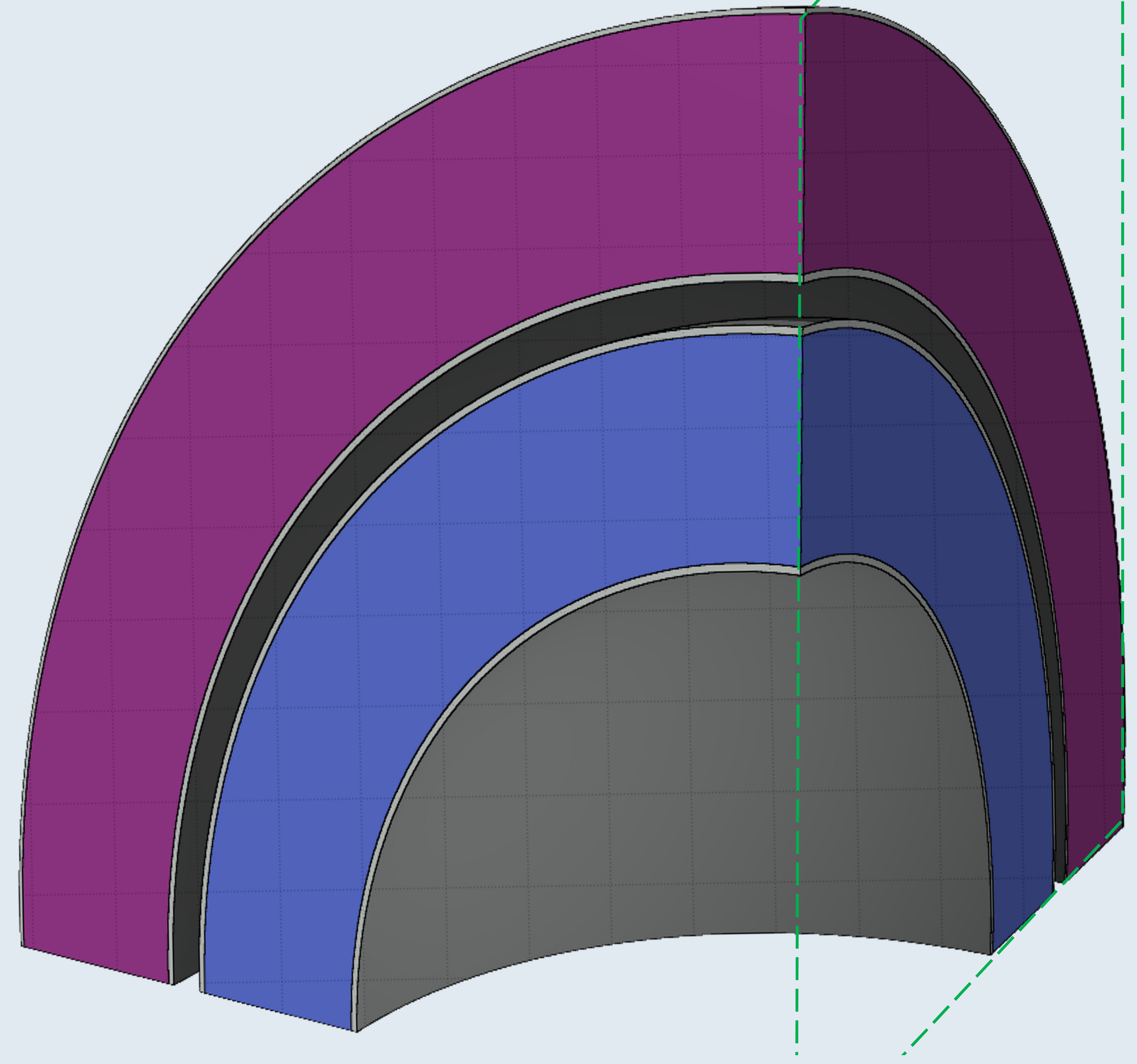

Figure 1. A cut-out of a representative power dump with several layers of materials. (blue, High-Z material for absorbing photons; purple, low-Z material for attenuating neutrons)

Radiation Damage in a Power Dump

Combining Monte-Carlo radiation transport calculations and COMSOL® to assess material integrity.

