Alternate Shutdown Systems

Regulatory Engagement 4th Meeting

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Reactivity Control System Regulation SRF-DC-26

A minimum of two reactivity control systems or means shall provide:

- A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the design limits for the fission product barriers are not exceeded and safe shutdown is achieved and maintained during normal operation, including anticipated operational occurrences.
- A means which is independent and diverse from the other(s), shall be capable of controlling the rate of reactivity changes resulting from planned, normal power changes to assure that the design limits for the fission product barriers are not exceeded.
- A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the capability to cool the core is maintained and a means of shutting down the reactor and maintaining, at a minimum, a safe shutdown condition following a postulated accident.
- A means for holding the reactor shutdown under conditions which allow for interventions such as fuel loading, inspection and repair shall be provided.

Alternate Shutdown Systems Need

An alternate shutdown system (non rod based) is not needed

- Self protecting nature of reactor
- Two separate rod based [primary and secondary (safety)] systems, each capable of shutting down reactor
- Very high reliability of diverse drive and actuation systems
- High Reliability of reactor protection systems
- A diverse protection system designed to drive the rods into the core
- Unlikely possibility that core and control elements deformations could develop (and not be identified in time) to an extent the rod insertion might be precluded

[redacted]

Inherent Reactivity Feedback

As temperatures rise, the net negative feedback reduces power. The natural feedbacks are self-regulating, inherent in the fuel design, and result in a safe and stable power level at which heat production and heat removal are in balance.

- Doppler feedback: Effect of changes in neutron fission and absorption cross sections due to Doppler broadening
  - Negative for ARC-100 at elevated temps
- Coolant density and void worth: Effect of changes in Na coolant atom cross sections
  - At elevated temperatures, this could be positive due to reduced Na absorption, or negative due to enhanced neutron leakage
- Axial fuel expansion: Effect of thermal expansion of metal fuels in the cladding tube
  - Negative at elevated temperatures due to reduced number density of fissionable isotopes
- Radial core expansion: Due to thermal expansion, irradiation-induced swelling, and irradiation-enhanced creep
  - Negative at elevated temperatures due to enhanced leakage

Following an anticipated operational occurrence (AOO) a design basis event (DBE), or a Beyond Design Basis event (BDBE),the ARC-100 inherently goes to a Controlled state: an inherently and passively stabe state in which, long-term heat removal is assured, radioactive releases are controlled and acceptable and reactor coolant inventory is acceptable, but the reactor in not subcritical.

The ARC-100 can remain in a controlled state for an indefinitely long period, without any fuel cladding breaching. Thus, the ARC-100 controlled state meets the first part of SFR DC 26(1) condition (i.e., the design limits for the fission product barriers are not exceeded), however, it does not meet the second condition (i.e., safe shutdown is achieved and maintained).

