

Pulsed Activation of Target and Chamber

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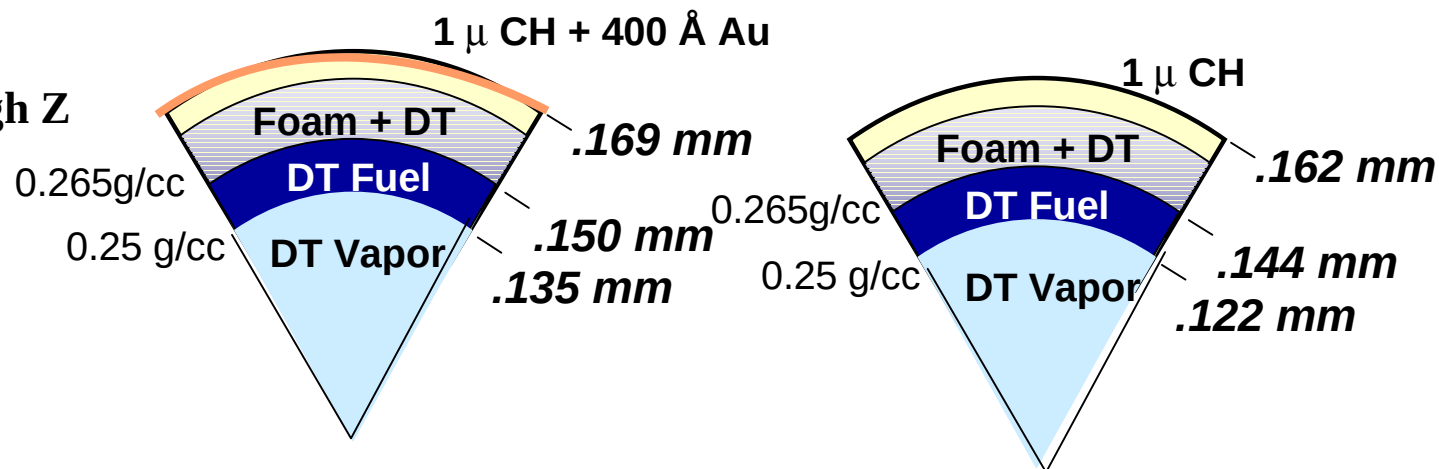
Madison ARIES Group Meeting, June 19 - 21, 2000

Overview of the Presentation

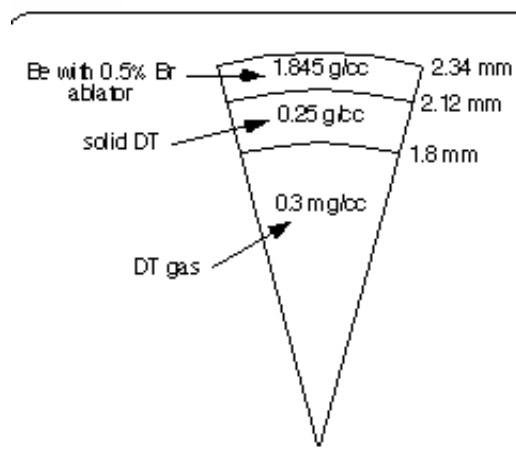
- Target Activation
 - Burn Characteristics
 - Illustration
 - Critical Issues
- Chamber Analysis
 - Source Normalization
 - Target Spectrum
 - Modelling of Pulsed History
 - Illustration
 - Critical Issues
- Activation Codes

Direct and In-Direct Drive Targets Under Consideration Have Different Output

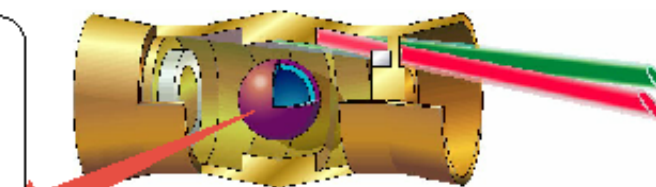
**NRL Direct-drive Laser
Targets May Contain High Z**



**Indirect-drive HIF and Z-pinch
Targets Have High-Z Hohlraums**

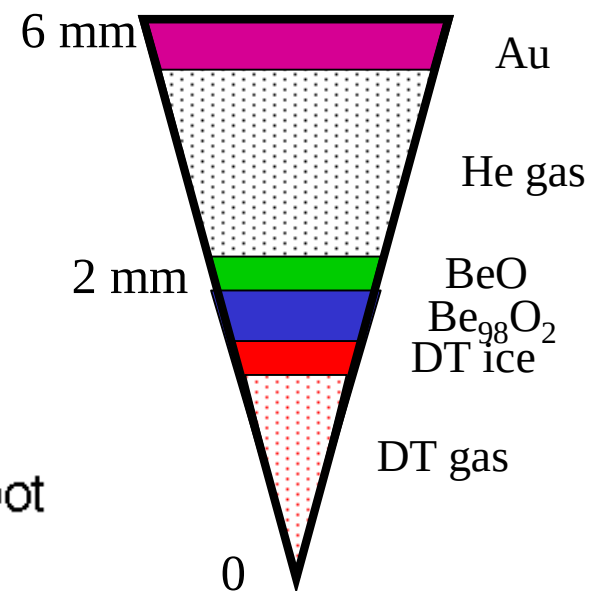


LLNL/LBNL HIF Target



Ion beam characteristics:
3.5 GeV Pb⁺ ions
3.3 MJ input energy
1.7 mm effective radius spot

X-1 Target



Fusion Technology Institute
University of Wisconsin - Madison

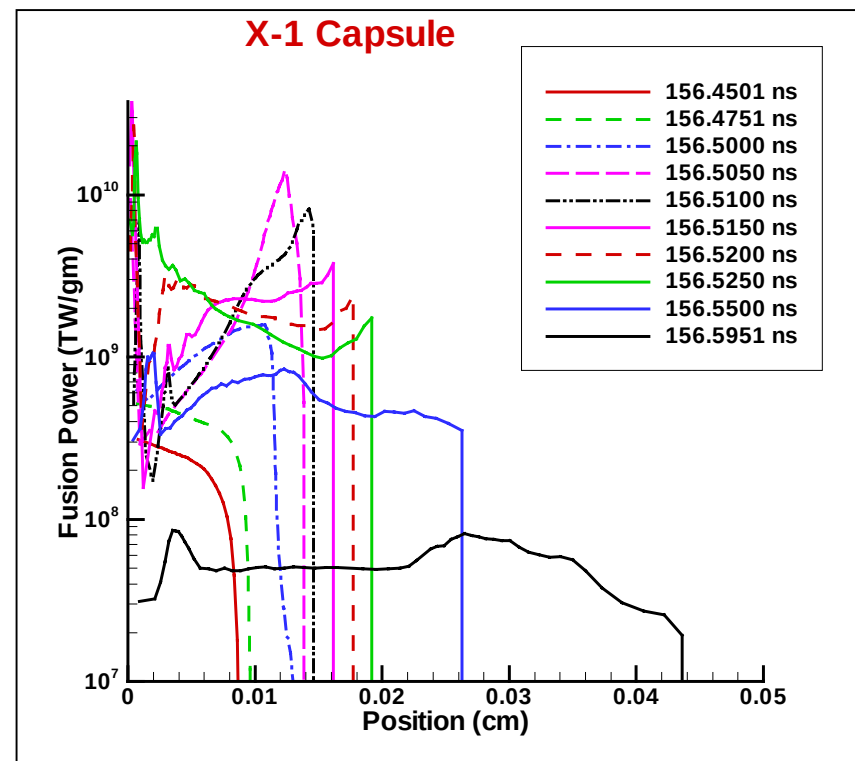
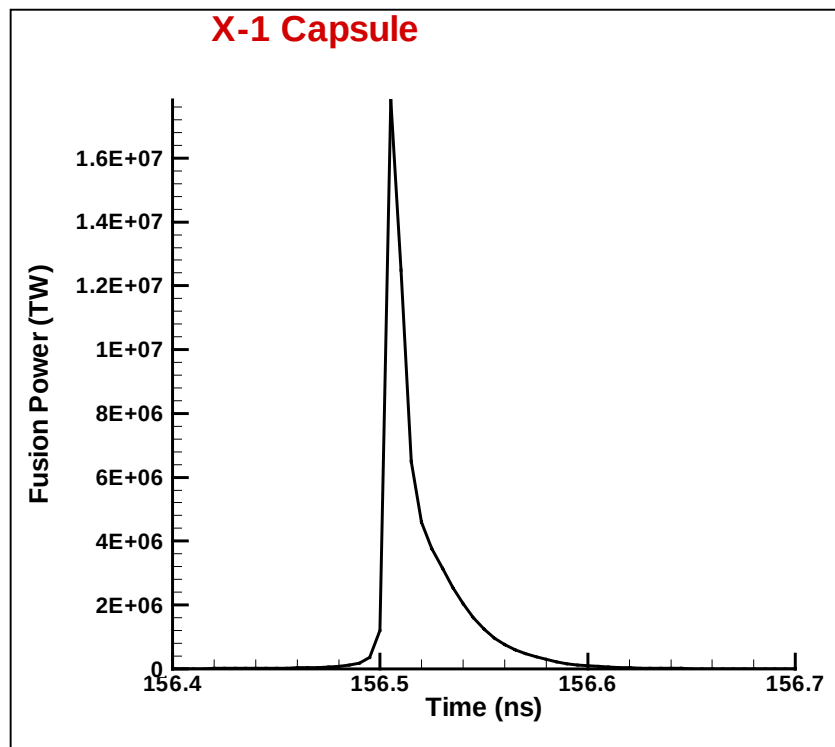
ARIES IFE

6/20/2000

IFE Capsule Thermonuclear Burn Drives Target Radiative Disassembly and Neutronics

Fuel burns in a few 10's of ps,
Power density is truly astronomical
(10^{22} W/gm)

Burns propagates from central hot spot to rest of compressed fuel.



