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Title: Module 8: Godiva-IV Critical Assembly Demonstration

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Module 8

Godiva-IV Critical Assembly Demonstration

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Goals

- To ensure trainees gain a working knowledge of the Godiva IV assembly, including its
 - design,
 - intent, and
 - controls.
- To ensure trainees gain a working knowledge of how to use the Inhour equation and associated parameters for the Godiva IV assembly to infer the reactivity addition during a transient excursion.
- To ensure trainees gain a working knowledge of the differences between subcritical, delayed-critical, and prompt-critical operations.
- To ensure the trainees gain a working knowledge of the concept of temperature-dependent reactivity feedback as it applies to the transient behavior of a critical assembly during a nuclear excursion.
- To ensure the trainees gain a basic working knowledge of how Godiva IV steady-state and prompt-critical operations are conducted.

Enabling Objectives

- (EO1) Trainees will illustrate a physical description of the Godiva IV assembly.
- (EO2) Trainees will recall how to infer reactivity addition from a measurement of the positive reactor period.
- (EO3) Trainees will describe the difference between subcritical, delayed-critical, and prompt-critical operations.
- (EO4) Trainees will explain the effect of temperature-dependent reactivity feedback on the transient behavior of a critical assembly.
- (EO5) Trainees will recall the basic controls and operations associated with the Godiva IV assembly, including the
 - assembly sequence for a “free-run” excursion,
 - assembly sequence for a prompt-critical burst operation, and
 - system interlocks.

Godiva IV Assembly Description^{1,2,3} (EO1)

- Cylindrical geometry core design.
- Dimensions of 7 in. in diameter (17.8 cm) × 6 in. tall (15.2 cm).
- Uranium-molybdenum alloyed metal (1.5 wt % molybdenum).
- Core mass of ~66 kg.
- Uranium content enriched to 93.5 wt % ^{235}U .

Godiva IV assembly, circa 1967.

Godiva IV Assembly Description (EO1)

- Operations performed in the subcritical, delayed-critical, and prompt-critical regimes.
- Theoretical maximum burst with a temperature rise of 525°C, FWHM of 25 μ s, is equivalent to 90,000 MW_{th}.
- Current applications include
 - sample reactivity worth studies,
 - reactor kinetics benchmark studies,
 - reactor dynamic excursion studies,
 - sample neutron activation studies,
 - dosimetry measurements,
 - criticality alarm testing,
 - critical assembly operator training, and
 - criticality safety training demonstrations.

Detailed Design Drawing of Godiva IV Core (EO1)

Godiva IV Mechanical Systems (EO1,EO5)

- Safety Block Drive Mechanism
 - Hydraulic pump package with integral three-way valve
 - Hydraulic system lifts, lowers, or holds stationary the safety block electromagnet
 - An energized electromagnet lifts the rod attached to the safety block
- Control Rod Drive Mechanism
 - Stepper motors operated at single speed
 - Control rods back-drive when power removed from stepper motors
 - W-Cu weights increase back-drive speed
- Burst Rod Mechanism
 - Pneumatic system with two-way valve
 - Pressure provided by air compressor

Godiva IV Control System (EO1,EO5)

■ Programmable Logic Controller (PLC)

- Allen-Bradley PLC-5
- Stores program files and a data table, reloaded from EEPROM on power-up
- Allen-Bradley modules for I/O, communication, control, sensors
- Located in Control Room

■ Human Machine Interface (HMI)

- RSVIEW software with multiple files stored as a project
- Located on Control Room and Local HMI computers
- Identical, except for communication checks between HMI and PLC
- Both share data with PLC data table

Godiva IV HMI Display (EO1, EO5)

Control System Interlocks (EO1,EO5)

Dead-Man Feature

- Releasing a button will stop the motion of the control element.

When operating in Remote:

- The Safety Block must be on in limit before Control Rod 1 and/or 2 can be inserted.
- All elements must be on out limit before reset is allowed.

When operating in Local:

- Only one element may be moved from out limit at a time.
- All elements must be on out limit before reset is allowed.

Burst Rod Interlocks (EO1,EO5)

When operating in Remote:

- The burst rod can be inserted by one operator if the Safety Block is on in limit and both Control Rods are on their out limits.
- The burst rod can be inserted by two operators if the Safety Block is on in limit and both Control Rods are not on their out limits.

When operating in Local:

- The burst rod can be inserted by one operator if the Safety Block is on its out limit and both Control Rods are on their out limits.
- There is no second burst button on the Local panel.

