Extension of hybrid micro-depletion model for decay heat calculation in the DYN3D code

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This work extends the hybrid micro-depletion methodology, recently implemented in DYN3D, to the decay heat calculation by accounting explicitly for the heat contribution from the decay of each nuclide in the fuel.

Coupling of neutron kinetics codes with plant thermo-hydraulic codes is widely used for analysis of complicated transient and accident scenarios where both 3-dimensional neutronics and thermal feedbacks from plant components and safety systems play essential role.
DYN3D is a 3D nodal reactor dynamic code developed at the Helmholtz-Zentrum Dresden–Rossendorf mainly for transients, but also for steady-state and fuel cycles analysis in LWR cores with hexagonal or square fuel assemblies.[1] It can be used as part of a coupled system with codes such as ATHLET and RELAP5.[2, 3]
Simulation of residual decay heat is important in a number of accident scenarios such as loss of coolant, main steam line break, etc.
DYN3D calculates node-wise decay heat power by applying methodology described in German normative document DIN Norm 25463.[4, 5] The fission products of four fissile isotopes ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu are divided into 24 groups each having a characteristic decay constant. Decay heat power is calculated individually for each node taking into account local power history. The model is suitable for decay heat calculation for UOX fuel in light water reactors with a maximum initial enrichment of 4.1 %.
This work presents an explicit method of decay heat calculation recently implemented in DYN3D. This method relies on "first principles" – it utilizes detailed information about nuclide content and does not require approximations or assumptions about fuel content evolution with depletion. Thus, the proposed method is general and not limited to particular fuel types.

EXPLICIT DECAY HEAT MODEL. The hybrid microscopic depletion method was recently developed and implemented in DYN3D.[6] The isotopic depletion solver is based on fast and accurate CRAM method and is able to calculate a nuclide content of each node taking into account local operational history which is used to improve the accuracy of homogenized cross sections.[7] DYN3D tracks about 1200 nuclides and utilizes complete decay and depletion chains (i.e. no shortcuts and asymptotic assumptions). The fact that DYN3D tracks full set of nuclides during all depletion and decay steps allows explicit calculations of important fuel characteristics such as decay heat power in each node:

$$P^n(t) = \sum_i N_i^n(t)\lambda_i q_i \, , \qquad (1)$$

where $P^n(t)$ is the decay heat power in node n at time t, $N_i^n(t)$ is the nuclide i concentration in node n, λ_i and q_i are the decay constant and energy release per decay of the nuclide i, respectively. The sum in Eq. (1) is over the entire set of nuclides in the node.
Currently, the depletion solver considers five types of neutron reactions: (n,γ), (n,fission), (n,2n), (n,3n), and (n,α).
Homogenized few-group *microscopic* cross sections (XS) for the considered reactions are generated by a lattice transport code along with homogenized few-group *macroscopic* XS and included in the few-group cross section library utilized by DYN3D. The decay constants, fission yield data, and energy release per decay of each nuclide are included in an internal DYN3D library of physical constants.

VALIDATION. A verification of the new decay heat power calculation capability has been performed using a simple test model. The considered test case is a BWR UOX fuel pin with reflective boundary conditions. The depletion and decay calculations were performed with DYN3D employing homogenized macro- and microscopic XS generated by Serpent 2 Monte Carlo code.[8] The obtained XS library was used to simulate different depletion and outage scenarios. DYN3D results were benchmarked against the reference Serpent Monte Carlo solution.

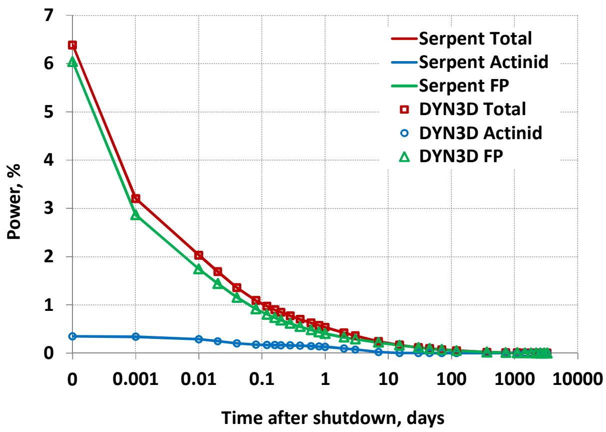

Fig. 1: Decay heat power after shutdown in test case.

The results of the decay heat power calculations depicted in Fig. 1 show excellent agreement between DYN3D and Serpent. For the entire simulated time period, from minutes to 10 years, DYN3D is able to reproduce the reference decay heat power and its components within 0.5 % deviations.

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