Target Activation Calculations

- Ideally, to perform a proper activation analysis, a time-dependent calculation needs to be performed.
 - Time-dependent neutron transport is required.
 - Spatial and density profiles are updated on the hydrodynamic time step scale.
- In the absence of time-dependent calculations, quasi-static neutron transport and activation calculations can be performed.
 - Take snapshots of the target spatial and density profiles.
 - Perform calculations for each configuration over the target hydrodynamic differential time period.

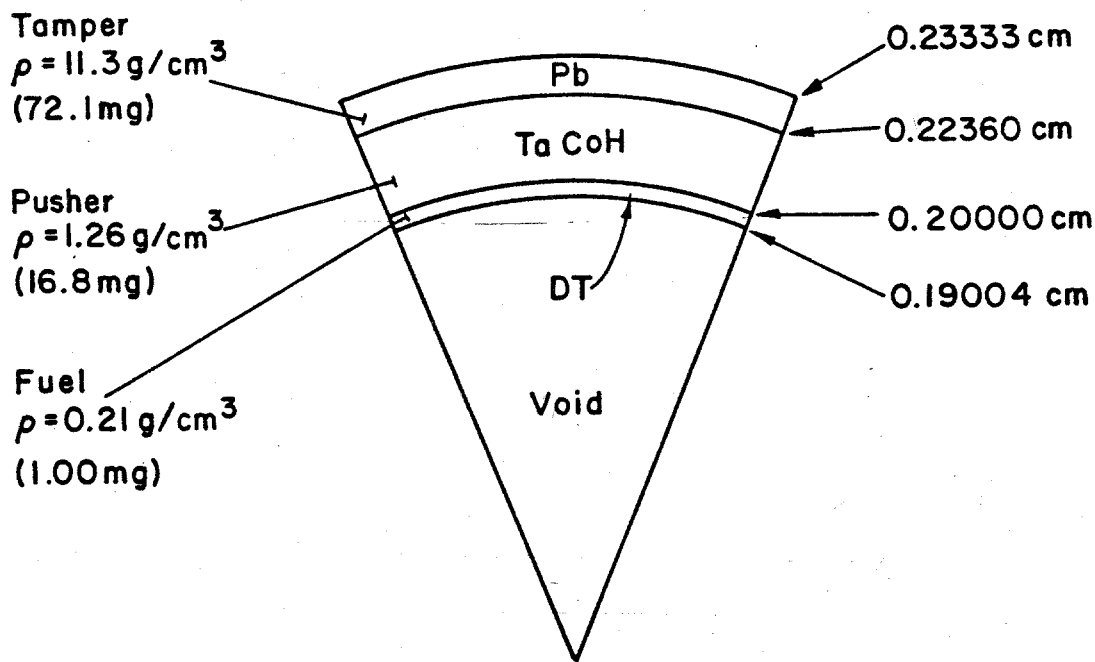


Fig. 2.3. Reference ion beam target as depicted in Ref. 2.

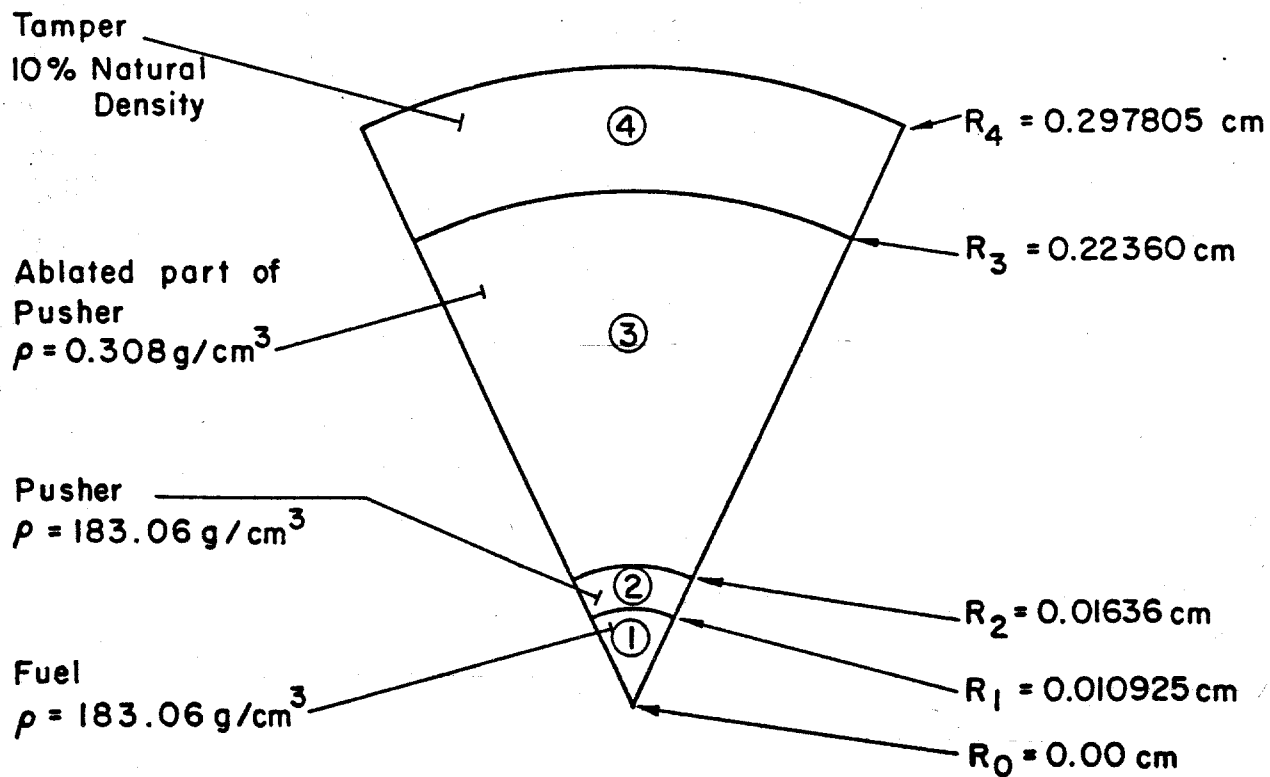


Fig. 2.4. The compressed target configuration used for the target neutronic and radioactivity calculations.

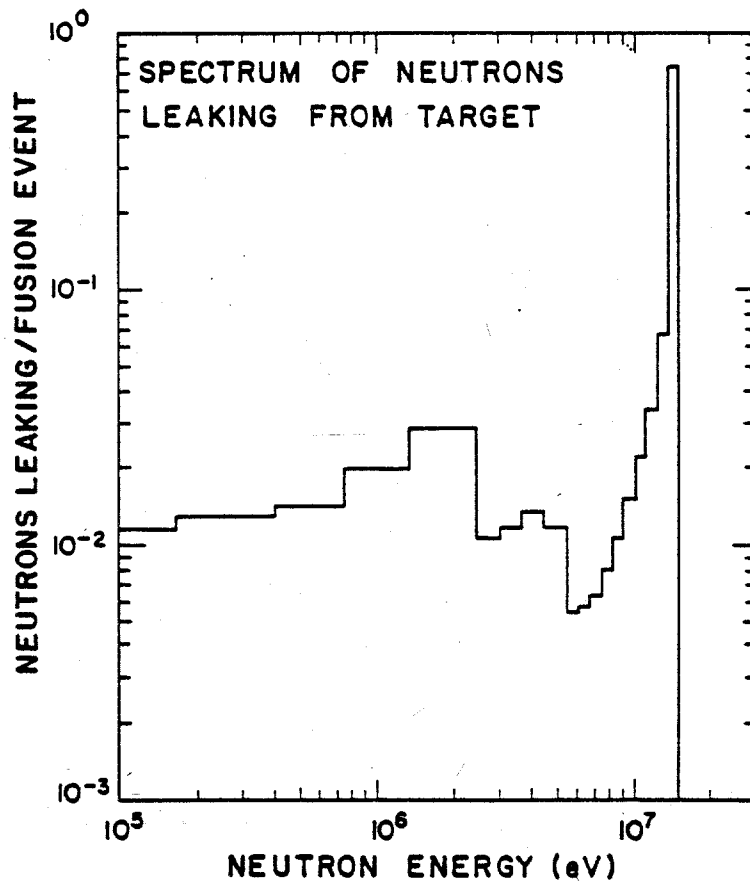


Fig. 2.6. The spectrum of neutrons leaking from the ion beam target normalized to one fusion neutron.

