Overview of Natrium™ Demonstration Plant Implementation of ASME QME-1 for Qualification of the Control Rod Drive (CRD)

Natrium®

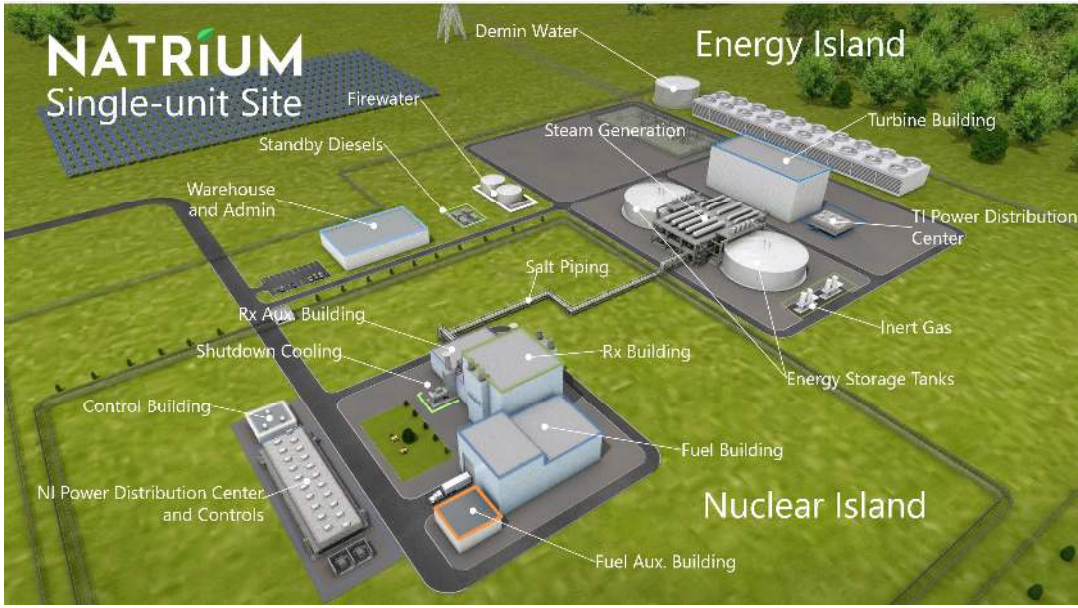
a TerraPower and GE-Hitachi technology

TerraPower Natrium

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

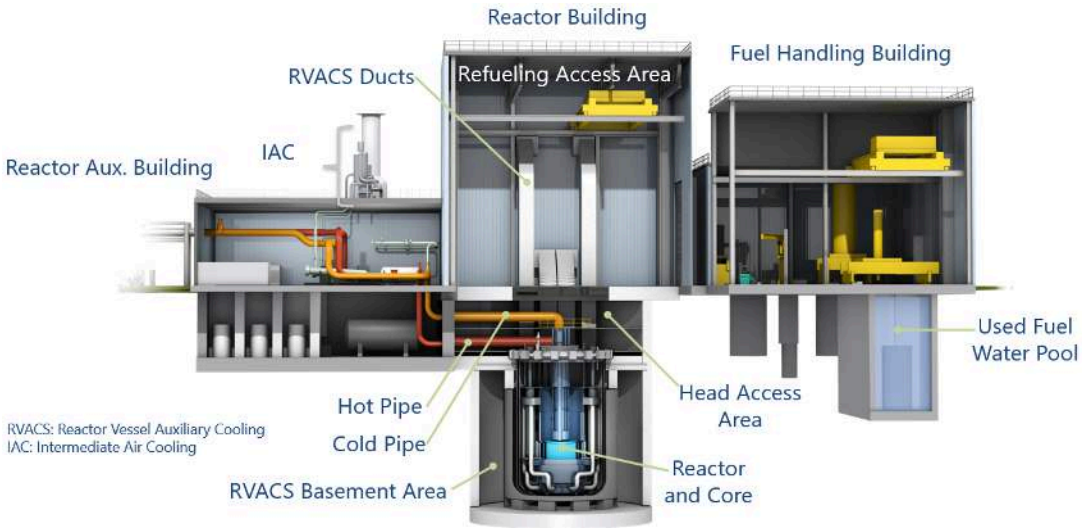
Natrium™ Overview

- In October 2020, the Department of Energy (DOE) selected the Natrium advanced reactor design for the Advanced Reactor Demonstration Program (ARDP)
- 345 MWe sodium cooled fast reactor (SFR)
- Under construction in Kemmerer Wyoming – generating electricity in 2030



