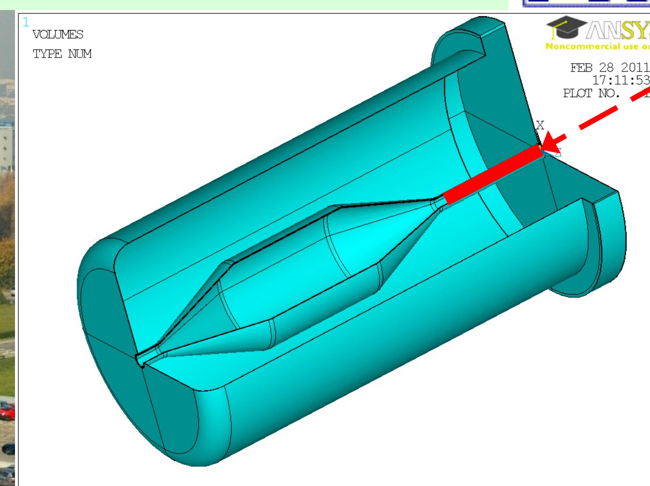
Target-horn integration and degradation of material properties due to radiation

Błażej Skoczeń, Aneta Ustrzycka

Cracow University of Technology

(Institute of Applied Mechanics, Centre for Particle Accelerators Design)



Target-horn integration – references

1. C. Bobeth et al., „The target and horn for the SPL-based Super Beam: preliminary design report". EuroNu WP2 Note 11-01, February 2011.