Target parameters:

100 MJ in fusion energy

71 MJ in neutrons

1 mg of DT load

TABLE 1. TARGET MATERIALS USED IN ACTIVATION CALCULATIONS

Region	Case I		Case II		Case III		Case IV	
	Comp.	Mass	Comp.	Mass	Comp.	Mass	Comp.	Mass
1	DT	1 mg	DT	1 mg	DT	1 mg	DT	1 mg
2	LiPb	2.36 mg	CH ₂	2.36 mg	CH ₂	2.36 mg	BeO	2.36 mg
3	LiPb	14.42 mg	CH ₂	14.42 mg	CH ₂	14.42 mg	BeO	14.42 mg
4	Pb	72.13 mg	W	122.55 mg	Au	123.32 mg	W	122.55 mg

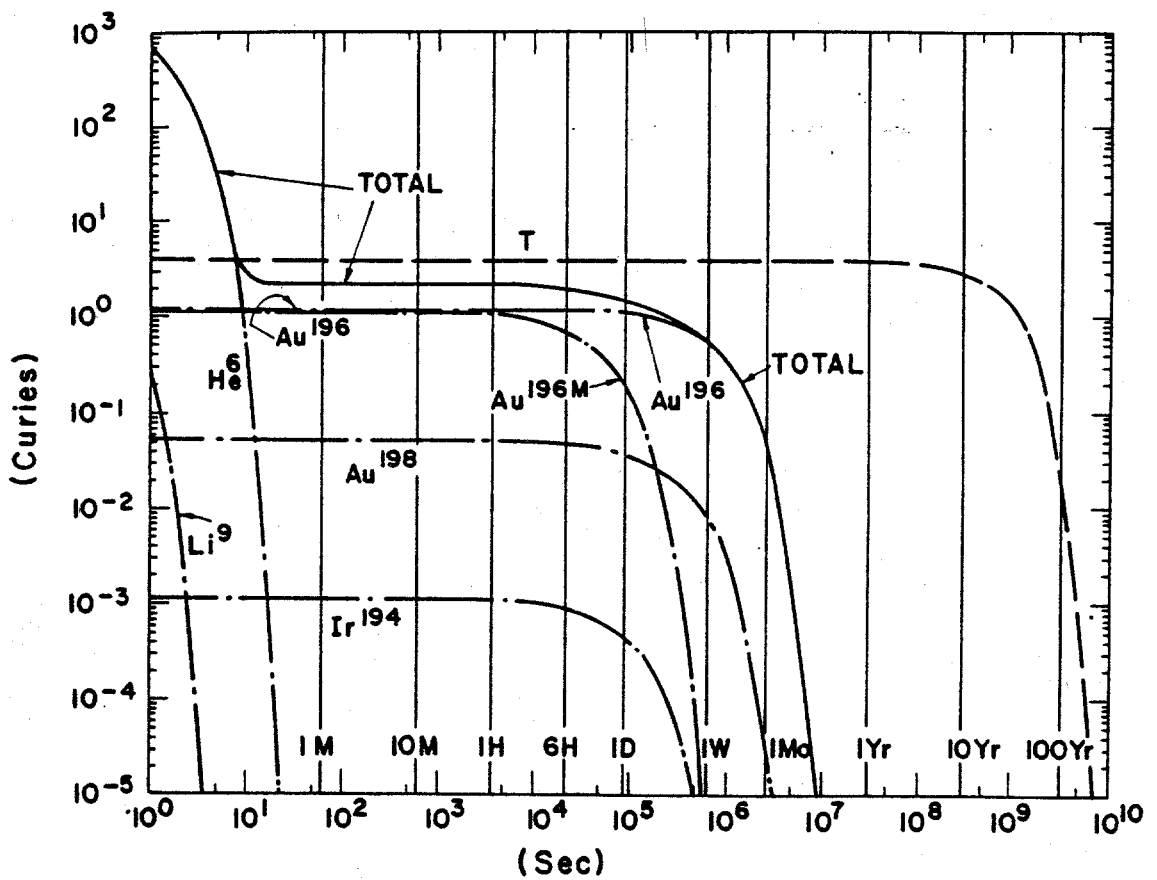


Fig. 6. Isotopic activity versus time for the Case III target constituents.

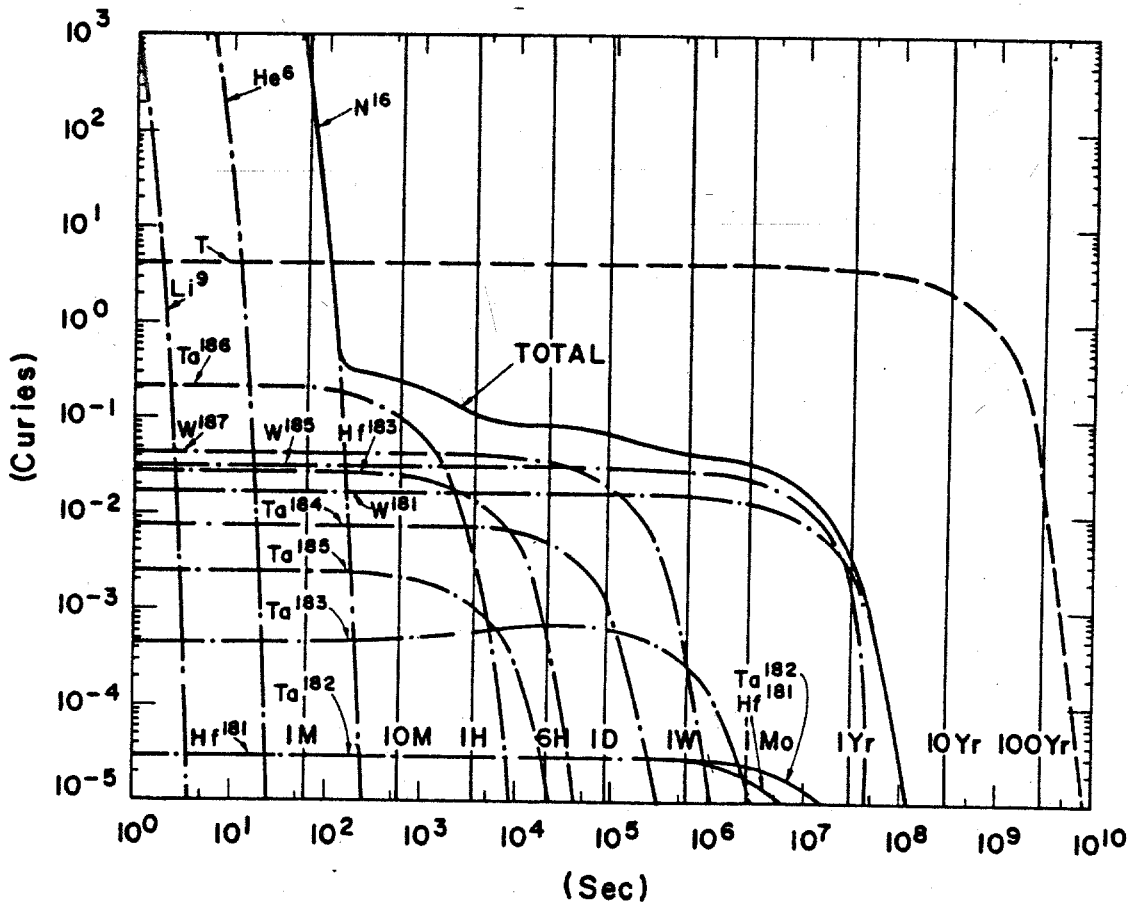


Fig. 7. Isotopic activity versus time for the Case IV target constituents.