Reactivity Control System

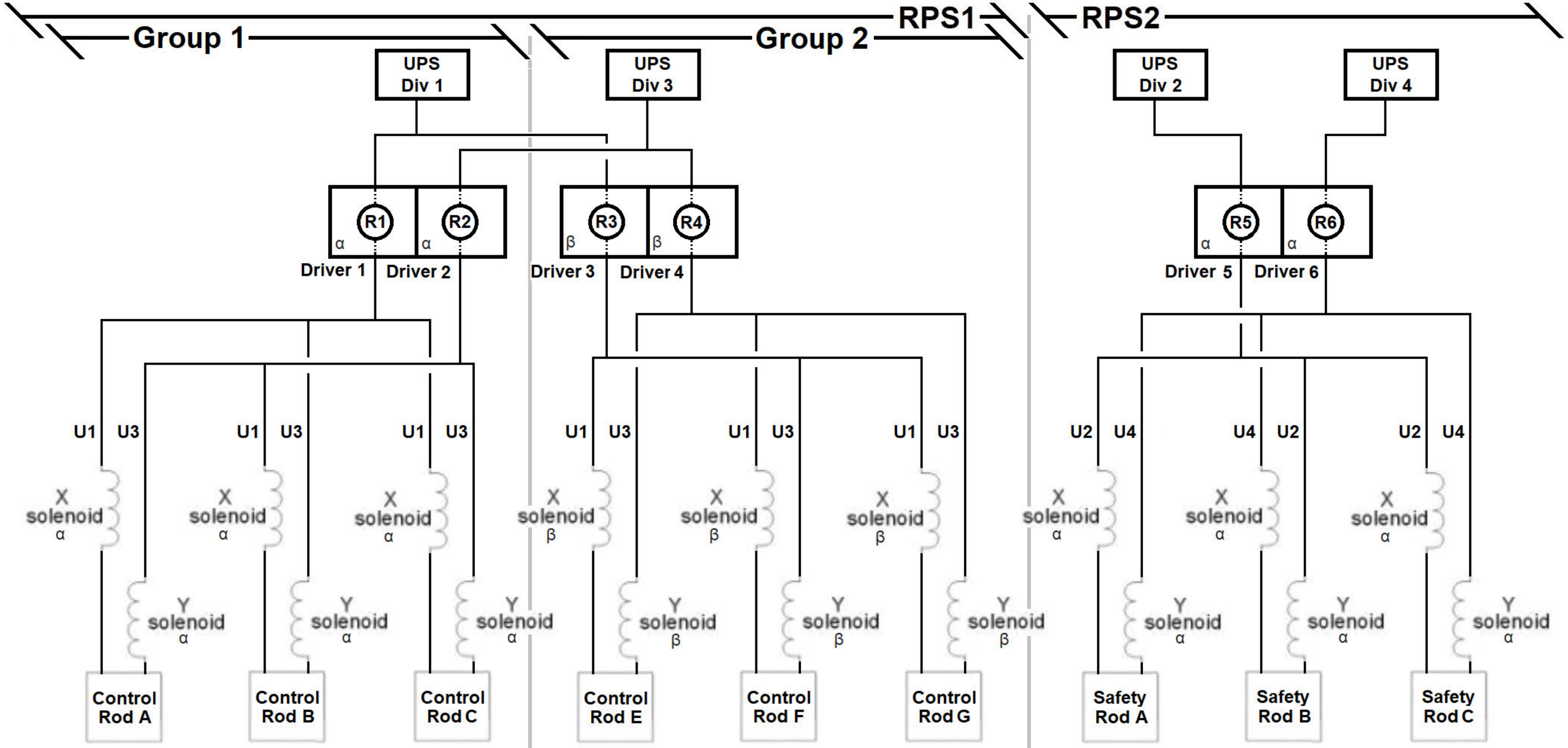
[redacted]

Primary Control Rod

Secondary (Safety) Control Rod

[redacted]

Diversity in Actuation



Manufacturer	Drivers	Rods	
		Primary	Secondary
Alpha (α)	1, 2, 5, 6	A, B, C	A, B, C
Beta (β)	3, 4	E, F, G	——

Alpha & Beta Driver manufacturers are not necessarily the same as Alpha & Beta Solenoid manufacturers.