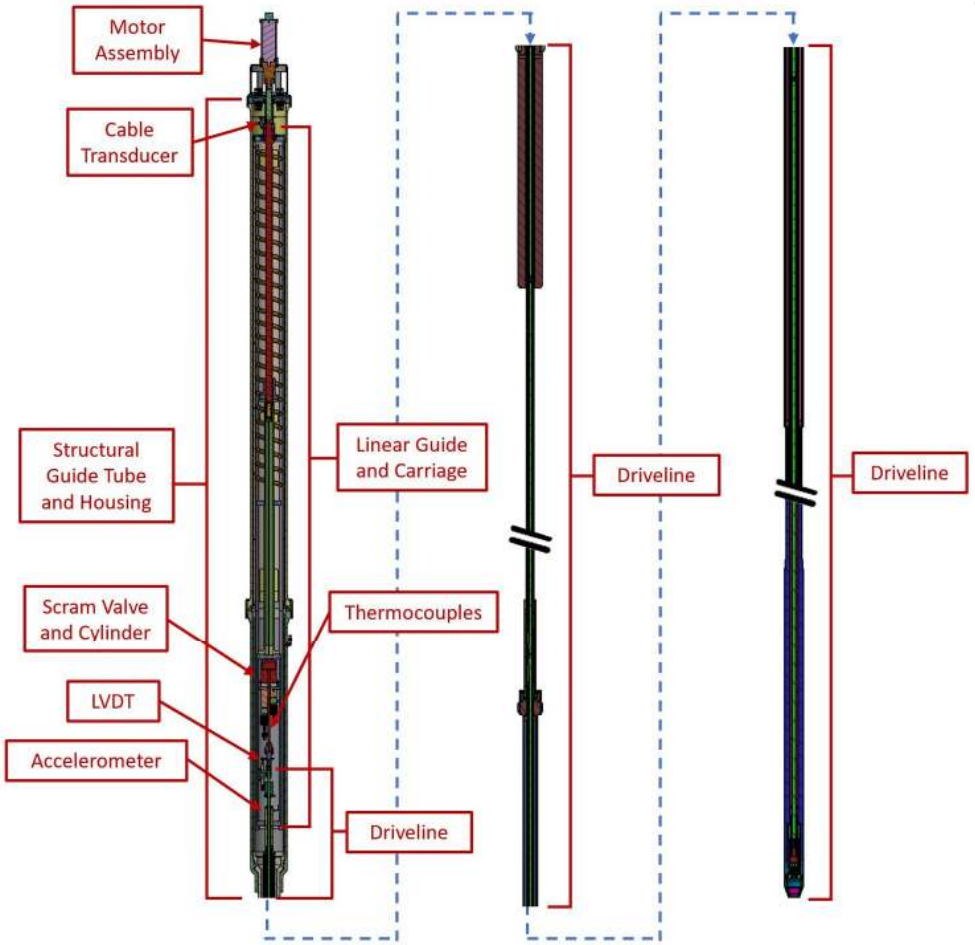
Control Rod Drive System Overview

- Function: Provide core reactivity control for the purpose of core power control, power shaping, and reactor shutdown.
- CRD positions control rods within the reactor core to change power and perform rapid shutdown of the reactor (Scram).
- Capable of inserting or withdrawing control rods at slow controlled rate, or at a rapid insertion in the event of an off-normal condition



Natrium CRD Overview

- Natrium CRD is motor driven from the top of the reactor head
- Full assembly is approximately 70 ft. long
- Composed of multiple subassemblies:
  - Drive Mechanism (CRDM)
    - Scram Valve and Cylinder Assembly, Motor, Carriage Assembly
  - Driveline
- Scram function is a gravity driven uncoupling of control rod assemblies
- Natrium CRD system consists of 13 CRDs



Natrium CRD Safety Related Functions

Reactivity Control

- Scram on signal
- Scram on loss of power

Retain Radionuclide

- The CRDM seal interface with Reactor Enclosure System performs part of the primary coolant boundary barrier function

ASME QME-1 Overview

- From QR-1000 Scope: “This Standard provides the requirements and guidelines for the qualification of active mechanical equipment whose function is required to ensure the safe operation or safe shutdown of a nuclear facility.”
- From QR-4000 Definitions: *Active mechanical equipment* is defined as “mechanical equipment containing moving parts, which, in order to accomplish its required function as defined in the Qualification Specification, must undergo or prevent mechanical movement. This includes any internal components or appurtenances whose failure degrades the required function of the equipment.”
  - Note: The QME-1 standard does not apply to electric components such as motors, electric valve actuators, instrumentation, and controls, which are qualified by conformance with appropriate IEEE standards.