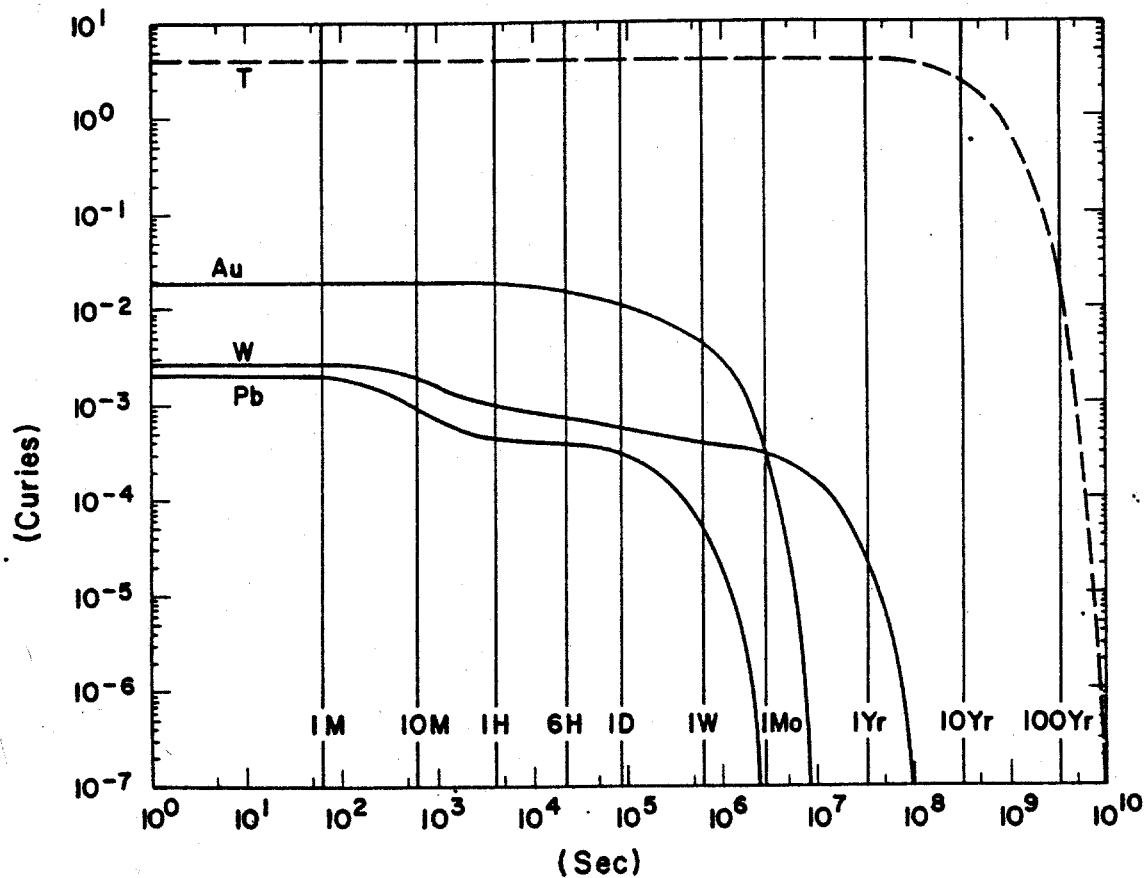


Fig. 8. A comparison of the target activity results normalized to 1 mg of tamper material.

Critical Issues For Target Activation Calculations

- Due to the rapidly changing spatial and density profiles during target burn, time-dependent or quasi-static calculations should be performed to obtain realistic (sensible) results.
- Target constituents become radioactive
 - In dry wall chamber schemes, target debris condenses or becomes plated to wall surfaces. Further activation at a lower flux level occurs during subsequent pulses.
 - In wet wall chamber schemes, target debris collects in protective liquid and is further activated during subsequent pulses.
- Effect of radioactive target debris on chamber analysis
 - Depending on the choice of target constituent materials, radioactive target debris can impact the activity of the chamber wall or protective liquid.
 - The activated target debris can also impact the biological dose rates, afterheat, WDR rating and chamber maintenance.

⇒ It is Important to analyse target activation.

- Target Design

- It has been suggested that the activated target material can be used as a diagnostic tool for analysing target compression.

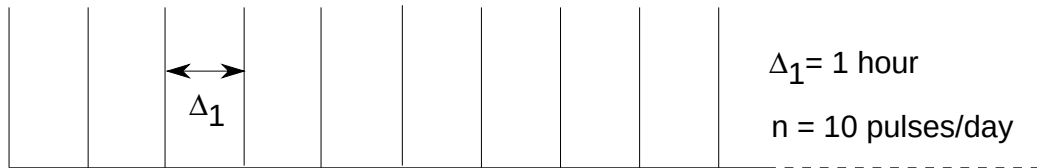
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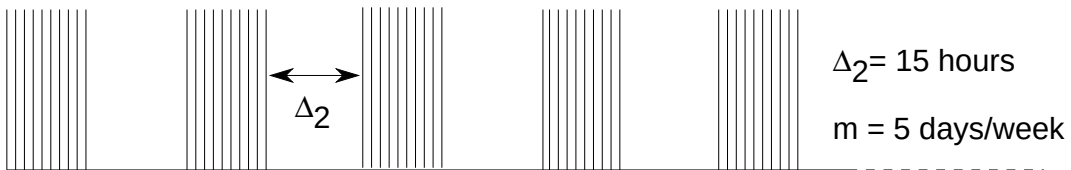
Chamber Activation Analysis

- **Experimental Facility**

Daily Pulse Sequence

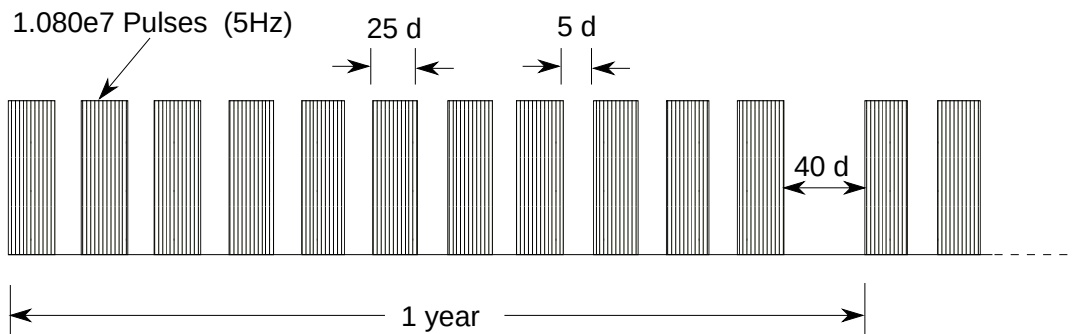


Weekly Pulse Sequence



Example of a Pulse Sequence for an Experimental Facility

- **Power Plant**



Example of a Pulse Sequence for a Power Plant

Target Burn Time, Neutron Time of Flight and Neutron Spectrum Considerations

- Target Burn Time: approximately 10 - 100 ps
 - Extremely short compared to the half-lives of radionuclides considered and dwell and maintenance periods.
 - Effectively a delta-function neutron source in time.
- Time-of-Flight and neutron moderation consideration: approximately 1 μ s
 - Extremely short compared to the half-lives of radionuclides considered and dwell and maintenance periods.
 - Effectively a delta-function neutron source in time.
- Neutron Spectrum Considerations

