
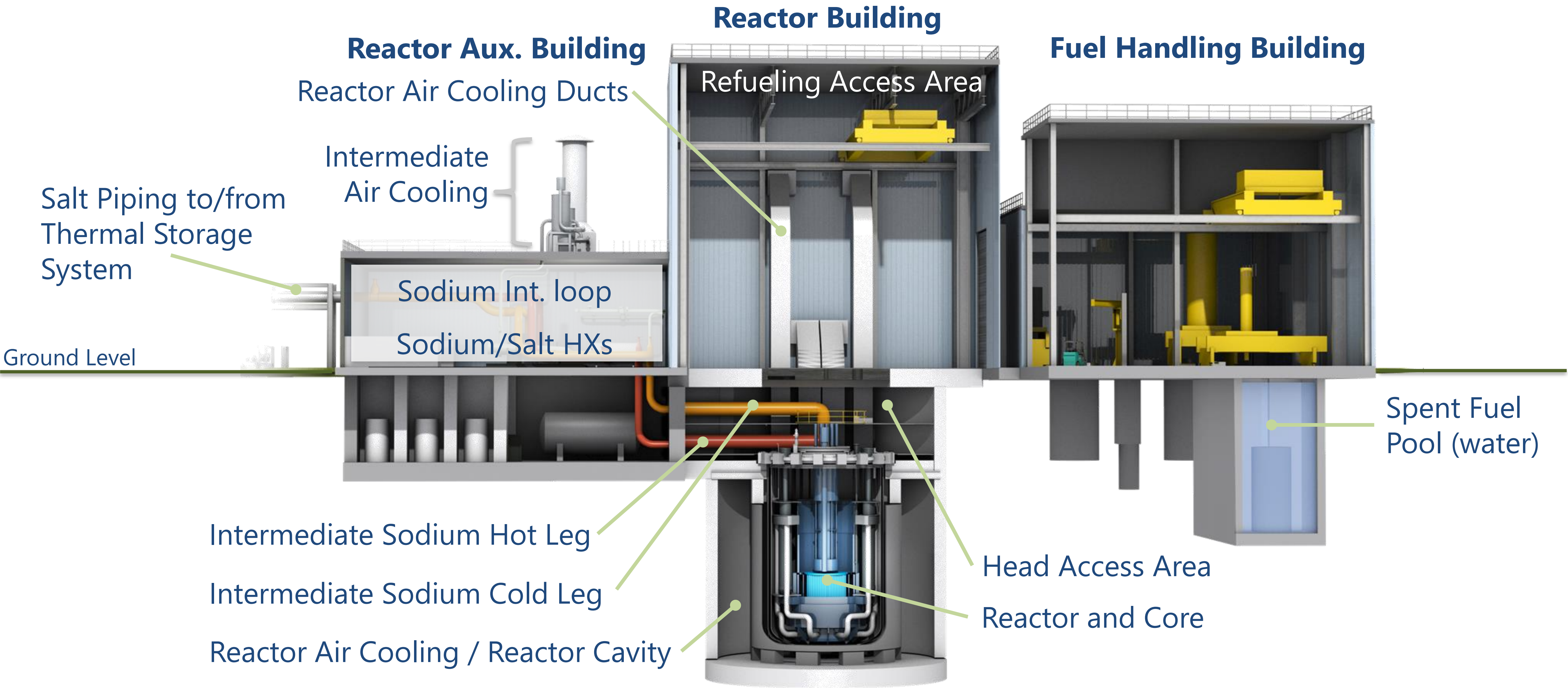

Demin Water
Firewater
Steam Generation
Turbine Building
Standby Diesels
Warehouse & Admin
Salt Piping
TI Power Distribution Center
Rx Aux. Building
Inert Gas
Shutdown Cooling
Rx Building
Energy Storage Tanks
Fuel Building
Control Building
NI Power Distribution Center & Controls
Fuel Aux. Building



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Fuel Cycle Review

Fuel Cycle Review

Input feed stock form

- Metallic fuel with sodium bonding
- Up to 19.75% enriched feed material

Metallic fuel fabrication

- Feed material cast with melted zirconium to form a slug, processed into a rod
- Up to 19.75% enriched fuel rods