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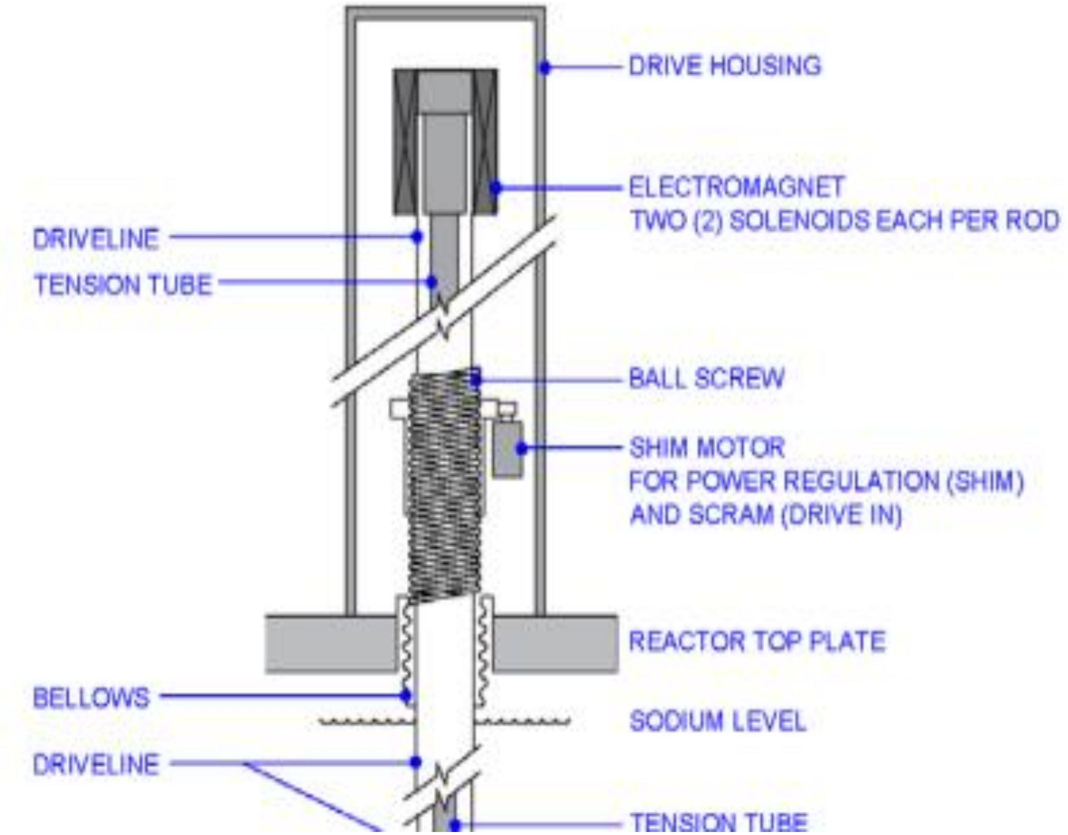
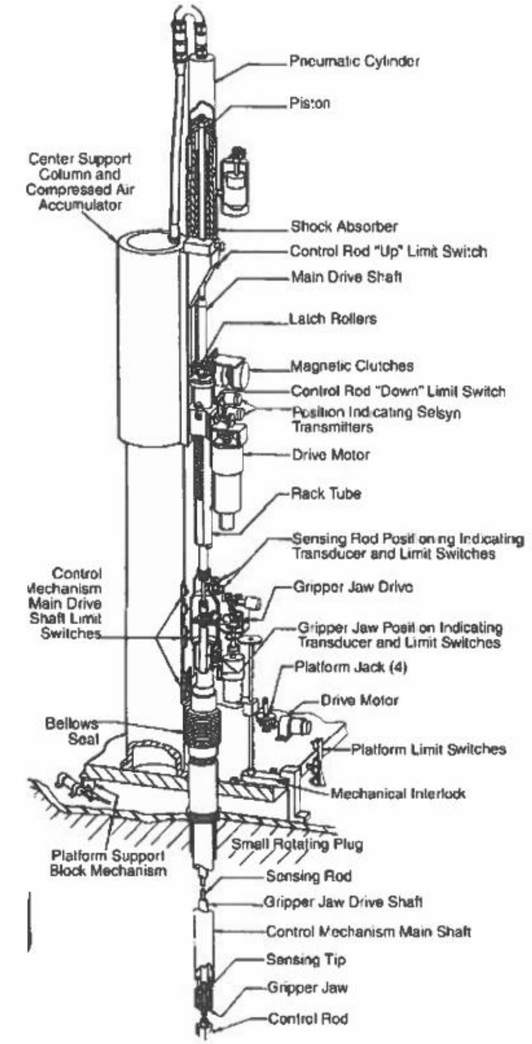
Diversity in Drives (See next two slides for more clarity