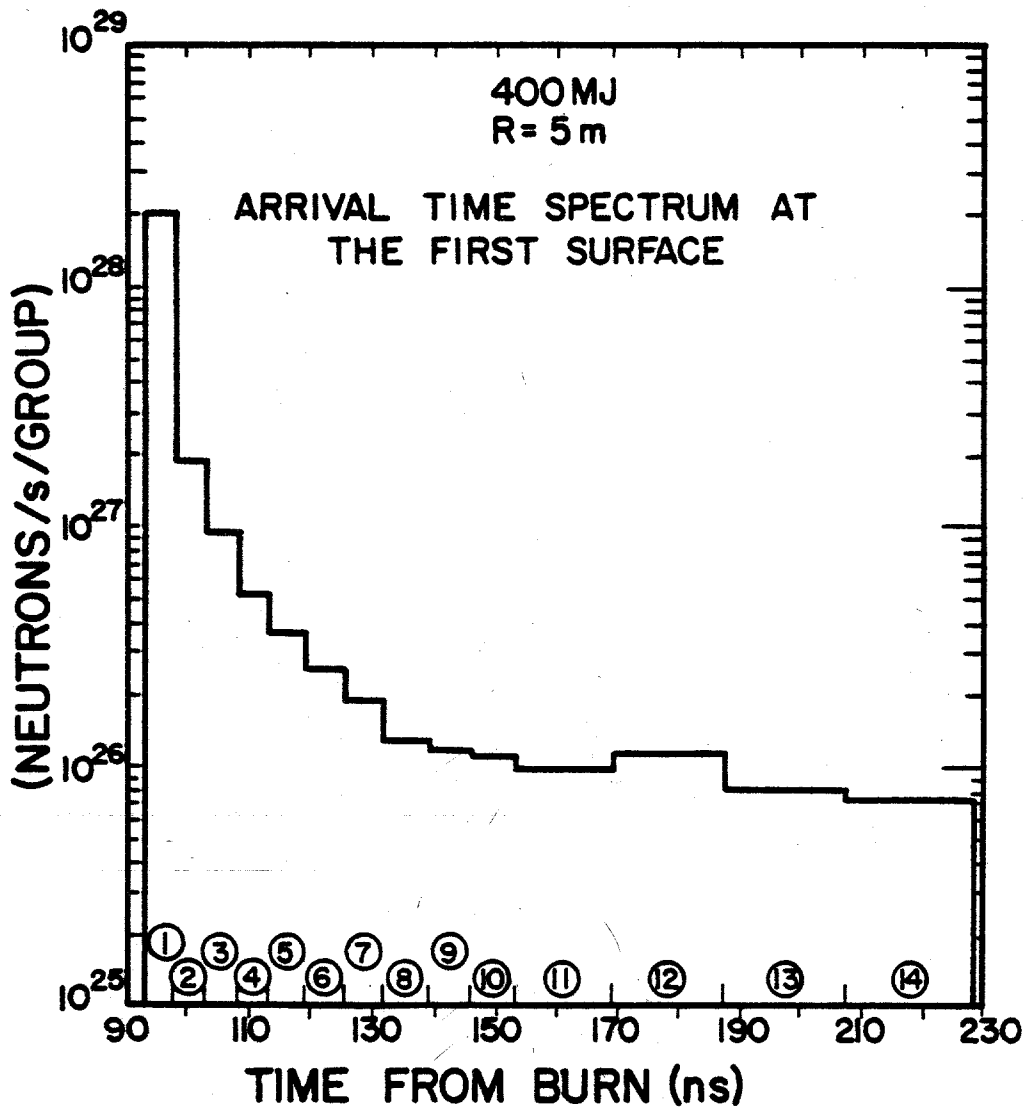


Figure VI.3-20 Arrival time spectrum at the first surface of the blanket.

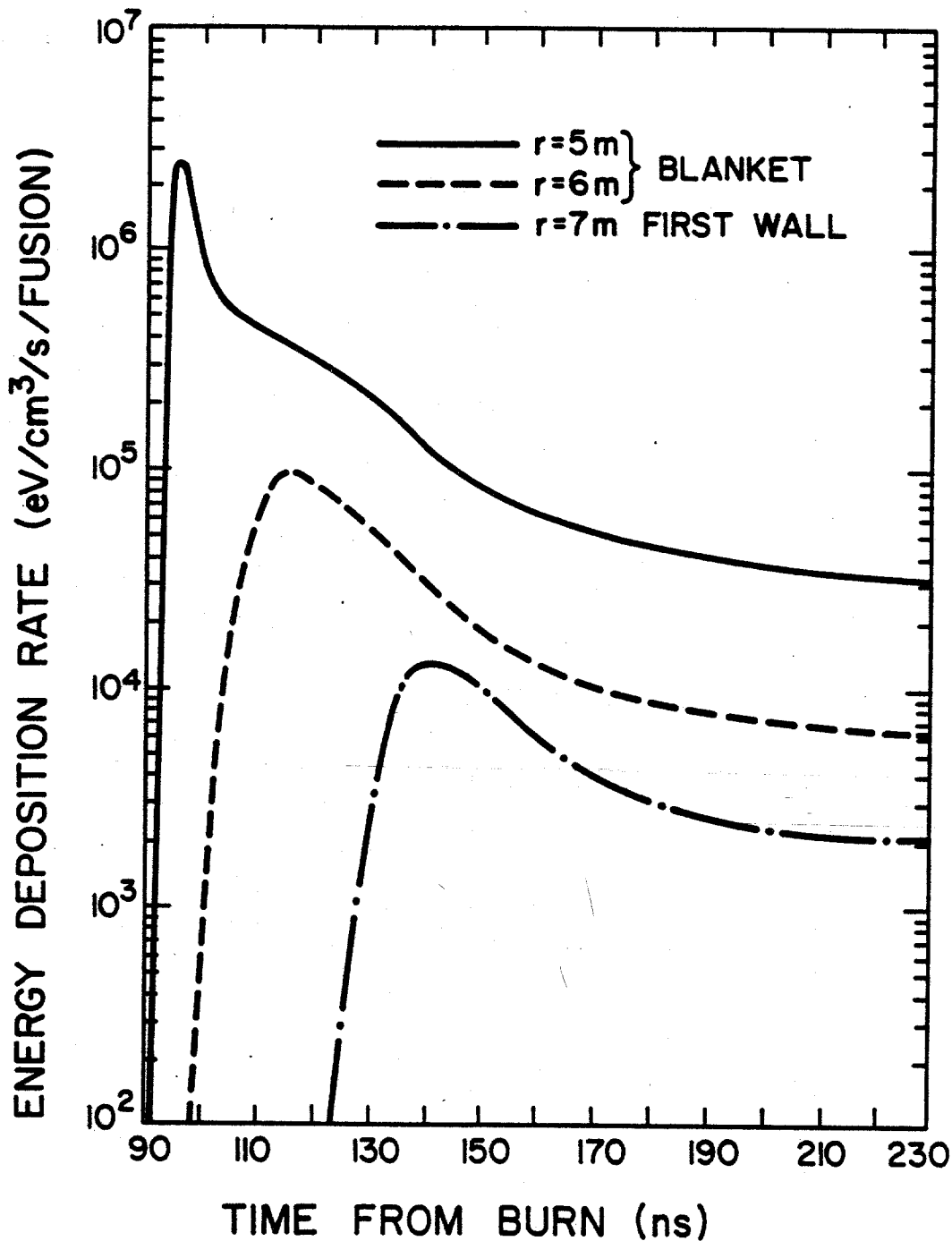


Figure VI.3-29 Energy deposition rate in HIBALL blanket and first wall.

Fuel Density-Radius Product (ρR) is High Enough to Absorb Some Neutrons and Soften Spectrum

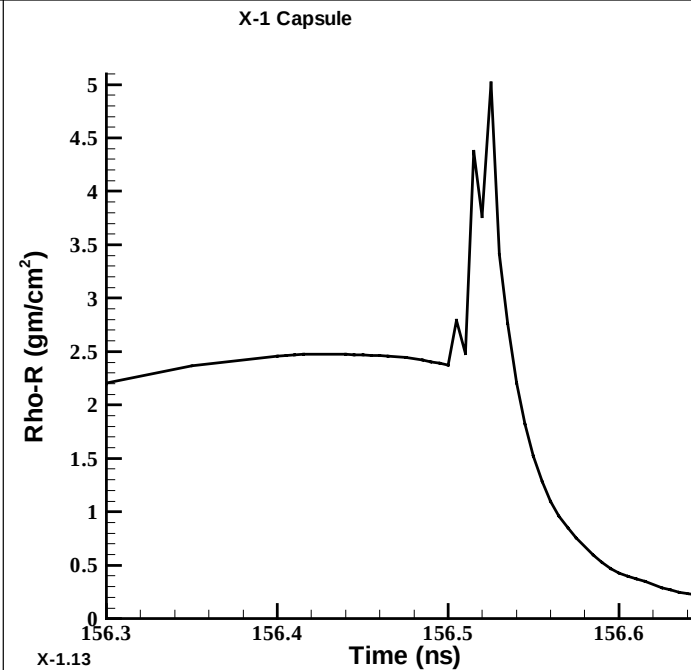
X-1 Energy Partition

Neutrons: 220 MJ (69.22%)
 Gammas: 0.95 MJ (.03%)
 X-rays: 61.3 MJ (19.3%)
 Ions: 28.6 MJ (9.0%)
 Endoergic: 7.8 MJ (2.45%)
Total: 318 MJ