Fuel Cycle Review

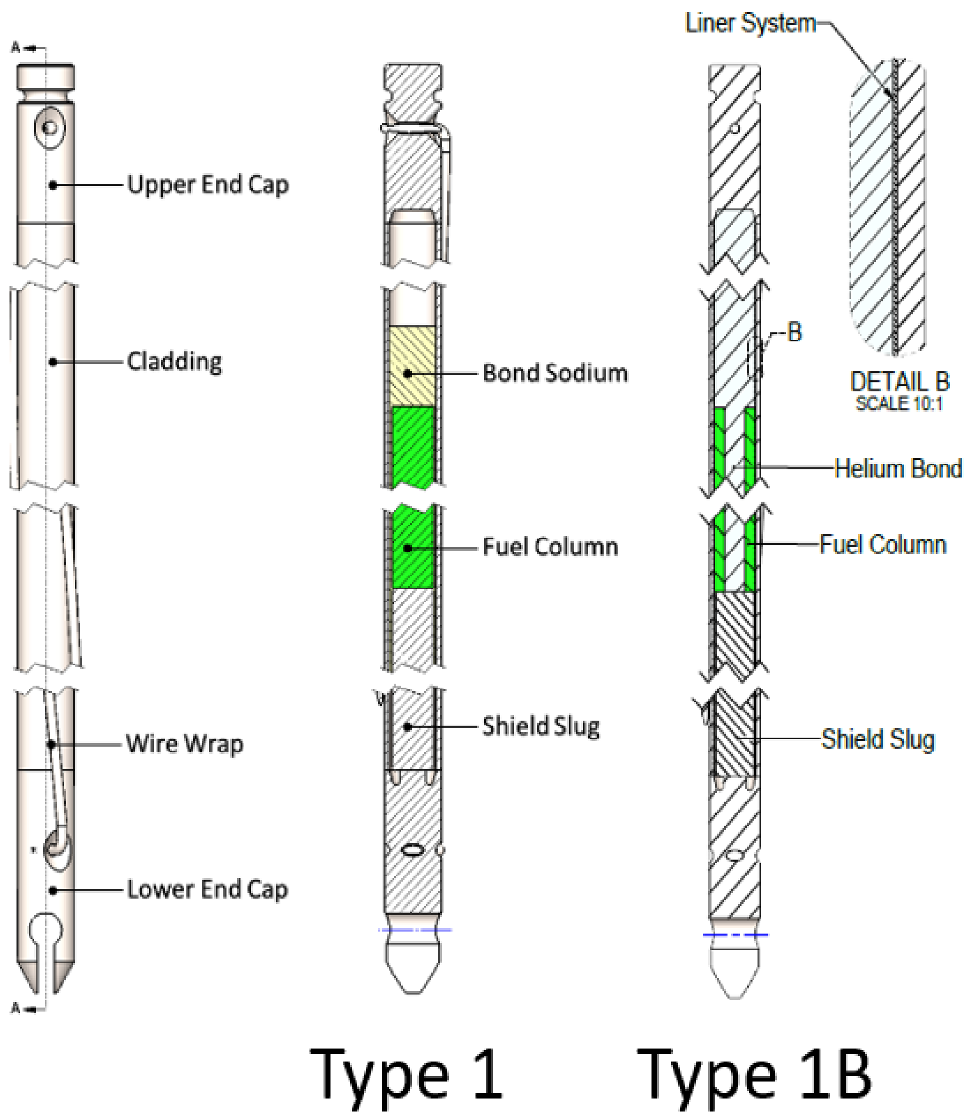
- Fuels are to be supplied by Global Nuclear Fuel – Americas, LLC (GNF-A)

- GNF-A will design and test a new fresh fuel shipping container per applicable NRC regulations

- Proposed transportation is via truck, similar to LWR fresh fuel

Fuel Cycle Review

- Natrium fuel pins employ a metal fuel system instead of oxides
  - U-10Zr fuel for the Type 1 fuel system
  - U-0Zr fuel for the Type 1B fuel system
- Type 1 fuel is based on previous fast reactor experience
  - Sodium bonded, slug metal fuel
  - Shield slugs within the pin with fission gas plenum
- Type 1B is a next generation fuel system
  - Mechanically bonded, no zirconium, annular fuel
  - Liner system to prevent Fuel Cladding Chemical Interactions (FCCI)
  - Shield slugs within the pin with fission gas plenum
  - Allows for significant increase in fuel pin lifetime to support high burnup, high DPA fuel system