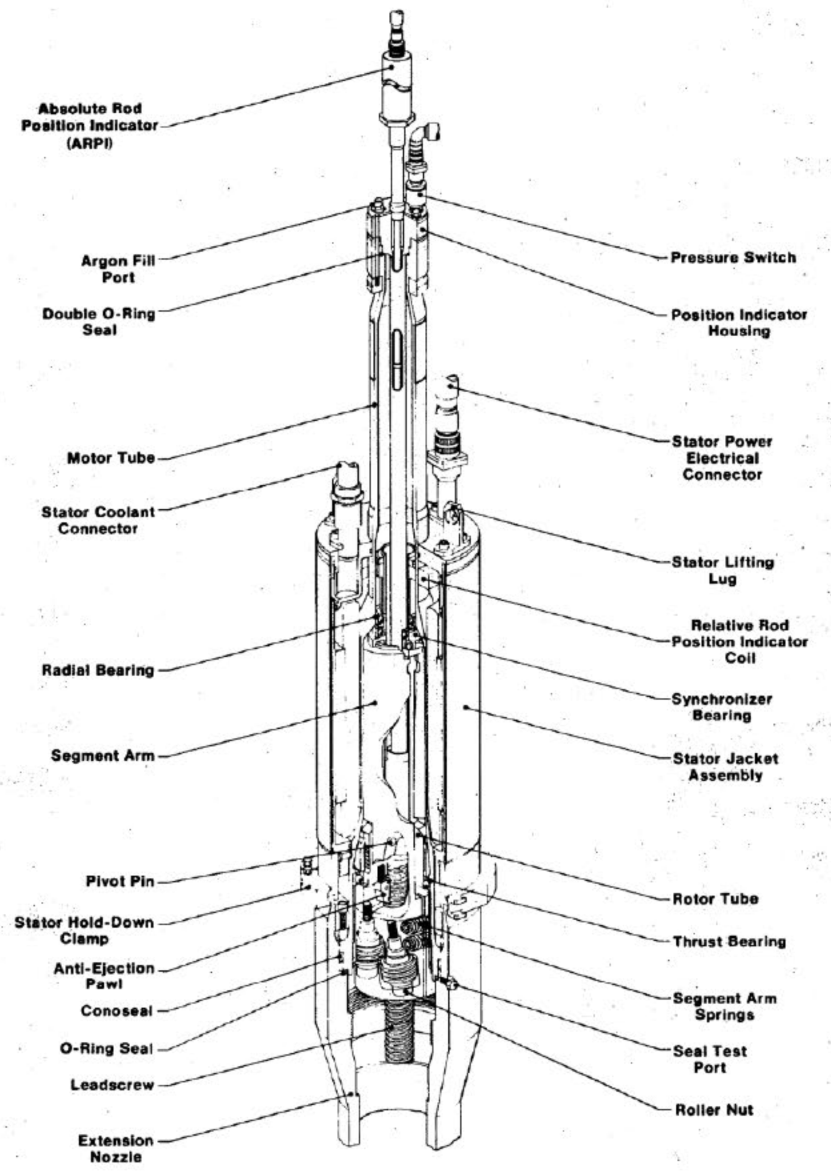


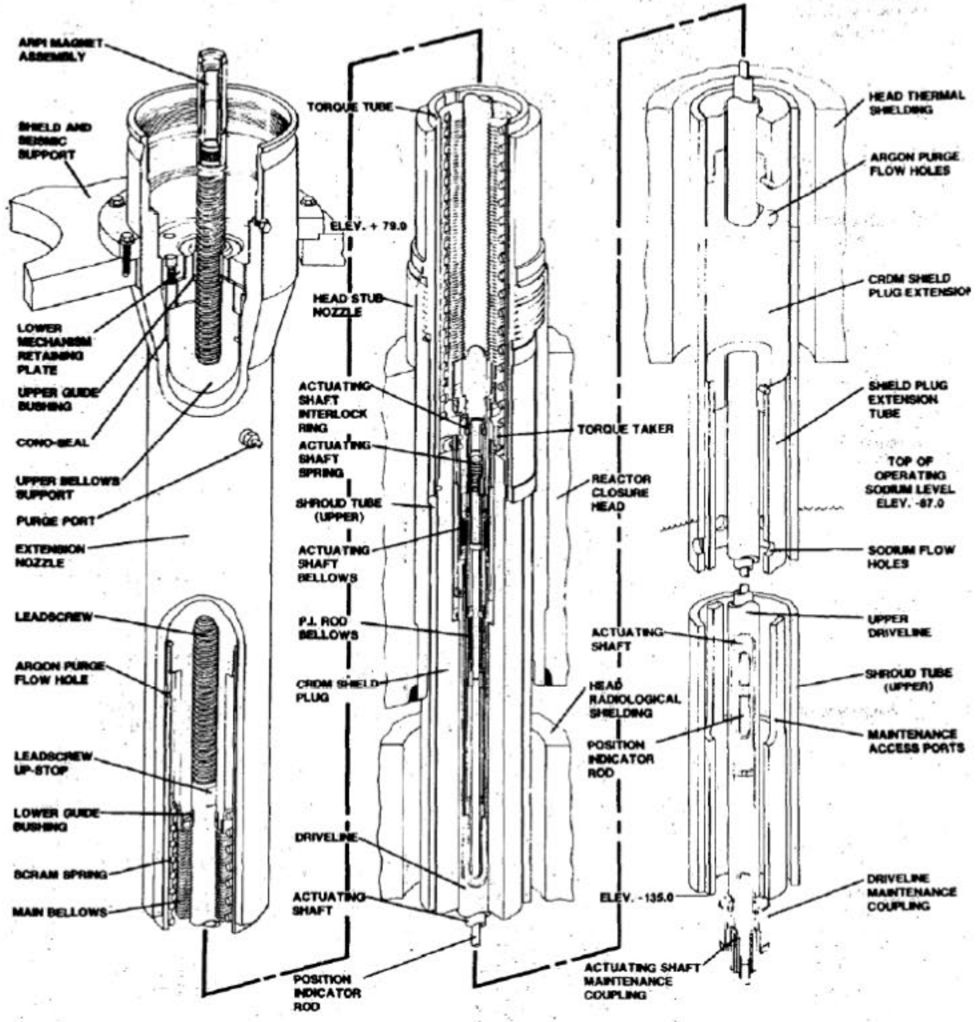
Primary Control Rod



Secondary (Safety) Control Rod

Electrical, backed up by pneumatic