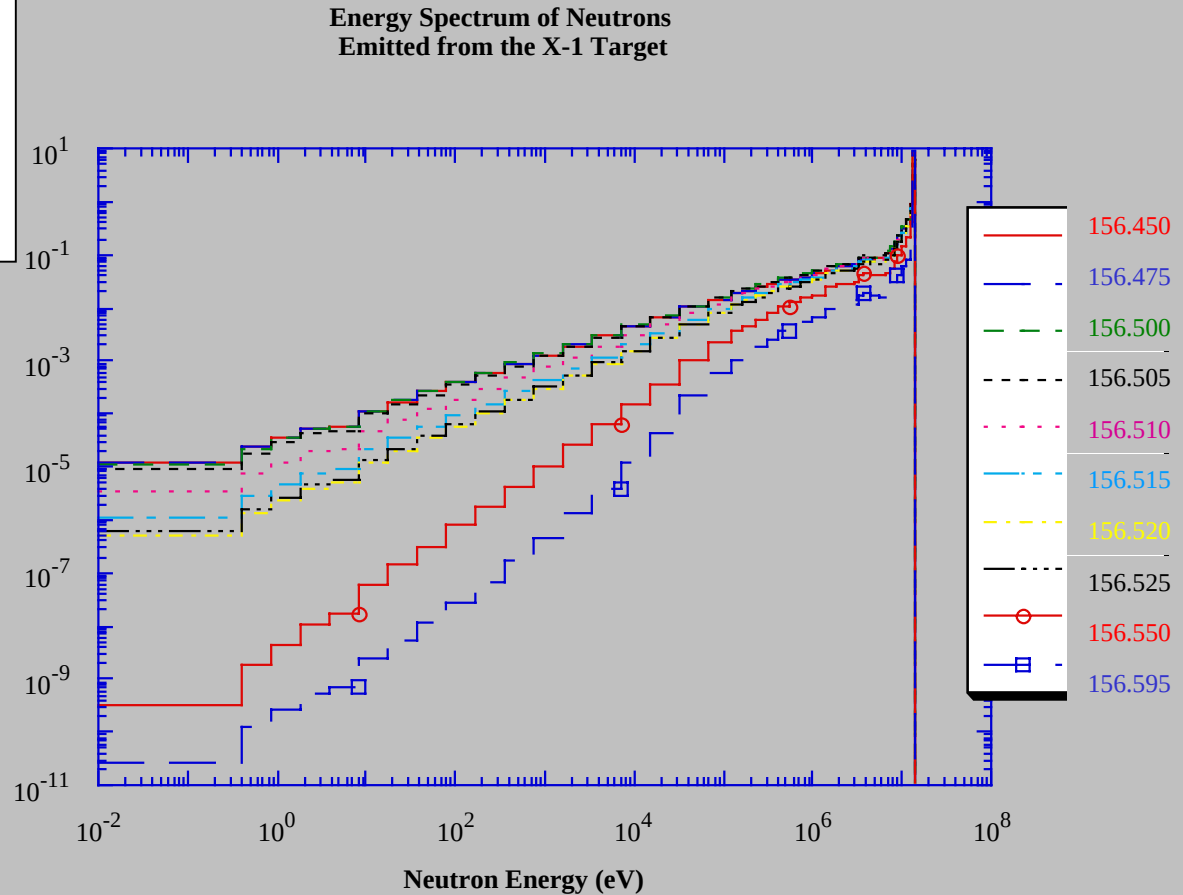
Fluence on 650 cm Wall

41.4 J/cm²
 0.18 J/cm²
 11.5 J/cm²
 5.4 J/cm²

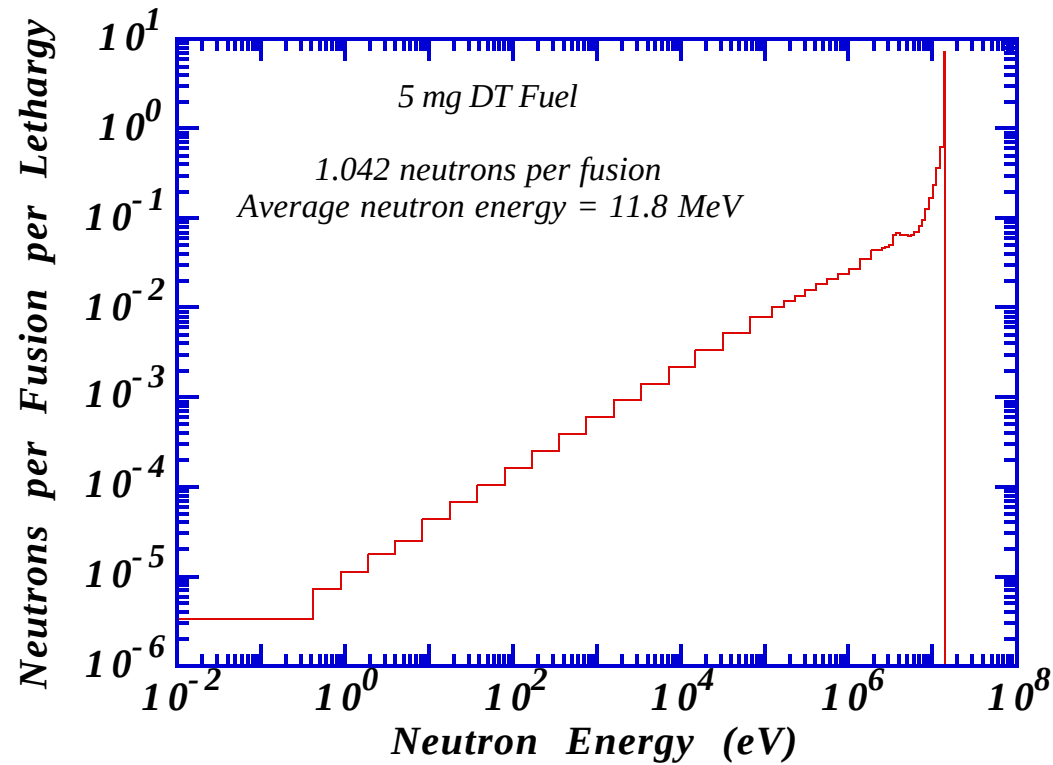
58.5 J/cm²



Neutrons per Fusion per Lethargy



1.042 Neutrons Emitted from Target per Fusion



- Source Normalization for the Chamber Analysis

$$\text{Norm} = \frac{\text{Number of neutrons produced per pulse}}{\text{Effective neutron 'pulse' duration time}}$$

Example: 400 MJ Fusion yield per pulse

$$\Rightarrow 1.50 \times 10^{20} \text{ n/pulse}$$

Effective 'pulse' duration: 10^{-6} seconds

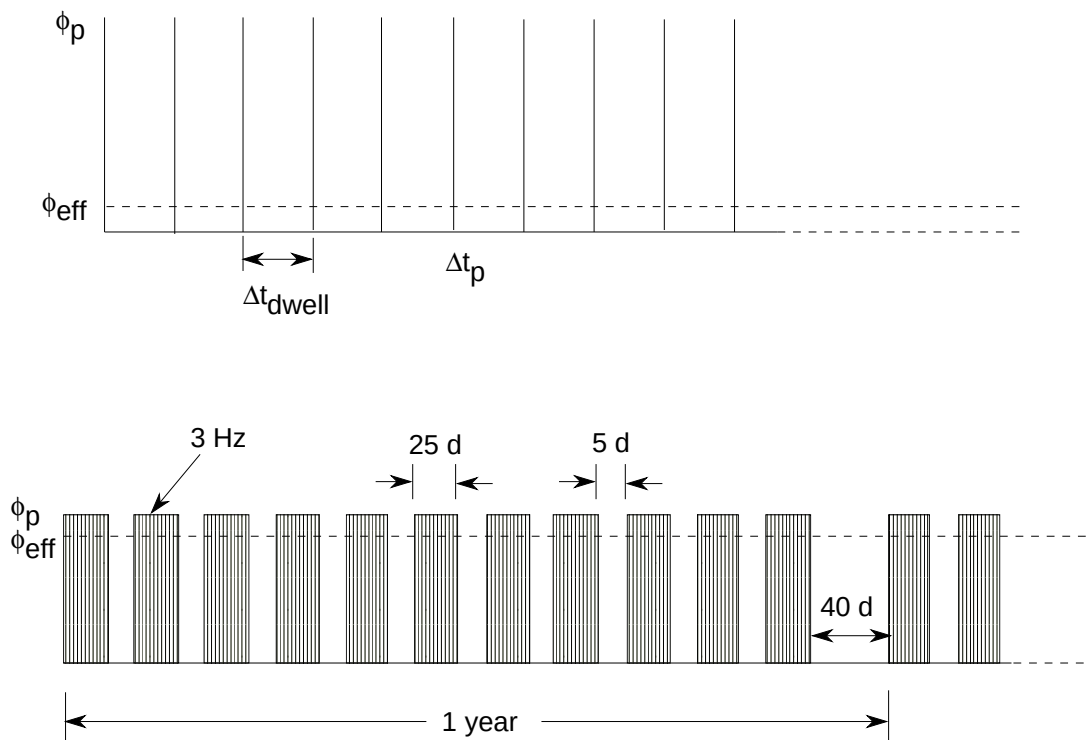
$$\Rightarrow 1.50 \times 10^{26} \text{ n/s}$$