Fuel Cycle Review

- Type 1B fuel will produce more electrical power per enriched MTU and greatly reduce the volume of waste, as compared to LWR fuels, as indicated in the previous meeting

- Natrium will transition from Type 1 to Type 1B fuel, in accordance with the lead test assembly program governed by technical specifications, for improved waste impacts and economics

Fuel Cycle Review

- For interim storage, the project is pursuing dry storage and transportation cask designs which account for Natrium-specific fuel differences

- The Sandia, Onkalo, and Deep Isolation models are planned to be evaluated for comparison against LWR characteristics

Regulatory Requirements and Guidance

Regulatory Requirements and Guidance

Fuel cycle impacts are evaluated against specific criteria in 10 CFR 51.51, "Uranium fuel cycle environmental data - Table S-3" for LWR designs

Environmental Considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1,000 MWe LWR
Natural Resource Use		
Land (acres)		
Temporarily committed[2]	100	
Undisturbed area	79	
Disturbed area	22	Equivalent to a 110 MWe coal-fired power plant.
Permanently committed	13	
Overburden moved (millions of MT)	2.8	Equivalent to 95 MWe coal-fired power plant.
Water (millions of gallons)		
Discharged to air	160	=2 percent of model 1,000 MWe LWR with cooling tower.
Discharged to water bodies	11,090	
Discharged to ground	127	
Total	11,377	<4 percent of model 1,000 MWe LWR with once through cooling.
Fossil Fuel:		
Electrical energy (thousands of MW-hour)	323	<5 percent of model 1,000 MWe LWR output
Equivalent coal (thousands of MT)	118	Equivalent to the consumption of a 45 MWe coal-fired power plant.
Natural gas (millions of scf)	135	<0.4 percent of model 1,000 MWe energy output.
Effluents—Chemical (MT)		
Gases (including entrainment):[3]		
SO_x	4,400	
NO_x[4]	1,190	Equivalent to emissions from 45 MWe coal-fired plant for a year.
Hydrocarbons	14	
CO	29.6	
Particulates	1,154	
Other gases		
F	.67	Principally from UF_6, production, enrichment, and reprocessing. Concentration within range of state standards—below level that has effects on human health.
HCl	.014	
Liquids:		
$SO-_4$	9.9	From enrichment, fuel fabrication, and reprocessing steps. Components that constitute a potential for adverse environmental effect are present in dilute concentrations and receive additional dilution by receiving bodies of water to levels below permissible standards. The constituents that require dilution and the flow of dilution water are: NH_3—600 cfs., NO_3—20 cfs., Fluoride—70 cfs.
$NO-_3$	25.8	
Fluoride	12.9	
CA^+	5.4	
$C1^-$	8.5	
Na^+	12.1	

Regulatory Requirements and Guidance

Transportation of fuel and wastes are to be evaluated against specific criteria in 10 CFR 51.52, “Environmental effects of transportation of fuel and waste - Table S-4” for LWR designs

Summary Table S–4—Environmental Impact of Transportation of Fuel and Waste To and From One Light-Water-Cooled Nuclear Power Reactor[1]

Normal Conditions of Transport

	Environmental Impact
Heat (per irradiated fuel cask in transit)	250,000 Btu/hr.
Weight (governed by Federal or State restrictions)	73,000 lbs. Per truck; 100 tons per cask per rail car.
Traffic density:	
Truck	Less than 1 per day.
Rail	Less than 3 per month.

Exposed Population	Estimated Number of Persons Exposed	Range of Doses to Exposed Individuals[2] (per reactor year)	Cumulative Dose to Exposed Population (per reactor year)[3]
Transportation workers	200	0.01 to 300 millirem	4 man-rem.
General public:			
Onlookers	1,100	0.003 to 1.3 millirem	3 man-rem.
Along Route	600,000	0.0001 to 0.06 millirem	

Accidents in Transport

Types of Effects	Environmental Risk
Radiological effects	Small[4]
Common (nonradiological) causes	1 fatal injury in 100 reactor years; 1 nonfatal injury in 10 reactor years; $475 property damage per reactor year.