Control Rod Integral and Inverse Differential Worths (EO1,EO5)

Control Rod Integral Worth

Control Rod Inverse Differential Worth

Inhour Equation⁴ for the Godiva IV Assembly (EO2)

$$\rho (\$) = \frac{l}{\beta_{eff} * T} + \sum_{i=1}^6 \frac{\beta_i / \beta_{eff}}{1 + \lambda_i T}$$

where

$\rho(\$)$ is the reactivity in dollars

$\beta_{eff}/1$ is the Rossi- α at delayed critical

T is the reactor period

β_i/β_{eff} is the relative abundance for ^{235}U for each of the six groups from fast fission

λ_i is the decay constant for ^{235}U for each of the six groups from fast fission

Parameters⁴ Needed for the Inhour Equation (EO2)

For the Godiva IV assembly:

$$\alpha(\text{DC}) = \beta/l = 1.1 \times 10^6 \text{ s}^{-1}$$

Decay Constants and Yields for ^{235}U from Fast Fission

Group Index, i	Decay Constant $\lambda_i \text{ s}^{-1}$	Relative Abundance $a_i = \beta_i/\beta_{\text{eff}}$
1	0.0127	0.038
2	0.0317	0.213
3	0.115	0.188
4	0.311	0.407
5	1.40	0.128
6	3.87	0.026

Graphical Representation of the Inhour Equation for the Godiva IV Assembly (EO2)

Delayed Critical and Prompt Critical (EO3)

Reactivity itself is unitless

However, it can be quoted in units of:

Dollars and cents

pcm (percent millirho)

Take the Delayed Critical Window ($0 < \rho < \beta$) and split that interval into 100 units (called cents)

One dollar is 100 cents

By definition, \$1.00 of reactivity is prompt critical

Delayed Critical and Prompt Critical (EO3)

- **Delayed Critical** Reactor needs both delayed and prompt neutrons to be a self-sustaining neutron chain reacting system.
 - Increase in neutron population (power) dominated by the timescales associated with the appearance of delayed neutrons (neutrons from fission product decay with half lives on the order of milliseconds to minutes).
 - Longer timescales **DO** allow for control mechanisms to affect the transient power behavior (control rods, mechanical safety systems, operator intervention, etc.)

Delayed Critical and Prompt Critical (EO3)

- **Prompt Critical:** Reactor needs only prompt neutrons to be a self-sustaining neutron chain reacting system.
 - Increase in neutron population (power) dominated by the timescales associated with the appearance of prompt neutrons (nanoseconds to milliseconds).
- Shorter timescales **DO NOT** allow for control mechanisms to affect the transient power behavior.

Temperature Coefficient of Reactivity (EO4)

$$\frac{\Delta\rho}{\Delta T} (\text{¢} / ^\circ\text{C})$$

Negative – temperature reactivity quench

Positive – autocatalytic or divergent reaction

Assembly	Approx. Temp. Coeff.
Godiva IV, Big Ten, Flattop U	-0.3 (¢/°C)
Flattop delta-phase plutonium	-0.2(¢/°C)
SHEBA U(5) solution	-4.0 to -10.0 (¢/°C)
CNPS(U(20)O ₂ -C matrix	-1.2 (¢/°C)

Contributions from expansion, Doppler shifts, geometry changes

Temperature Coefficient of Reactivity for Godiva (EO4)

Godiva IV Operation (EO3,EO5)

1. Control Room OSS placed in Remote (key is captured)
 - a. Lights go steady and horn sounds for 30 s
 - b. Press Reset
2. Delayed Critical Operation
 - a. Safety Block inserted
 - b. Insert Control Rods to 1.000 in., 1.000 in. (wait)
 - c. Insert Control Rods to 0.500, 0.500 (wait 1-5 min to verify at or below DC)
 - d. Insert Control Rods to 0.000, 0.500 (wait until neutrons are observed)
 - e. Insert Control Rods to 0.000, 0.000; record in positions
 - f. Measure period to determine excess reactivity

Burst Operation (EO3,EO5)

Continuing from previous steps

3. Prompt Critical Operation
 - a. Move Control Rod 2 out to 0.350, then back in to 0.250
 - b. Find DC with Control Rod 1 (maintain for one full linear channel screen)
 - c. Insert burst increment with Control Rod 2
 - d. (nominally 95 mils for 70°C burst, 150 mils for 100°C burst)
 - e. Retract safety block 2-5 in.
 - f. Wait 15-20 minutes
 - g. Arm instrumentation, O'scope, trigger module
 - h. Insert safety block, then immediately burst rod (requires both crew members)

Godiva IV Operation (EO3,EO5)

Burst Occurs

BURST

What Terminates the Burst? (EO1,EO3,EO4,EO5)

- Expansion and Neutron Leakage
- Shock Wave Removal of Safety Block
- Trigger Module Input to Control System
- Log-N SCRAM Signal

When the PMT signal (1) exceeds a threshold, the trigger signal (3) sends input to the control system and O'scope to capture PD signal (2).

Burst Data (EO3,EO5)

PD signal for 150 °C

RTD data for 200 °C burst

Dosimetry

\$1.03/60° Burst

	Gamma Dose (rem)	Neutron Dose (rem)	Total Dose (rem)
X1	6	169	175
X3	7	134	141
X5	13	330	343
X7	17	272	288
X14	0	.1	.1

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