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Organization of QME-1

- QME-1 consists of four major sections:
  - (a) Section QR: Qualification Requirements
  - (b) Section QDR: Qualification of Dynamic Restraints
  - (c) Section QP: Qualification of Active Pump Assemblies
  - (d) Section QV: Qualification Requirements for Active Valve Assemblies for Nuclear Facilities.

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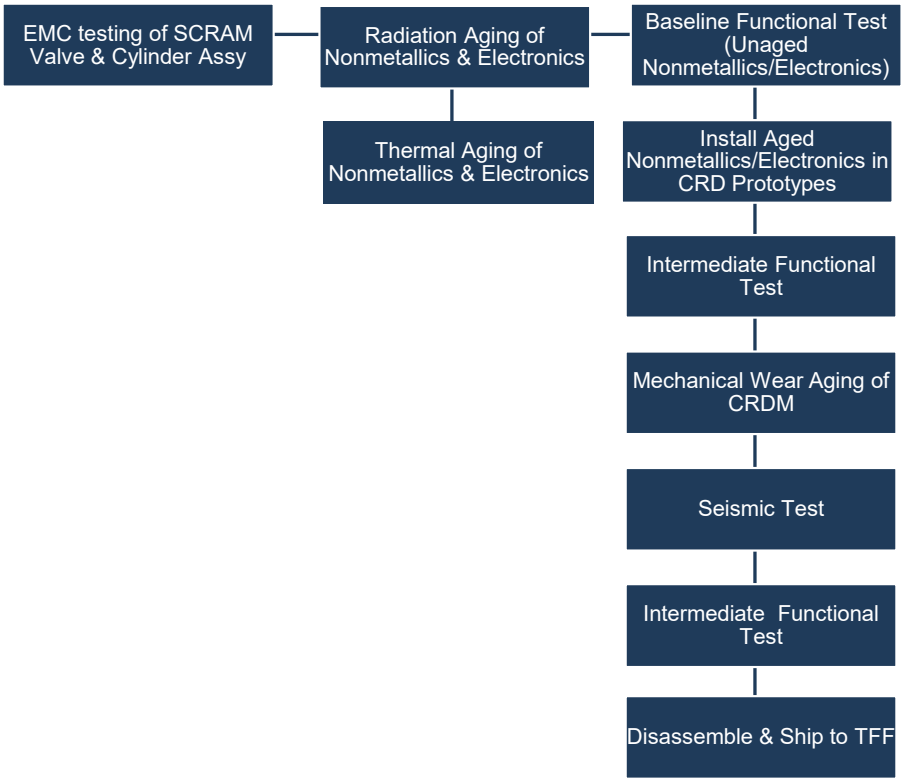
QME-1 Application to CRDs