[1] Data supporting this table are given in the Commission's "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH–1238, December 1972; and Supp. 1 of NUREG–75/038, April 1975. Both documents are available for inspection and copying at the Commission's Public Document Room, One White Flint North, 11555 Rockville Pike (first floor), Rockville, Maryland 20852 and may be obtained from National Technical Information Service, Springfield, VA 22161. The WASH–1238 is available from NTIS at a cost of $5.45 (microfiche, $2.25) and NUREG–75/038 is available at a cost of $3.25 (microfiche, $2.25).

[2] The Federal Radiation Council has recommended that the radiation doses from all sources of radiation other than natural background and medical exposures should be limited to 5,000 millirem per year for individuals as a result of occupational exposure and should be limited to 500 millirem per year for individuals in the general population. The dose to individuals due to average natural background radiation is about 130 millirem per year.

[3] Man-rem is an expression for the summation of whole body doses to individuals in a group. Thus, if each member of a population group of 1,000 people were to receive a dose of 0.001 rem (1 millirem), or if 2 people were to receive a dose of 0.5 rem (500 millirem) each, the total man-rem dose in each case would be 1 man-rem.

[4] Athough the environmental risk of radiological effects stemming from transportation accidents is currently incapable of being numerically quantified, the risk remains small regardless of whether it is being applied to a single reactor or a multireactor site.

[49 FR 9381, Mar. 12, 1984; 49 FR 10922, Mar. 23, 1984, as amended at 53 FR 43420, Oct. 27, 1988; 72 FR 49512, Aug. 28, 2007; 79 FR 66604, Nov. 10, 2014; 86 FR 67843, Nov. 30, 2021]

Regulatory Requirements and Guidance

- Regulatory Guide 4.2, "Preparation of Environmental Reports for Nuclear Power Stations" states the ER should address the environmental impacts from the uranium fuel cycle and solid waste management, the transportation of radioactive material, and the decommissioning of the proposed nuclear plant (including considerations in preliminary draft DG-4032)
- Continued storage impacts are addressed in NUREG-2157, "Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel" and are deemed incorporated into the EIS

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Regulatory Requirements and Guidance

- 10 CFR 51.51, "Uranium fuel cycle environmental data - Table S-3" states ERs for LWRs shall include Table S-3 and may be supplemented by a discussion of the environmental significance of the data set forth in the table as weighed in the analysis for the proposed facility
- Data of Table S-3 are given in WASH-1248, NUREG-0116, and NUREG-0216
- WASH-1248, "Environmental Survey of the Uranium Fuel Cycle" indicates it is based upon an LWR fuel cycle with the following characteristics:
  - UO_2 fuel (vs metallic fuel for Natrium)
  - Enrichment of 2-4% (vs up to 19.75% for Natrium)
  - Lifetime average irradiation level of 33,000 MWd/MTU (vs the maximum Natrium burnup in the range of that exhibited by Gen III+ LWR designs and PRISM)

Regulatory Requirements and Guidance

- 10 CFR 51.52, "Environmental effects of transportation of fuel and waste - Table S-4" states ERs for LWRs shall contain a statement indicating the conditions in paragraph (a) are met or a full description and detailed analysis of the environmental effects of transportation of fuel and wastes to and from the reactor
- The Natrium reactor does not meet the following conditions of 10 CFR 51.52(a)
  - (a)(2) fuel form of sintered UO_2 pellets (vs metallic fuel for Natrium) of up to 4% weight enrichment U235 (vs up to 19.75% for Natrium)
  - (a)(3) average irradiation of irradiated fuel is not to exceed 33,000 MWd/MTU (vs the maximum Natrium burnup in the range of that exhibited by Gen III+ LWR designs and PRISM)

Regulatory Requirements and Guidance

- 10 CFR 51.23, “Environmental impacts of continued storage of spent nuclear fuel beyond the licensed life for operation of a reactor” states:
  - ERs are not required to discuss the environmental impacts of spent nuclear fuel storage in a reactor facility storage pool or an ISFSI for the period following the term of the reactor operating license
  - Impact determinations in NUREG-2157 regarding continued storage shall be deemed incorporated into the EIS
- NUREG-2157, “Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel” indicates that ANRs are not within the scope and are not addressed
- Draft NUREG-2249, “Generic Environmental Impact Statement for Advanced Nuclear Reactors” indicates that the Staff will incorporate NUREG-2157 by reference in the EIS and will evaluate applicability to ANRs