Modelling of Pulse Sequences (Irradiation History)

- The following frequently used steady state approximation produces incorrect results.
 - Effective steady state method: both neutron fluence and operation time are preserved.

$$\phi_{eff} = \phi_p \left(\frac{\Delta t_p}{\Delta t_p + \Delta t_{dwell}} \right)$$

Examples:



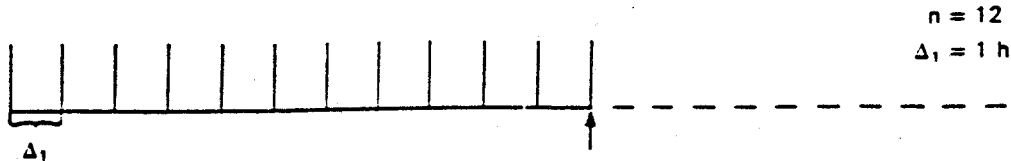
TDF Operating Parameters

- 15,000 Shots Over a 5 year period
- Target Yield: 50 - 800 MJ per shot
- Nominal Target Yield: 200 MJ
- Shot Rate: 10 - 12 shots per day

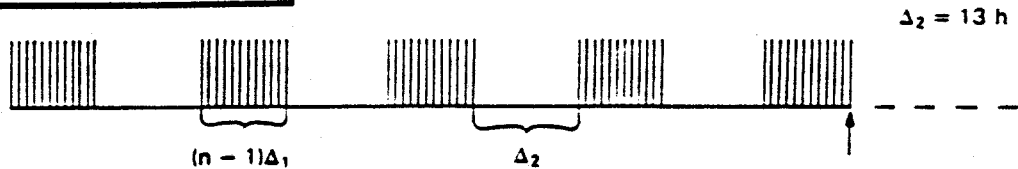
LIBRA Operating Parameters

- Power: 1200 MW_e
- Target Yield: 320 MJ
- Target Gain: 80
- Shot Rate: 3 Hz

Daily Pulse Sequence



Weekly Pulse Sequence



Yearly Pulse Sequence

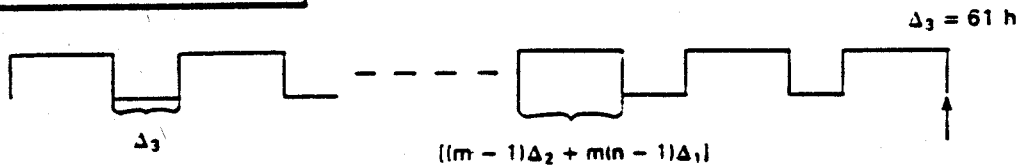
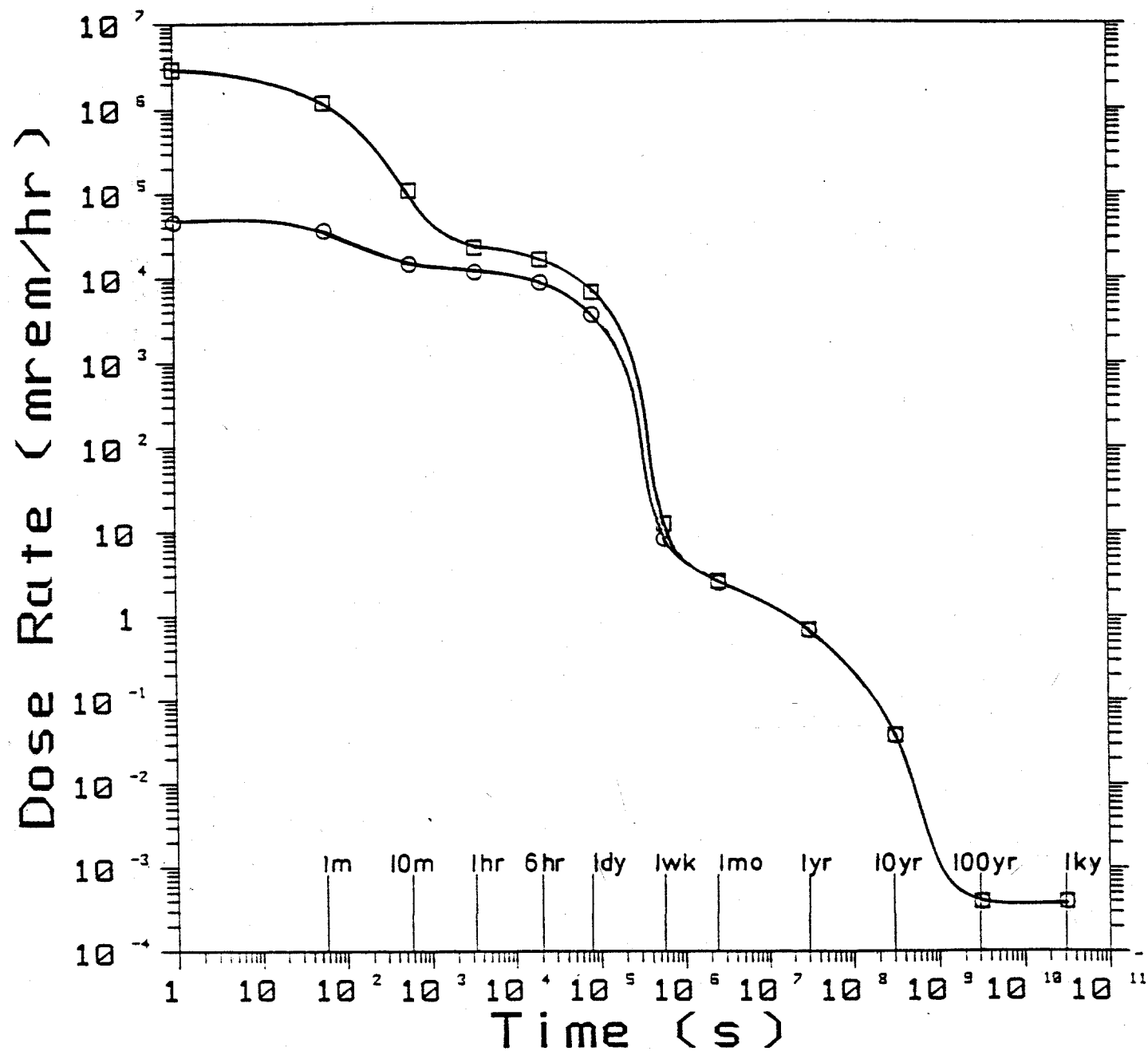


Figure 2 : Pulse Sequence Schedule used for the proposed Light Ion Fusion Target Development Facility.