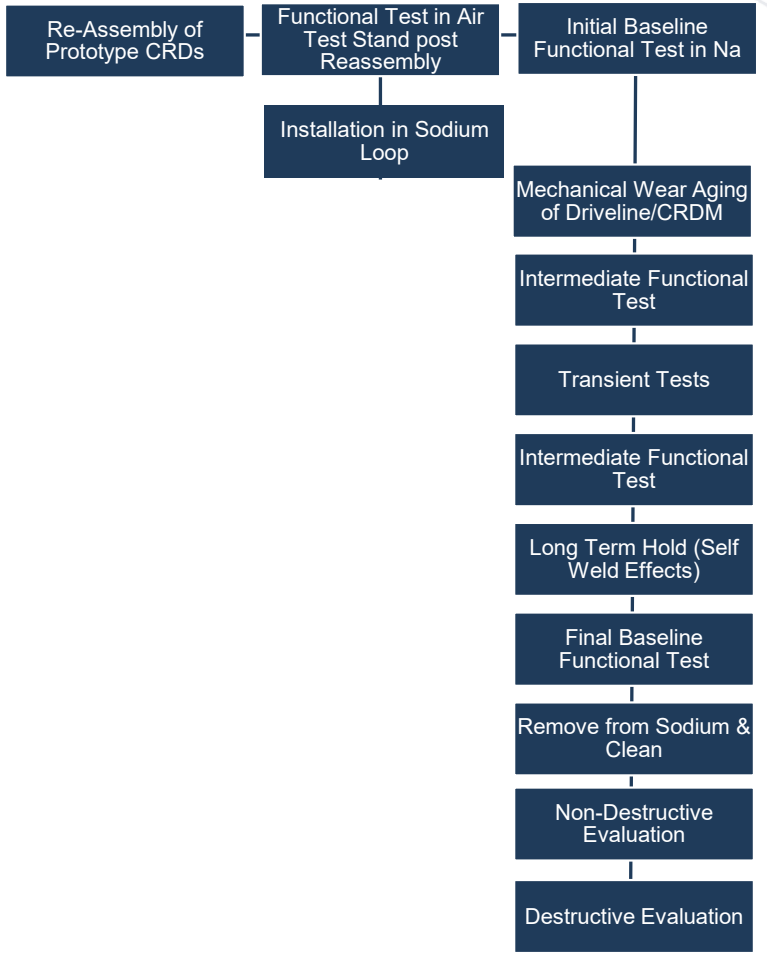
- QR-2000 Purpose “The purpose of this Standard is to provide the requirements and recommended practices to qualify active mechanical equipment to meet specified functional requirements during operation and during or after any postulated abnormal or accident conditions.”
- The CRD is neither a dynamic restraint, a pump, or valve. However, it is an active mechanical assembly whose function is required to ensure the safe operation or safe shutdown of the Natrium™ Demonstration Plant.
- The Guidance from QME-1 Section QR and its nonmandatory Appendixes will be applied for the requirements and guidelines for the qualification of the CRD assembly to meet its specified functional requirements during operation and during or after any postulated abnormal or accident conditions.

Test Strategy

3rd Party Labs



TFF



Test Facilities

GEH San Jose

- In San Jose, CA
- Used to support assembly and full assembly baseline functional test

TBD 3rd party test labs

- Being selected & finalized to support non-sodium qualification testing
- Challenges associated with height requirements

Test & Fill Facility (TFF)

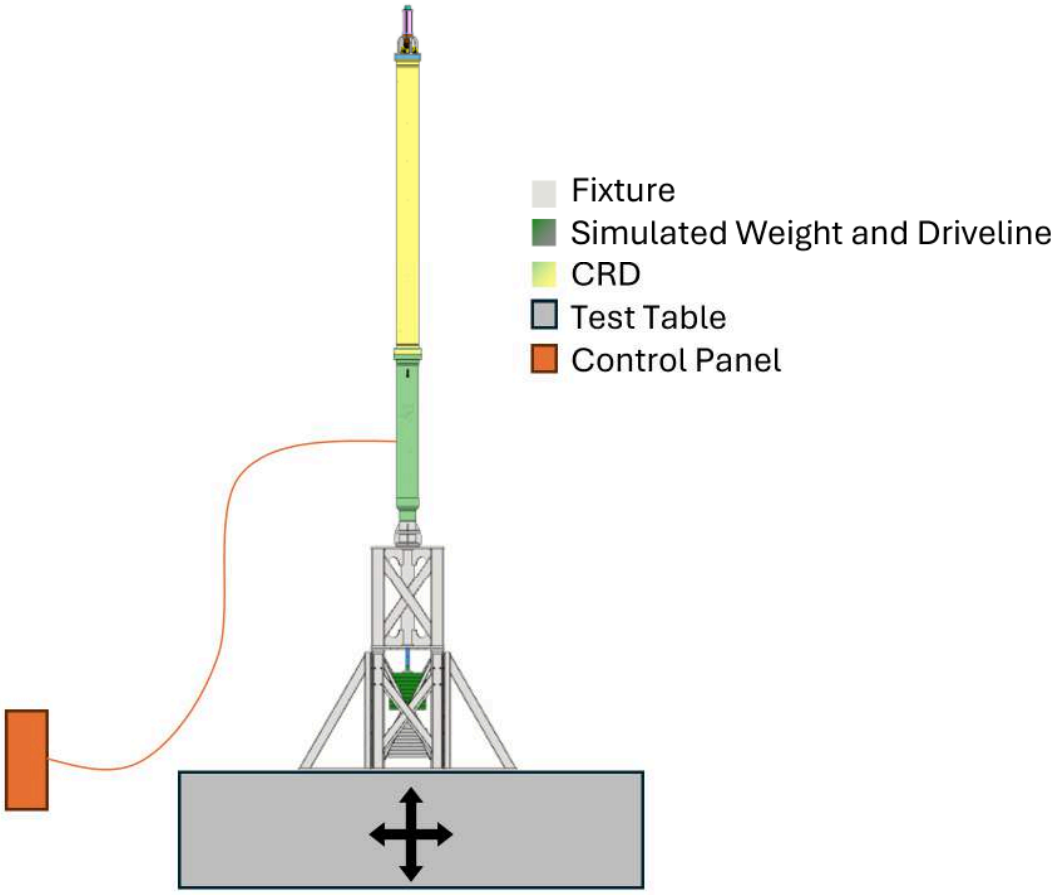
- Currently under construction in Kemmerer, Wyoming via Bechtel
- Specifically built to support in sodium testing of Natrium Components such as the CRD