Primary Control Rod Upper and Lower Roller-Nut Mechanism from CRBR

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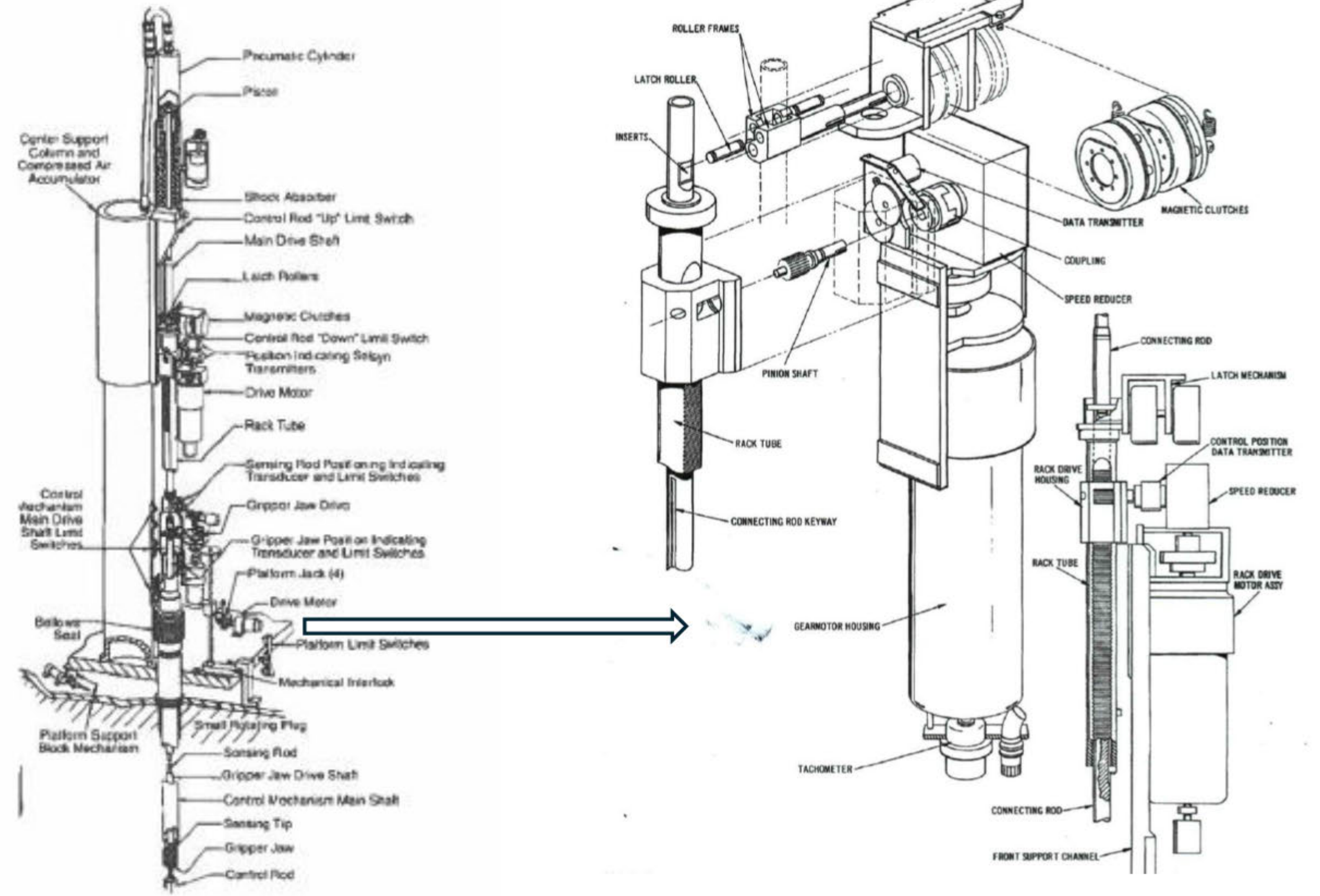