C. Spruijtenburg, W. Chu

Demcon Multiphysics, Enschede, The Netherlands

Abstract

In applications like nuclear reactors or particle accelerators, mechanical components near a source of radiation develop radiation damage. This typically means a change in tensile properties and fracture toughness, which depends on the radiation induced damage (commonly measured in 'displacements per atom', or DPA), and thermal environment. In addition to such radiation hardening, radiation damage can also cause swelling, which in turn can lead to additional stresses.

Here, we needed to assess the risk of failure for a power dump. The purpose of this power dump is to absorb gamma radiation emitted from a target that is irradiated by an electron beam, but it also stops many other types of radiation (neutrons, electrons, positrons). The material of which this component is made can become very brittle after irradiation, so fast fracture is the most likely failure mechanism we need to assess here.

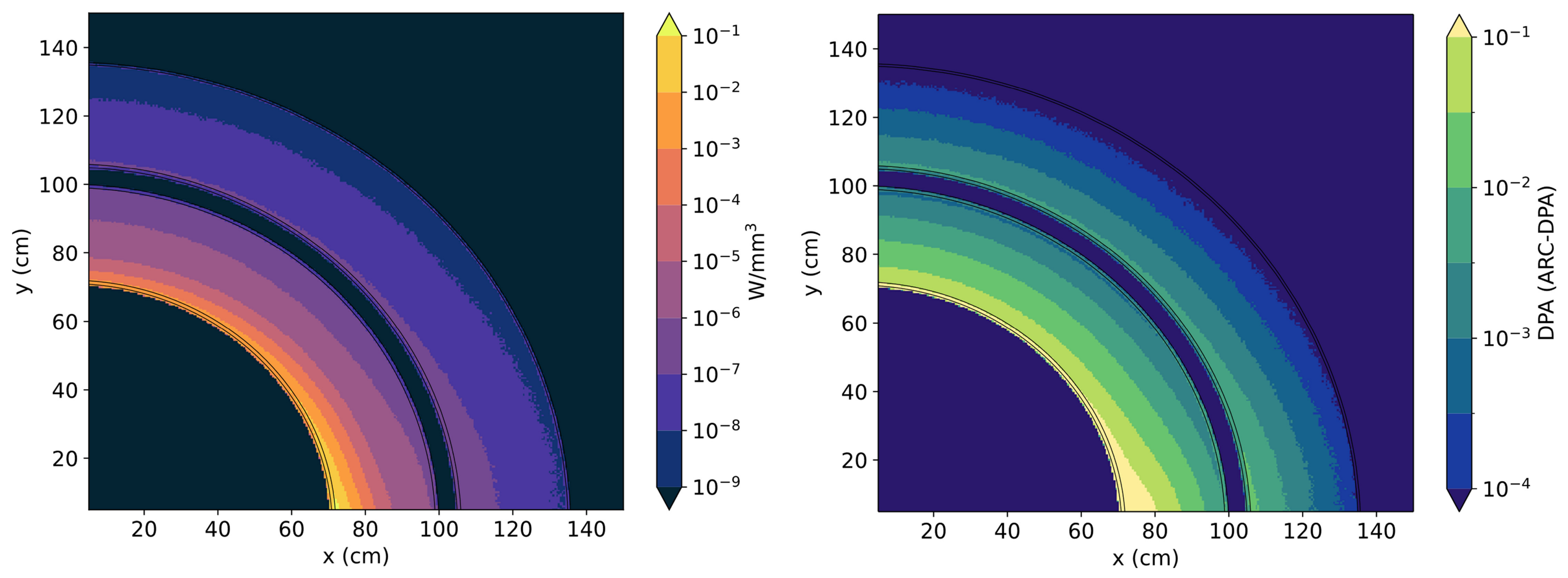

Figure 1. Radiation transport calculations in FLUKA. (left) Results showing heat load (W/mm^3) (right) Results showing Displacements per atom (DPA).

Monte Carlo Radiation Transport Using FLUKA

Full irradiation profile from interaction of electron beam with target:

- Bias relevant interactions, such as photo-nuclear and neutron interactions.

Relevant radiological parameters are extracted:

- Damage: the number of displacements per atom (DPA). FLUKA directly captures this quantity while also taking into account defect recombination.
- Heat: Deposited energy per unit volume (W/mm^3)

COMSOL Structural Mechanics – Thermal Expansion and Swelling

Input

- The spatial distribution of damage production (DPA/s) is used in a relation that determines swelling strain, and varies in space and time.
  - The relation for swelling strain is $\epsilon_{swell}(DPA) = \epsilon_{saturation} \cdot f(DPA)$. Here, $f(DPA)$ is a saturating function.
- From the heat load, a temperature is calculated and imposed to account for thermal expansion.