2. J.M. Maugain, S. Rangod, F. Voelker, „Study of a horn with integrated target for a neutrino factory", CERN-NUFACT Note 80.

3. N. Simos, „Superbeam Horn-Target Integration", BNL, EUROnu-IDS Target Meeting, December 15-18, 2008.

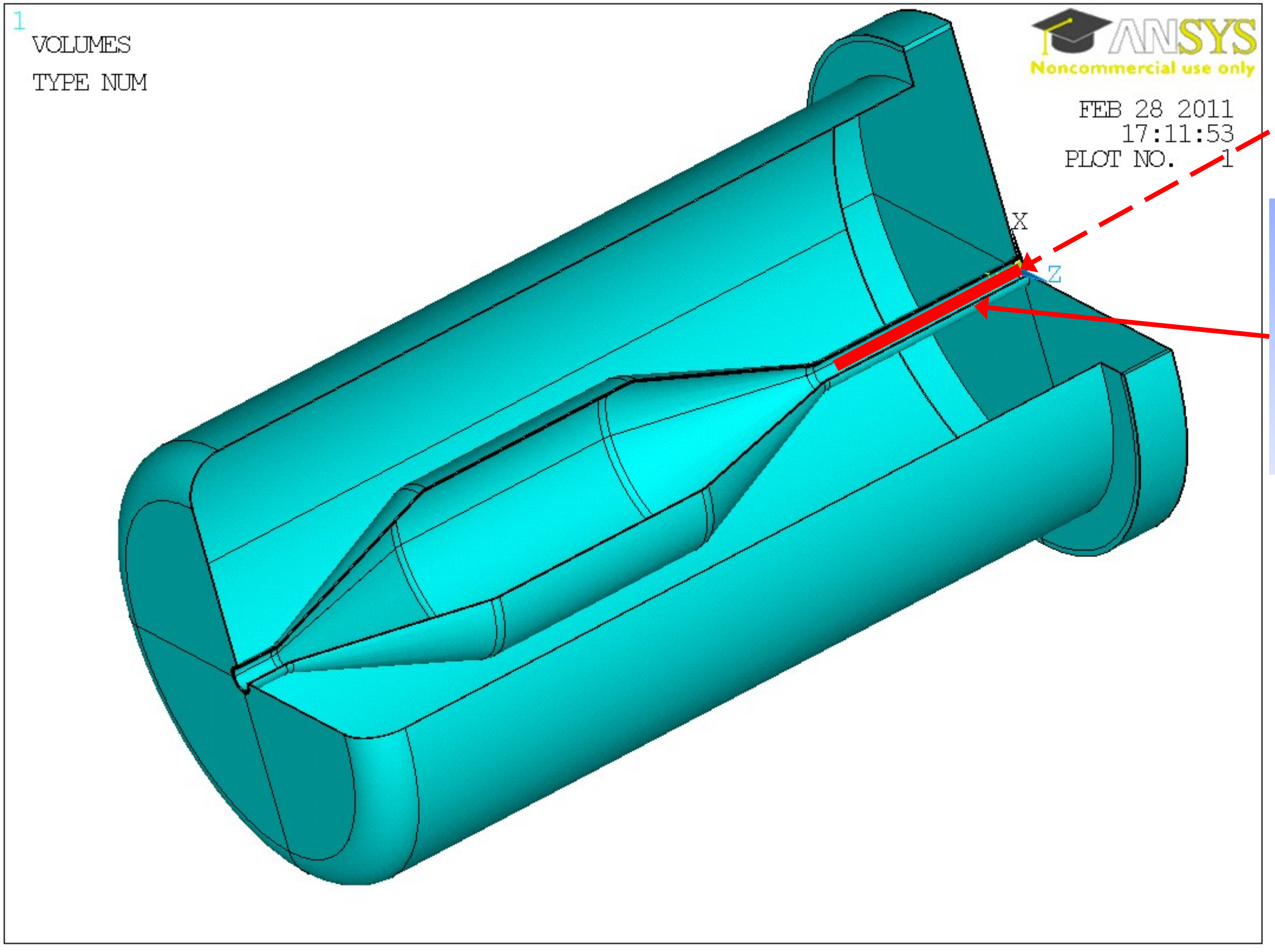
4. N. Simos, „Horn/Target Material Studies at BNL. Towards multi-MW Beam", LBNE Science Collaboration, Meeting - FNAL July 15, 2009.