Rack and Pinion Drive for Safety Rod (From EBR II - with air accumulator backup)

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Reactor Protection System Probability of Failure

Frequency of ARC-100 RPS failure to shutdown determined for two cases

- Primary rod with maximum worth is withdrawn/ejected prior to RPS actuation
  - Rod withdrawal probability 3.3×10^{-2} times RPS failure to shutdown $1.371 \times 10^{-5} = 4.52 \times 10^{-7}$
- All primary rods in their normal position
  - RPS failure to shutdown 6.175×10^{-8} per demand

Both individual component failures and common cause failures considered in establishing probabilities of failure

A diverse protection system designed to drive the rods into the core

Deformations Preventing Insertion

R&D on Power Reactivity Decrement informed possible deformations (i.e. within core restraint system)

- Forces necessary to withdraw/insert rods predicted and periodically measured (via IVTM pull on assemblies) during operations
- Significant deviations of measured vs. predicted indicative of deformation trending toward unacceptable
- Assembly rotation can rectify potentially unacceptable trends (done at EBR II)

Reactivity also predicted and measured during operations

- Very important to set baseline during startup of facility to minimize uncertainties in prediction
- Significant deviations of measured vs prediction indicative of anomaly in core

Deformation Prediction

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NUBOW-3D Model **Predicted contacts at ACLP**

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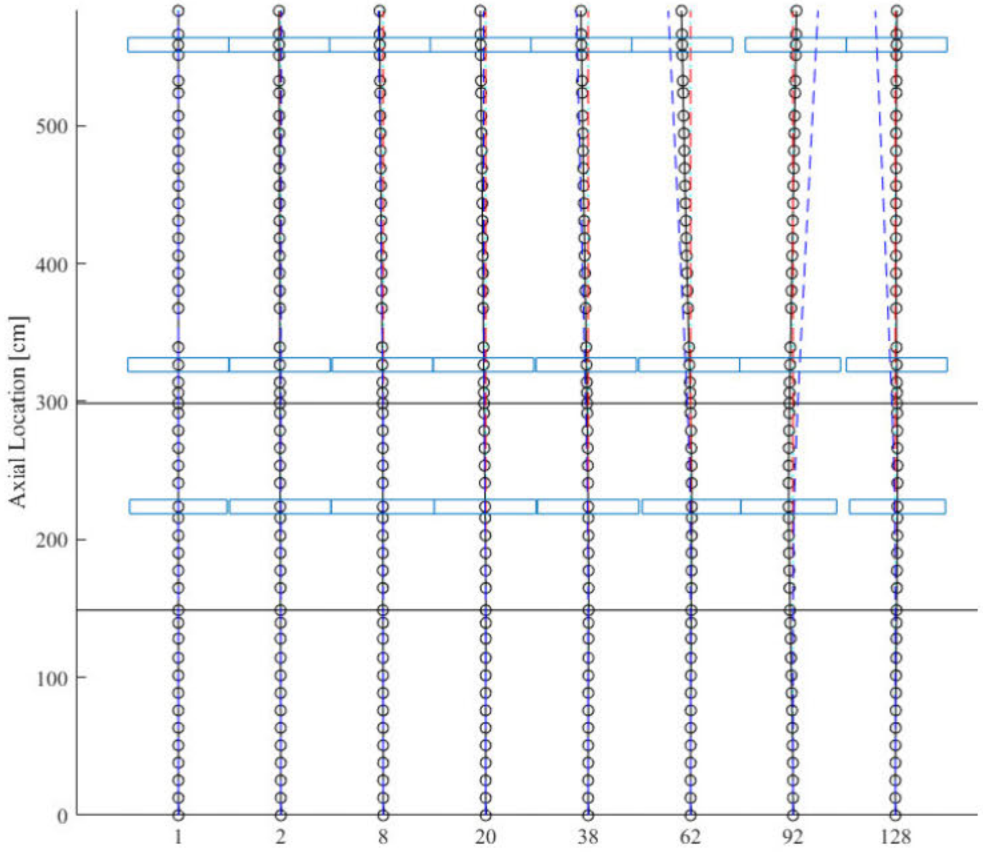
Deformation Prediction (Cont'd)