Radiation & Thermal Aging

- Equipment to be qualified per ASME QME-1, IEEE/IEC 60780-323 as endorsed by Reg Guide 1.89.
- Equipment shall be designed to perform its safety function when exposed to the normal operational radiation levels and accident radiation levels.
- Artificial aging shall be used to simulate time-temperature degradation. Artificial aging shall be determined from the Arrhenius Equation. Artificial accelerated aging will also expose the components to temperature dependent aging mechanism if existent
- All Age sensitive elastomeric components and instrumentation; individual subcomponents will be separately aged then assembled into the CRDM.

Seismic Qualification and Vibration Aging

- Seismic qualification shall be performed consistent with IEEE/IEC 60980-344, ASME QME-1, and Regulatory Guide 1.100
- Due to height limitations the CRDM and Driveline is not planned to be seismically tested as a full assembly
- The CRDM and a truncated version of the driveline shall undergo a low level resonance search
- The driveline will be seismically qualified via analysis, whereas the CRDM assembly will be seismically tested on a tri-axial table.
- CRDM shall demonstrate safety function during Safe Shutdown Earthquake (SSE) test



Mechanical Aging

- Mechanical cyclic fatigue test to qualify the assembly's ability for lifetime function
- Mechanical Aging to be performed in sodium on the full assembly
- Aging will consist of lifetime scram cycles and lifetime insertion and withdraw linear movements, under expected loads

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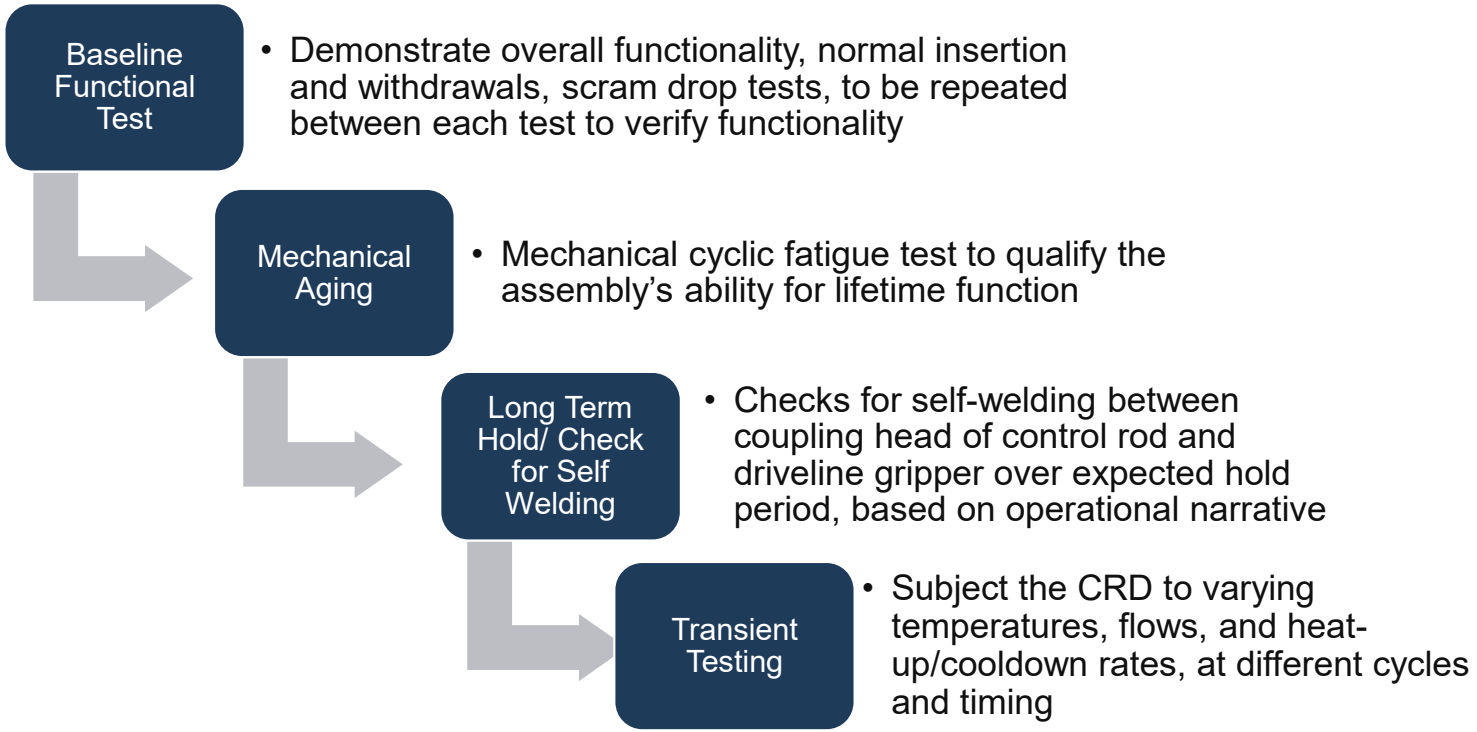
In Sodium Functional Tests and Qualification