5. R. Flukiger, „What do we know about irradiation problems in High Luminosity LHC?", MSC Seminar, CERN, 2012.

Target-horn integration - assumptions

1. Target station composed of 4 targets and collectors is envisaged,
2. The consecutive beam pulses will be sequentially directed to one of the four targets/collectors,
3. Each of four targets will be embedded in the bore of the relevant conventional pulsed current magnetic horn (inside magnetic reflector),
4. Within 4-target assembly, each target is designed for 1 MW beam,
5. For the sake of simplicity, a solid beryllium target has been analysed as an option.

Target-horn configuration



NIEL

↓

dpa

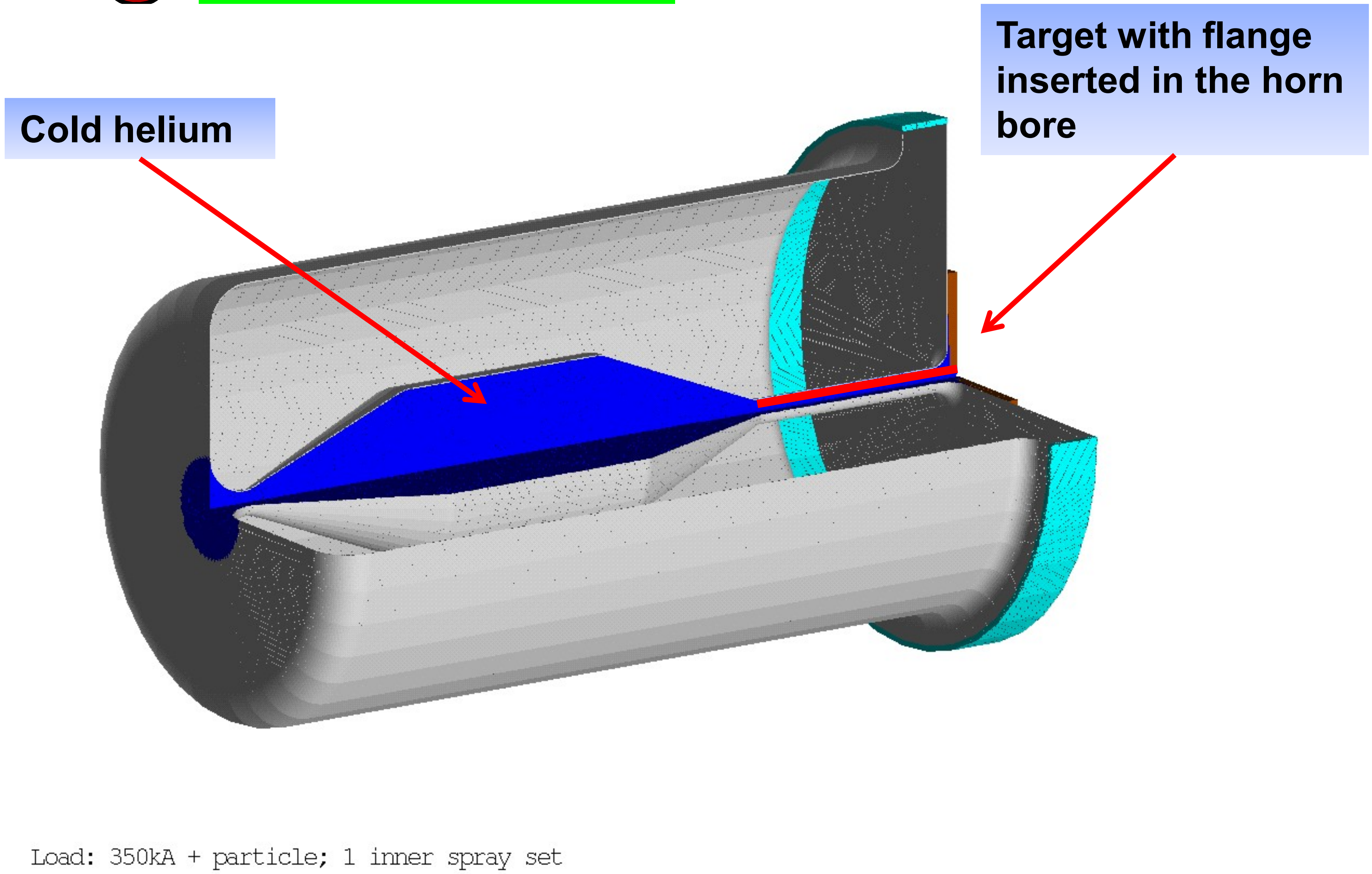
↓

$D = D_r + D_m$

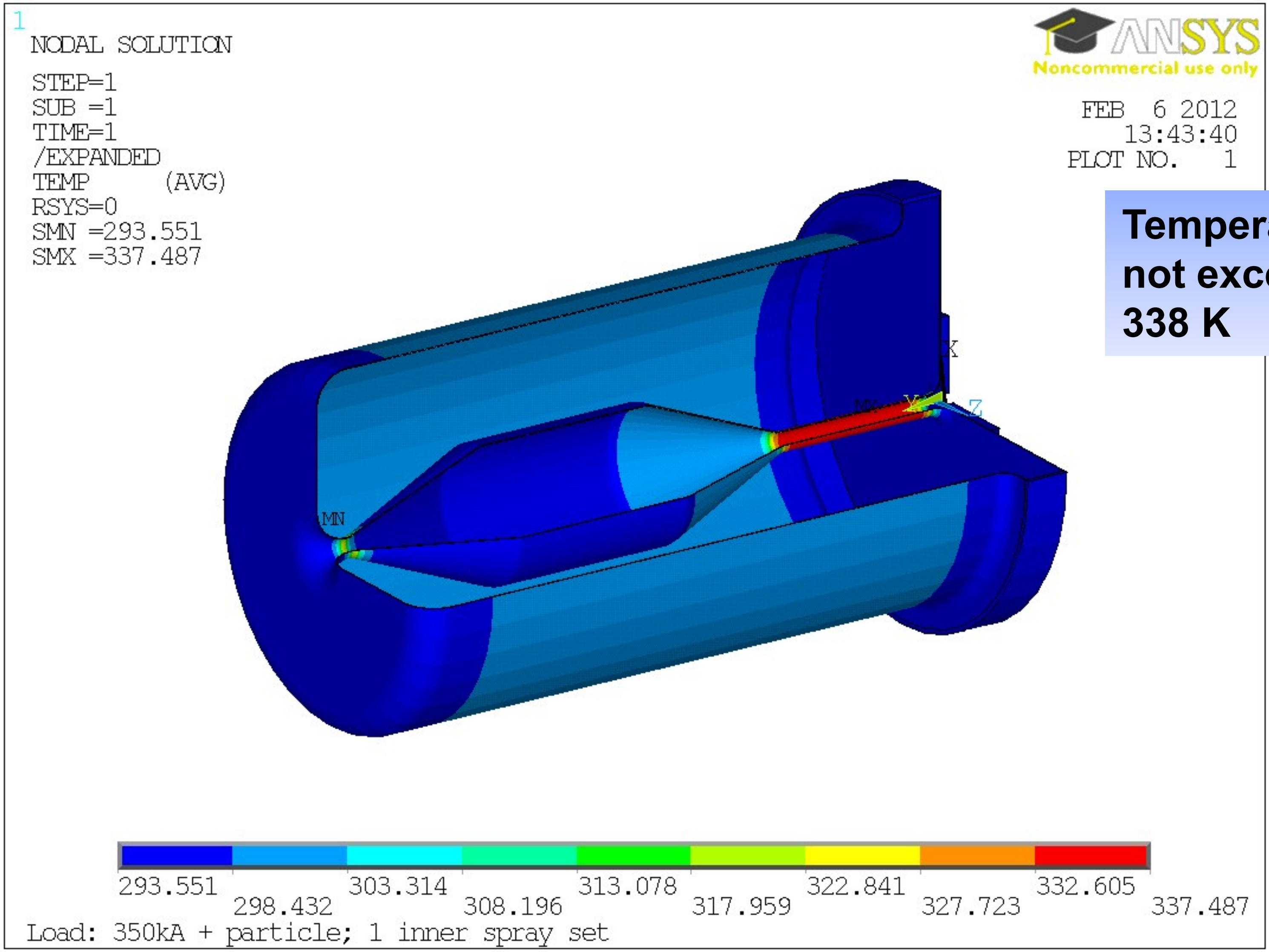
Target-horn integration – main issues

1. Mechanical integration of target inside horn should be simple and remotely operated (if possible),
2. The target should be inserted in the horn bore as one component only,
3. The target will be cooled by the forced flow of cold helium – the flow impedance should be defined and tested,
4. Beam deposition in the target should not drastically affect horn temperature (heat transport should be thoroughly analysed),
5. Secondary particles flux will affect integrity of the horn – degradation of material properties due to irradiation should be evaluated.