DOSE RATES FOR ALUMINUM DIODE

○ - Steady State

□ - Pulsed



Time of Operation = 1 month

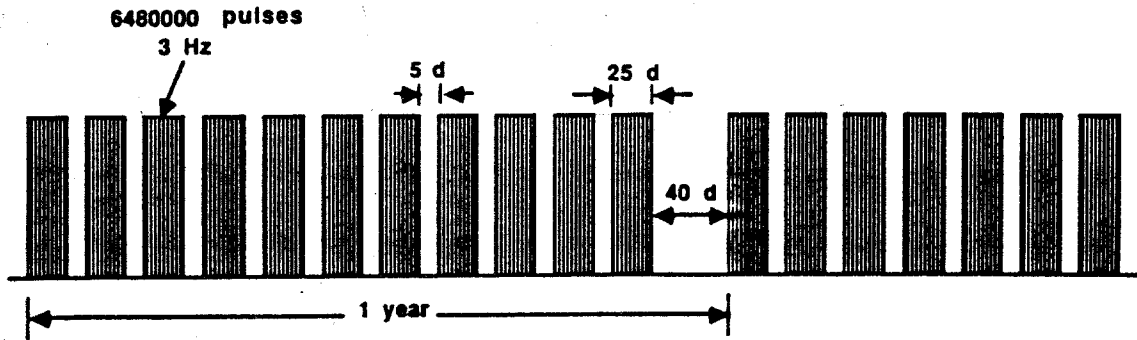
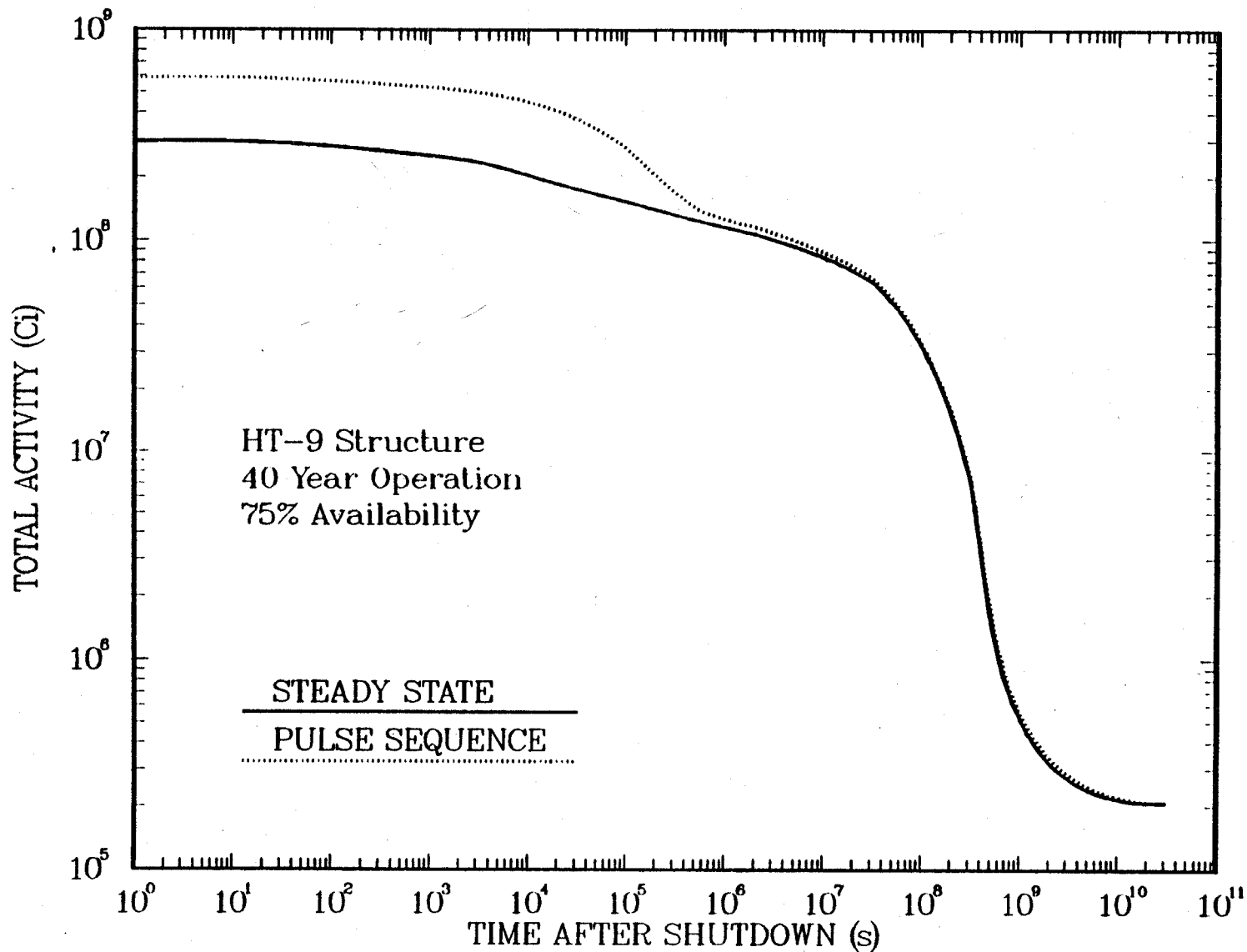


Figure 5 . Pulse Sequence Schedule used in the LIBRA Reactor Study.

EFFECT OF PULSE SEQUENCE ON TOTAL ACTIVITY IN LIBRA CHAMBER



Exact Treatment of Pulse/Intermittent Activation

- **Linear Chain Method**

- Define a matrix $\mathbf{B}$ for activation during a pulse
- Define a matrix $\mathbf{C}$ for decay period between pulses
- It can be shown that the solution after n pulses is:

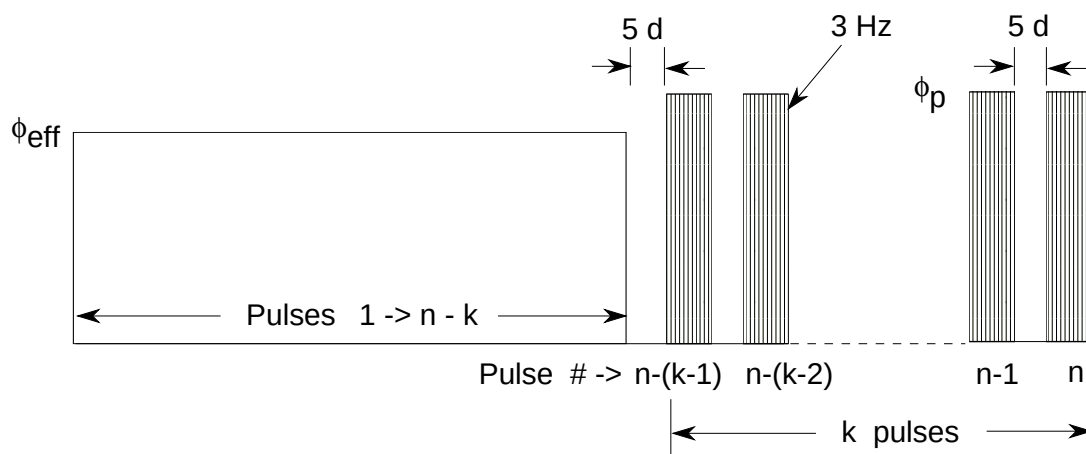
$$\overline{N}((n\Delta t_1 + (n-1)\Delta t_2)) = \mathbf{B} \times (\mathbf{C} \times \mathbf{B})^{n-1} \times \overline{N}(0)$$

- **Complex irradiation histories can be constructed in a similar manner.**

Modelling of Pulse Sequences (Irradiation History), cont'd

- The following hybrid steady state/pulse calculational model has been shown to give accurate results for most cases.

- One uses the Effective steady state method for the majority of pulses (operation history) and adds on several to many pulses at the end to complete the operation history. Both neutron fluence and operation time are preserved during the Effective steady state calculational period.



- In order to generate accurate results, the modeler must choose the appropriate number of pulses, based on the dwell/maintenance period, duty cycle, and half-lives of the dominant nuclides and their relationship to each other. The modeler must therefore devise a prescription for choosing the number or rely on experience and multiple calculations as checks.

Critical Issues For Chamber Activation Calculations

- Neutron Source

- Due to the rapidly changing spatial and density profiles during target burn, time-dependent or quasi-static neutron transport calculations should be performed to obtain a realistic neutron spectrum for the chamber analysis.

- Chamber Analysis

- It is important to model the pulse irradiation history as accurately as possible to obtain accurate, sensible results. In the absence of an exact treatment, the hybrid steady state/pulse method, if properly arranged, provides a sufficiently accurate alternative.
- Depending on the choice of target constituent materials, radioactive target debris can impact the activity of the chamber wall or protective liquid.
- Neutrons emanating from target will activate structural materials, coolant/protective liquid, breeding material and chamber buffer gas (Xe).
- The standard quantities of interest in MFE fusion chamber analysis are also of interest for IFE chambers: biological dose rates (during operation and after shutdown), WDR ratings, decay heat, clearance index and breeding ratio's.

State of the Art Codes are used for the Activation Calculations

- **Neutron Transport Codes**
 - **DANTSYS Discrete Ordinates Code System**
 - **MCNP-4b**
- **Activation Analysis**
 - **DKR-Pulsar v2**
 - **ALARA**

UW Activation Codes

DKR-PULSAR v2

- Multi-dimensional capability
- Has pulse/intermittent calculational capability
- Limited loop capability
- Uses the linear chain method
- Uses a variant of the Bateman equation solution
- Truncates linear chain on a stable nuclide
- Produces accurate results (slight inaccuracy for loop case)
- Computes activity, afterheat, biological hazard potential, and biological dose rate
- The DKR series of codes have been used for MFE and IFE design studies for over 2 decades

ALARA

- Multi-dimensional capability
- Models complex pulse histories and varying pulse heights
- Straightens loop into linear chains
- Uses the Laplace transform solution method
- Truncates chains using exact operation time
- Produces accurate results
- Computes activity, afterheat, WDR ratings, clearance index, provides pathway analysis
- Future additions: biological dose rate and adjoint activation capability
- New to the MFE and IFE fusion community
- Use of C++ language which allows for:
 - dynamic memory allocation
 - complex data structures
 - simplified use of specific sparse matrix methods