Natrium Approach to Fuel Cycle and Transportation Environmental Impacts

Natrium Approach to Fuel Cycle Environmental Impacts

- Consistent with the information in 10 CFR 51.51 Table S-3:
  - Analysis to determine the fuel cycle and waste management environmental impacts from mining, milling, conversion, enrichment, fuel fabrication, and disposal will be performed
  - Areas of impact to be considered are land use, water use, fossil fuel impacts, chemical effluents, radiological effluents, and radiological wastes
- Analysis will consider the guidance of:
  - RG 4.2, Rev. 3 (as well as Appendix C to preliminary draft DG-4032)
  - PNNL-29367, "Non-LWR Fuel Cycle Environmental Data" which provides information to aid in the determination of environmental impacts
  - Draft NUREG-2249

Natrium Approach to Fuel Cycle Environmental Impacts

- Industry improvements since the development of Table S-3:
  - Assumed use of in-situ uranium recovery (consistent with draft NUREG-2249 and PNNL-29367) results in reduced impacts as compared to conventional mining techniques
  - Assumed use of gas centrifuge technology (consistent with draft NUREG-2249 and PNNL-29367) requires less energy consumption than that required for gaseous diffusion
  - More recent fuel mix for electric generation (to support fuel processes) is likely to result in less environmental impacts than that originally assumed
  - Potential use of foreign source of uranium would mitigate impacts due to mining, milling, and conversion

Natrium Approach to Transportation Environmental Impacts

- As the conditions in 10 CFR 51.52(a) are not met, our analysis will be consistent with 10 CFR 51.52(b) (and Table S-4) and will determine the environmental impacts of transportation of fuel and wastes. The analysis will include evaluations of:
  - Transportation of unirradiated fuel
    - Radiological impacts of normal transportation
    - Non-radiological impacts of accidents
  - Transportation of irradiated fuel
    - Radiological impact of normal transportation
    - Radiological impacts of accidents
    - Non-radiological impacts of accidents
  - Transportation of radioactive wastes
    - Radiological impacts of normal transportation
    - Radiological impacts of accidents
    - Non-radiological impacts of accidents

Natrium Approach to Transportation Environmental Impacts

- Analysis will consider guidance of:
  - RG 4.2, Rev. 3 (as well as Appendix C to preliminary draft DG-4032)
  - PNNL-29365, "Environmental Impacts from Transportation of Fuels and Wastes to and from Non-LWRs"
  - Draft NUREG-2249
- Analysis will use the following computer codes:
  - WebTRAGIS for routing analysis used as input into RADTRAN
  - RADTRAN to estimate the radiological impacts from normal transportation and accidents

Natrium Approach to Transportation Environmental Impacts

- Inputs to analyses include:
  - Mode of transportation
  - Shipment distance and routing information (i.e., from fabrication facility, to LLW disposal facility, and to repository)
  - Number of shipments
  - Transportation package characteristics
  - Anticipated dose rates
- Bounding assumptions will be made for input for which final information has not been established, for example:
  - Transition to a next generation fuel system
  - Location of LLW disposal and repository facilities
  - Transportation package characteristics
  - Package dose rates

Natrium Approach to Fuel Cycle and Transportation Environmental Impacts

- A description of the methods of the analyses regarding environmental impacts of the fuel cycle and transportation of fuel and waste will be included in the ER

- The ER will include the results of the analyses and a comparison with the information provided in Tables S-3 and S-4

Questions?

Acronym List

ARDP – Advanced Reactor Demonstration Program
DOE – Department of Energy
DPA – Displacements per Atom
EA – Environmental Assessment
EBR – Experimental Breeder Reactor
EIS – Environmental Impact Statement
ER – Environmental Report
FCCI – Fuel Cladding Chemical Interactions
FFTF – Fast Flux Test Facility
GNF-A – Global Nuclear Fuel – Americas, LLC
GWe – Gigawatt Electric
GWe-yr – Gigawatt Electric Year
HALEU – High-Assay Low-Enriched Uranium
HM – Heavy Metal
LWR – Light-Water Reactor
MT – Metric Ton
MTU – Metric Ton Uranium
NRC – Nuclear Regulatory Commission
SFR – Sodium Fast Reactor
TREAT – Transient Reactor Test