Target-horn integration

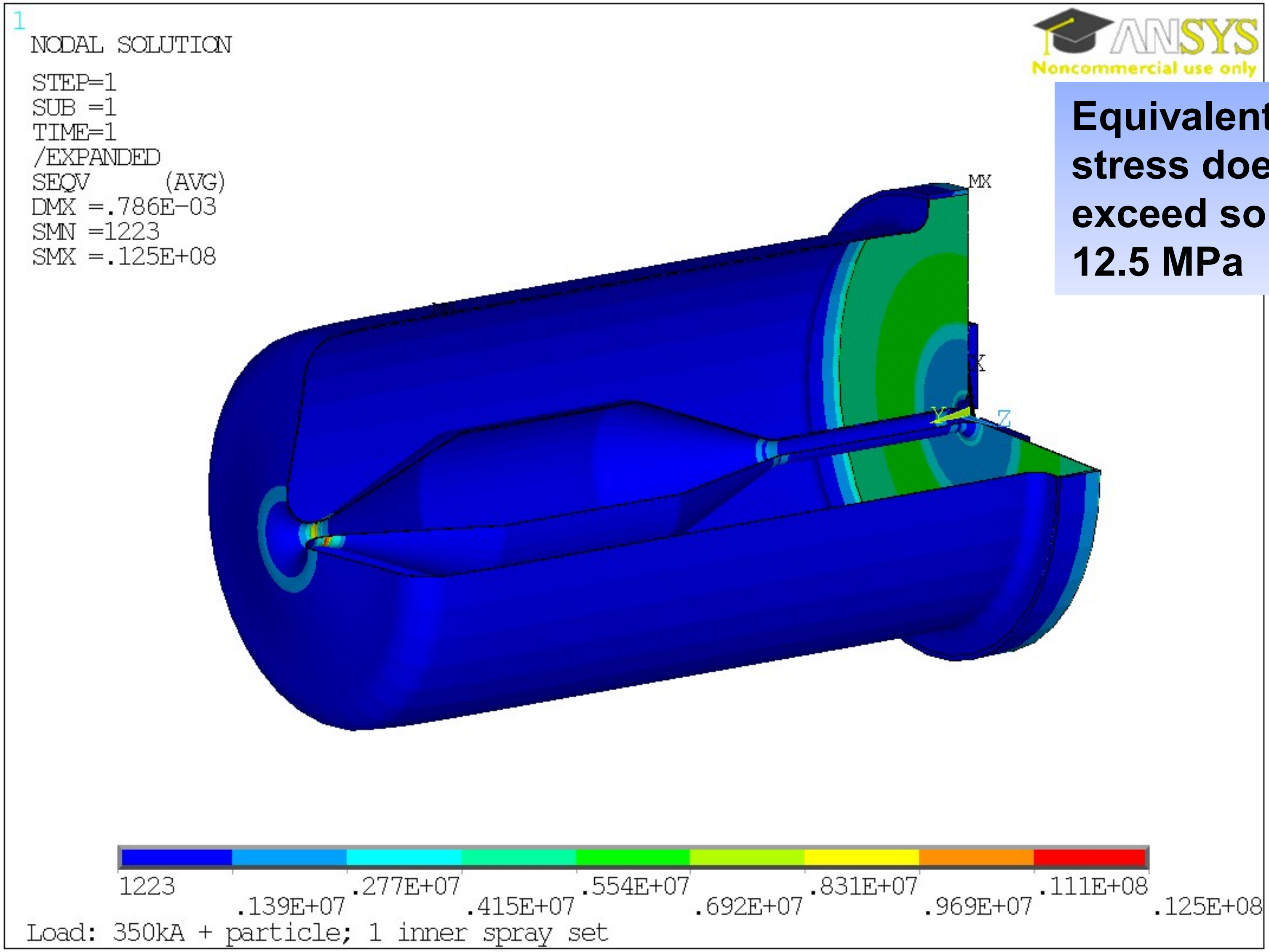


Thermo-mechanical analysis



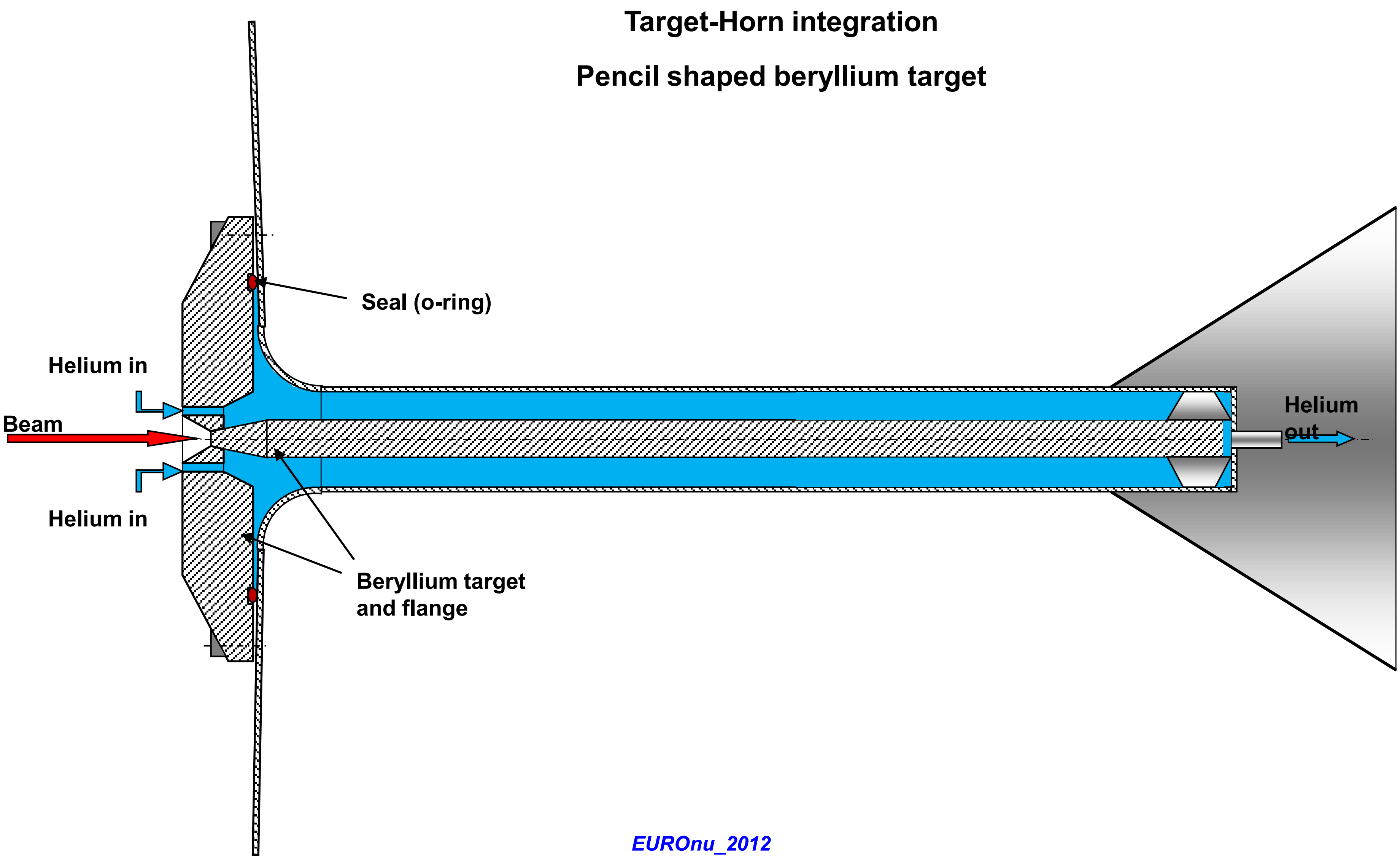
Temperature does not exceed some 338 K

Thermo-mechanical analysis



Equivalent stress does not exceed some 12.5 MPa

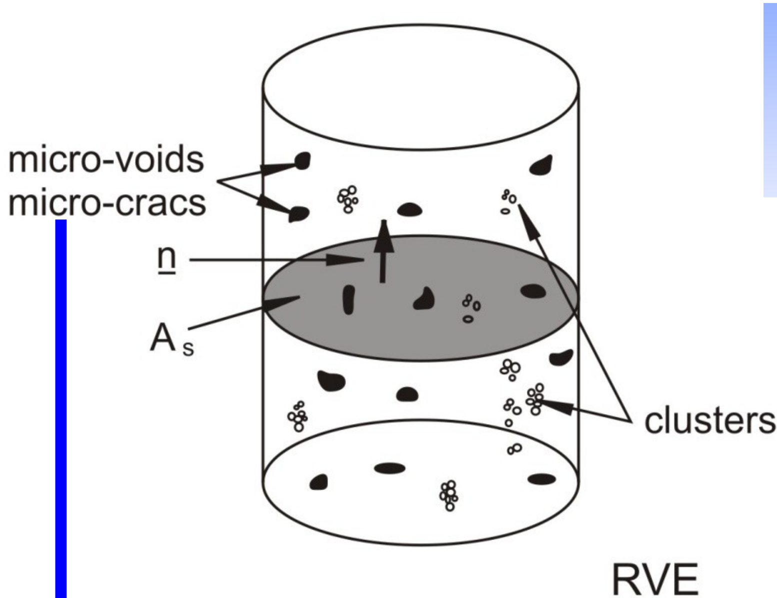
Target-horn integration



