A well-established methodology for the conceptual design and neutronic analysis of Accelerator-Driven Systems (ADS), based on both deterministic and Monte Carlo codes

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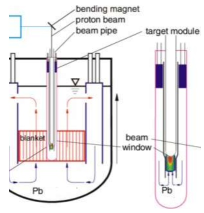

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INTRODUCTION

Since 2000s, ENEA laboratory for Design and Analysis of Nuclear Systems was engaged in international research studies related to **ADS** concept aiming **fuel cycle closure** [1, 2]. Recently (commission of Transmutex Swiss company), feasibility study for **~600 MW$_{th}$ lead-cooled ADS** (Fig. 1):

- sub-critical core loaded by **metallic Th** & **spent fuel**, made of U & transuranics (**UTRU**) coming from PWRs
- coupled with **800 MeV proton (p+)** accelerator having p+ spallation target in two central rings of core lattice

Well-established ENEA methodology was applied to this **dual-purpose** ADS: **TRU burning** and **^{233}U breeding.**

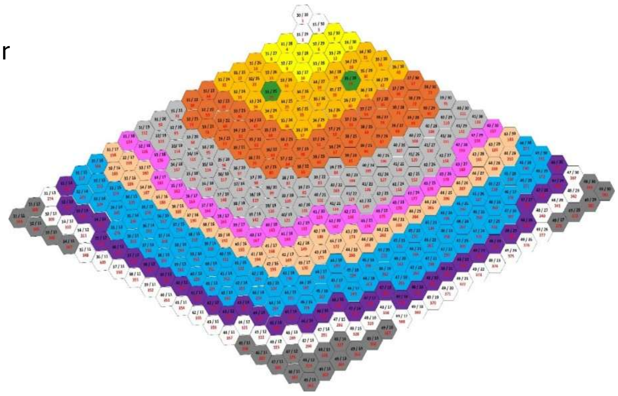

Fig. 1: ERANOS 3D hexagonal model of ~600 MW$_{th}$ ADS core ($2\pi/3$ symmetry).

RATIONALE

Both deterministic (as ERANOS [3]) and **Monte Carlo** (MC) **codes needed** for conceptual core design and neutronic analyses of ADSs

- Deterministic codes can "easily" perform fuel cycle analyses
- MC codes (as MCNP [4]) can do burnup calcs only in "*k-mode*" and not in "*fixed-source mode*" (used for external p+ source)

But, ERANOS requires "**external source term**": n density (**<20 MeV**) deriving from p+ spallation, that can be computed only by MC codes

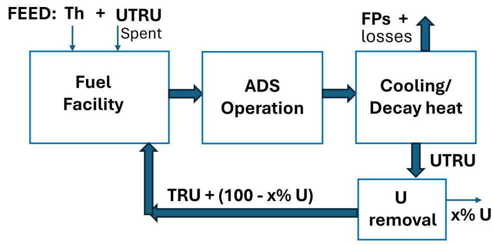

Fig. 2: Closed fuel cycle with TRU (and part of U) recycling.

Application of the METHODOLOGY

External source term for ERANOS 3D hexagonal model of ADS core (Fig. 1, ~1 m fissile length) was calculated by GEANT-4 MC code [5].

Fuel composition at equilibrium of a 5-year closed cycle was inferred by a procedure based on solution of reverse Bateman's equations [6] and modified accordingly with conceptual scheme of Fig. 2: part of U produced is re-loaded to limit k_{eff} (→ p+ current) swing in operation.

Starting from ERANOS results on multiplication "M" per spallation neutron (1) and related "k_S" (2) parameters, relation between core power "P_{core}" (MW) and p+ current "i_p" (mA) can be retrieved by (3):

$$M = \iint \phi \nu \Sigma_f \, dE dV \quad (1) \qquad k_S = \frac{M}{M+1} \quad (2)$$

$$i_p[mA] = 10^3 \frac{P_{core}[MW]}{Q\,[MeV]} \frac{\nu\,(1-k_{eff})}{\varphi^* \, N_S \, k_{eff}} \quad (3) \qquad \varphi^* = \frac{(1-k_{eff})}{k_{eff}} \frac{k_S}{(1-k_S)} \quad (4)$$

where:

- "N_S" is number of n (< 20 MeV) per spallation p+
- "ν" is average n multiplicity per fission, of "Q" energy
- "ϕ" is n flux inducing fissions "Σ_f" in Th-UTRU metal fuel
- p+ current (3) is independent from the cut-off at 20 MeV (typical of deterministic codes) for the "$\varphi^* \cdot N_S$" product

Similar k_{eff} & k_S values (Fig. 3) yield a unitary source importance (4): in a 5x1 year irradiation cycle (simulated by one-batch approach), max k_{eff} was tuned ~0.98 & current i_p estimated in [BoC, EoC] sub-cycle.

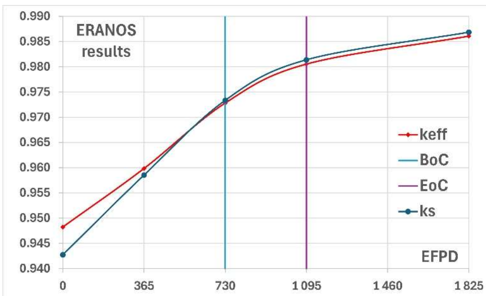

Fig. 3: k_{eff} and k_S variation in 5-year irradiation cycle (one-batch approach).

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