Deformations at refueling-control assembly is line 20

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Predicted upper bound assembly loads (w/o assembly weight)

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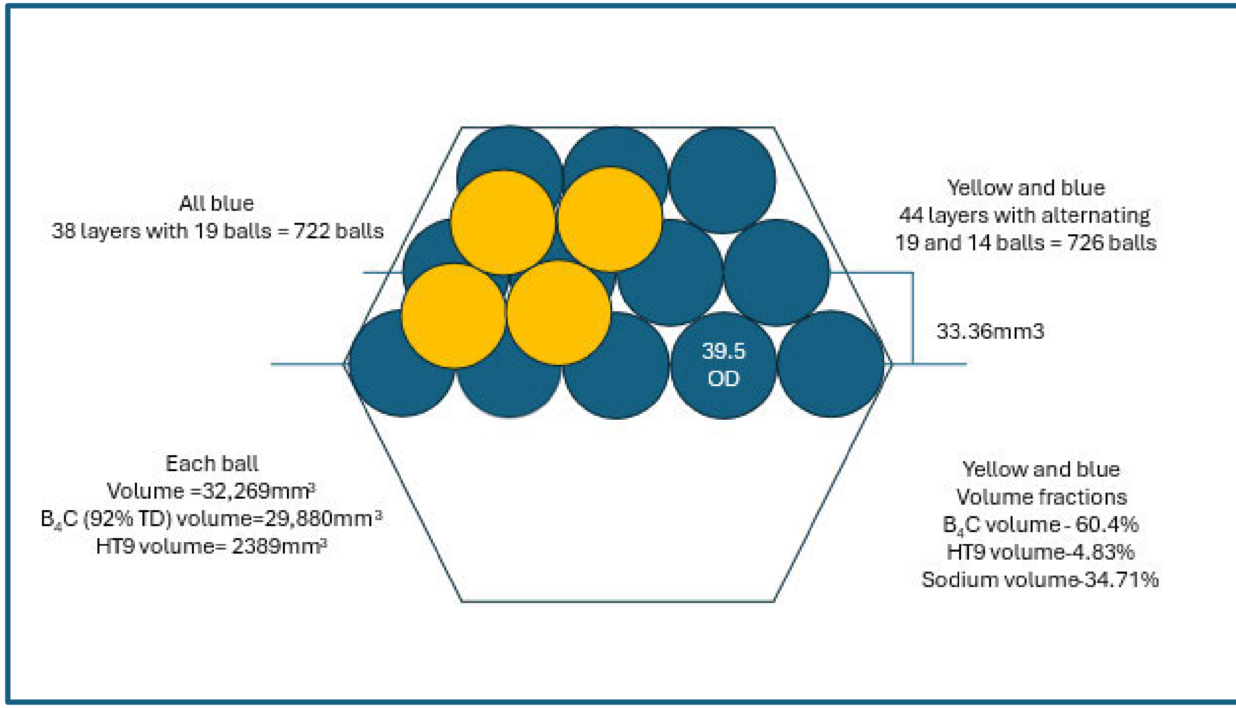
Potential Alternate Shutdown Scheme (Non-Rod)

- Examined system proposed worldwide
- Selected one pioneered by PRISM (boron carbide rods)
  - Manual activation of B4C balls into central vacant core assembly
  - Easily retrievable
  - Determined to have sufficient worth by detailed analysis (by ANL)
    - Analysis done with conservative packing fraction
    - Assumed 45 % boron enrichment
    - Concluded shutdown achievable, but with small margins
    - Margin significantly increased by enriching Boron to 90-92 %



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