EUROnu_2012

Radiation and mechanical damage components – additive formulation

Postulate:
both micro-damage components are treated in additive way



$$D_r = D_{r0} + \int_0^{\hat{p}} dD_{rm}$$

$$\underline{\underline{D}}_r = \frac{D_r}{3} \underline{\underline{I}}$$

isotropic

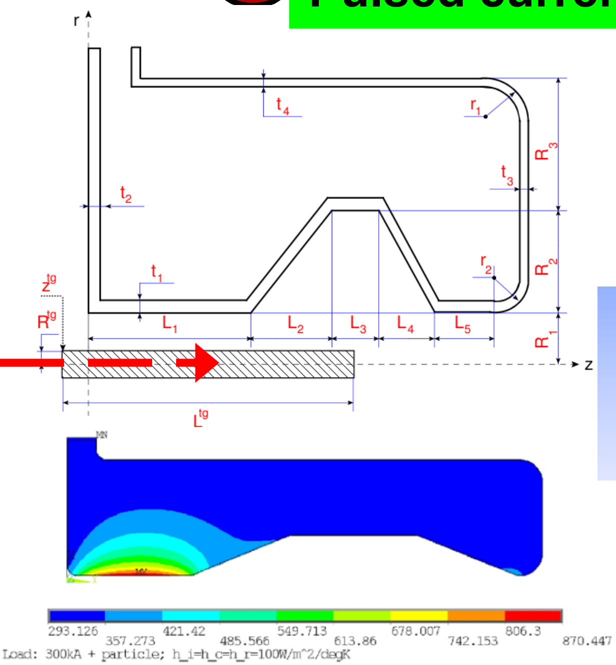
$$d\underline{\underline{D}}_m = \underline{\underline{C}}\,\underline{\underline{Y}}\,\underline{\underline{C}}^T dp$$

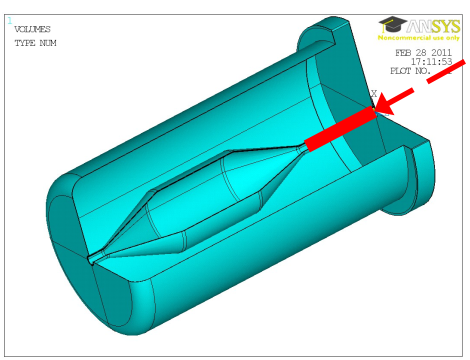
anisotropic

$$\underline{\underline{D}} = \underline{\underline{D}}_m + \underline{\underline{D}}_r = \underline{\underline{D}}_m + \frac{1}{3} D_r \underline{\underline{I}}$$