Result

For the fracture toughness of the material we assume a conservative value of K=5 MPa$\sqrt{m}$. The maximum expected crack size is much smaller than the part, so we can use a simple relation to deduce that such a crack will tear at a stress of 250 Mpa.

Using these conservative estimations, we conclude that the part is not likely to fail under these irradiation conditions.

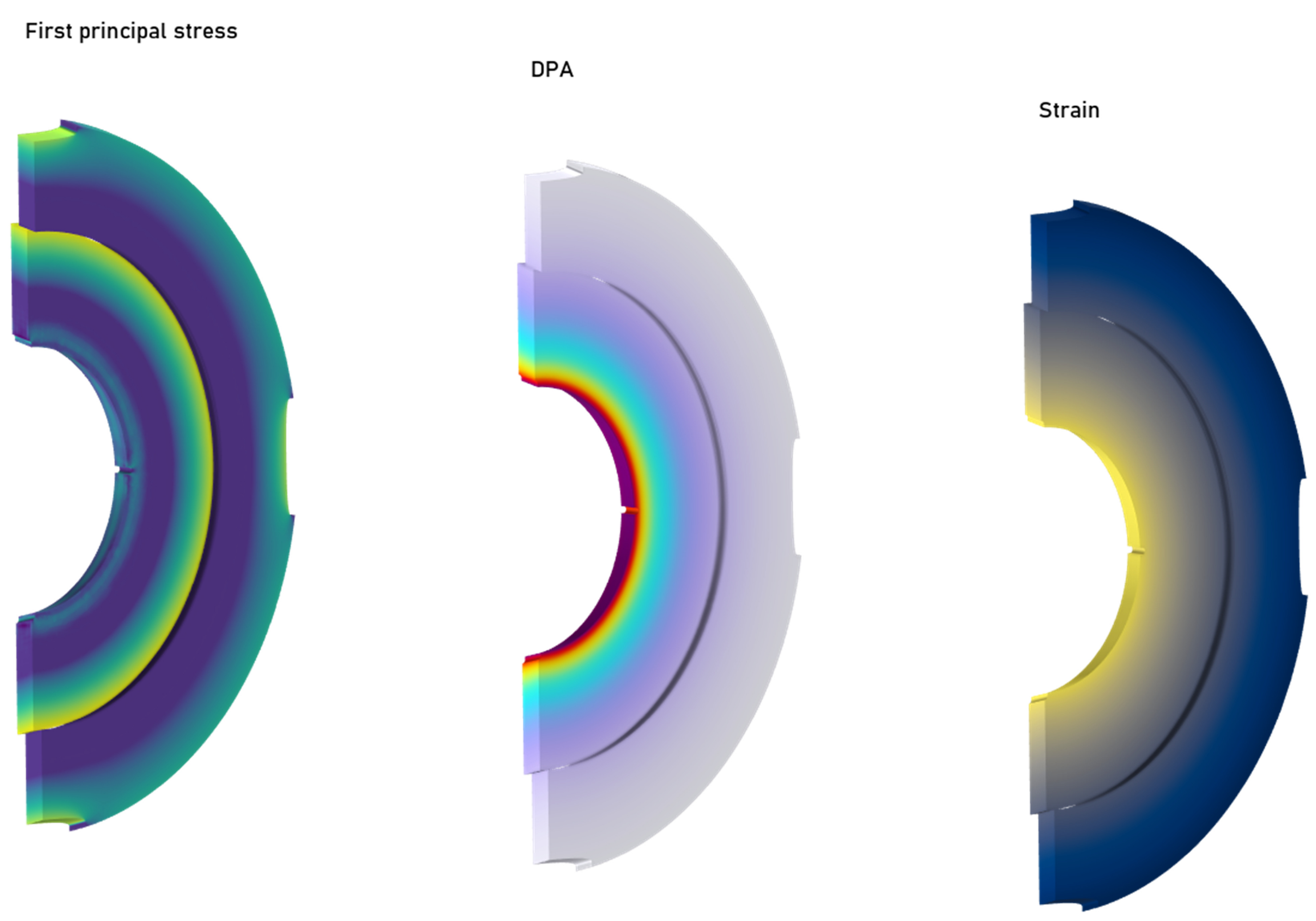

Figure 2. Structural mechanical calculations in COMSOL®, which take into account swelling due to radiation damage.

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