*Functional Test to be performed between each test case and at the end of the test program

THANK YOU

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Why Sodium Coolant?

Thermophysical

- Low vapor pressure
- High boiling point (883 C)
- Practical melting point (98 C)
- Similar viscosity and density to water

Neutronics

- Low absorption, negligible moderation
- No degradation w/ irradiation
- Na-24 activation (15h half life)

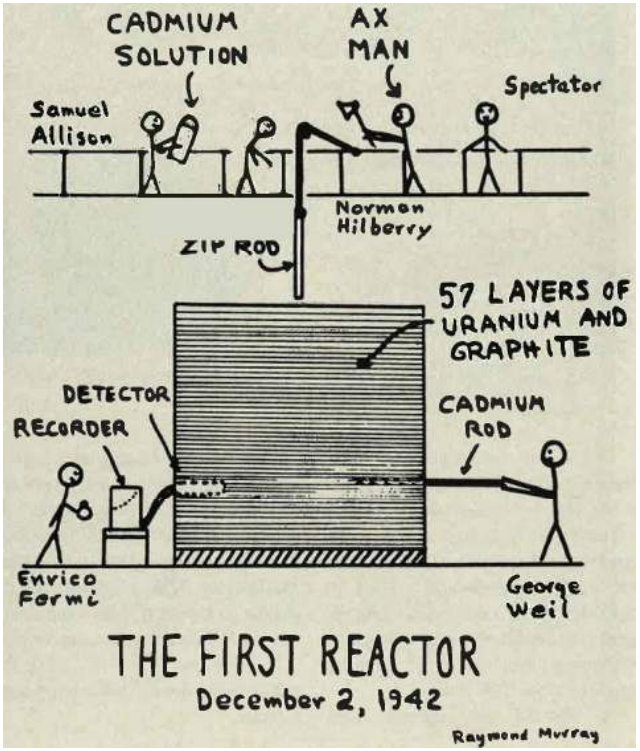
Safety

- Atmospheric pressure coolant
- Phenomenal passive heat transfer
- Must maintain inert cover gas
- Must avoid water

Costs

- Reasonable ~$9/kg
- No makeup required
- Low pumping power
- Practically corrosion free

SCRAM



- The term "scram" is often attributed to the early days of nuclear reactors, specifically from the Chicago Pile (CP-1), the first atomic reactor developed for the Manhattan Project. It is commonly believed to stand for "Safety Control Rod Axe Man." A worker was reportedly stationed with an axe to cut a rope, dropping control rods into the reactor to stop the reaction if it became uncontrollable.
- However, this is a myth according to the NRC website. More likely scram came from 20th century slang. Once you hit the big red scram button you, you scram out of there.
- https://www.nrc.gov/reading-rm/basic-ref/students/history-101/putting-axe-to-scram-myth.html