Example 3: Horn

Pulsed current & irradiation





i=i+1 pulse

$$NIEL^i \Rightarrow dpa^i$$

$$D^i_{r0} = q_A \pi r_{c0}^2$$

irradiation

Quasi-static and cyclic loads

$$dr_c = r_c \alpha_r \exp\left(\frac{3\sigma_m}{2\sigma_{eq}}\right) dp$$

$$dD^i_{rm} = q_A dA_{rm} = q_A 2\pi r_{c0} dr_c$$

$$D^i_r = D^i_{r0} + \int_0^{\hat{p}} dD^i_{rm}$$

Quasi-static and cyclic loads

$$\dot{D}^i_m = \left(\frac{Y}{S}\right)^s \dot{p} H(p - p_D)$$

$$D^i = D^i_m + D^i_r$$

$$D = \sum_{i=1}^{N} D^i$$

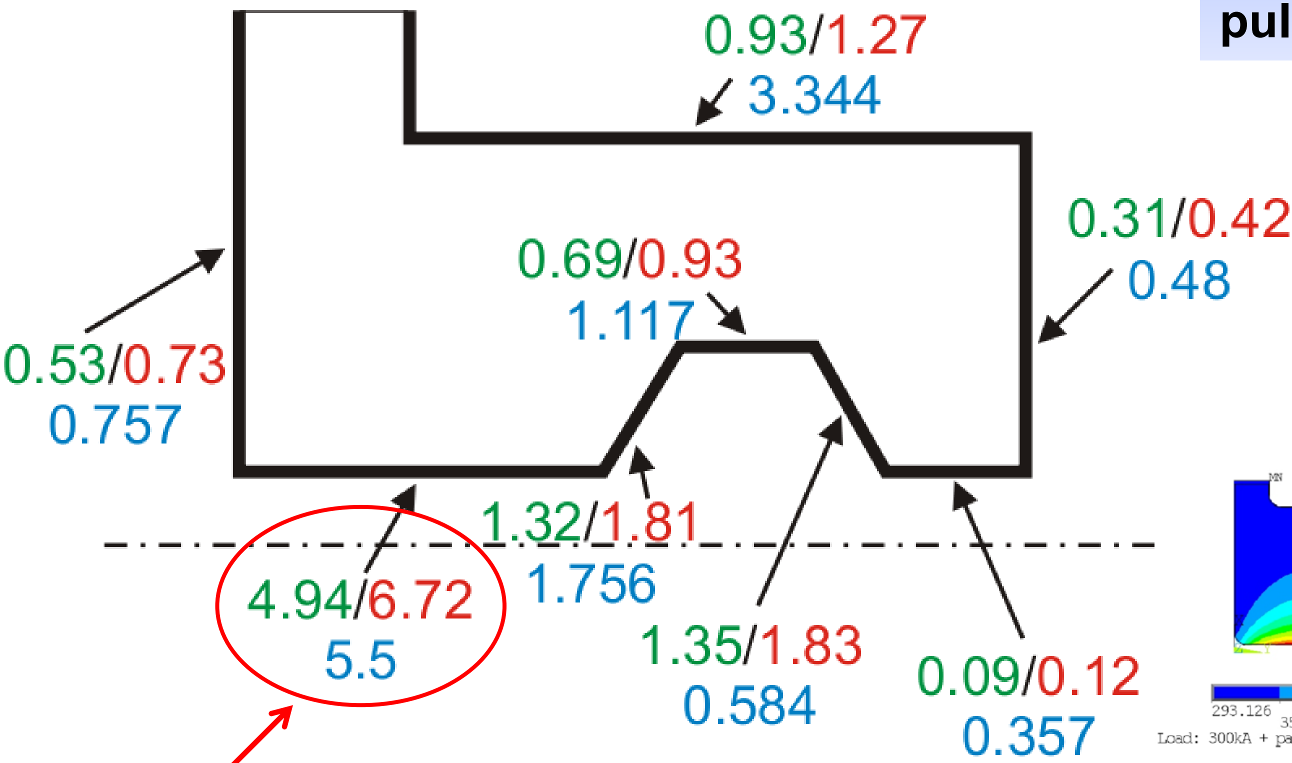
Algorithm for structures subjected to pulsed irradiation

Example 3: Horn

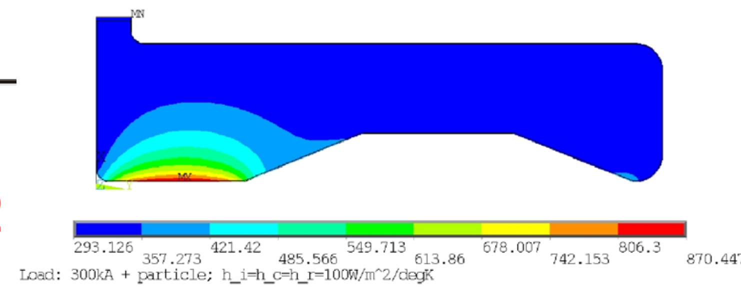
Pulsed current & irradiation

current 300/350kA + particles

Horn scheme containing the distribution of power resulting from current pulses and particle flux



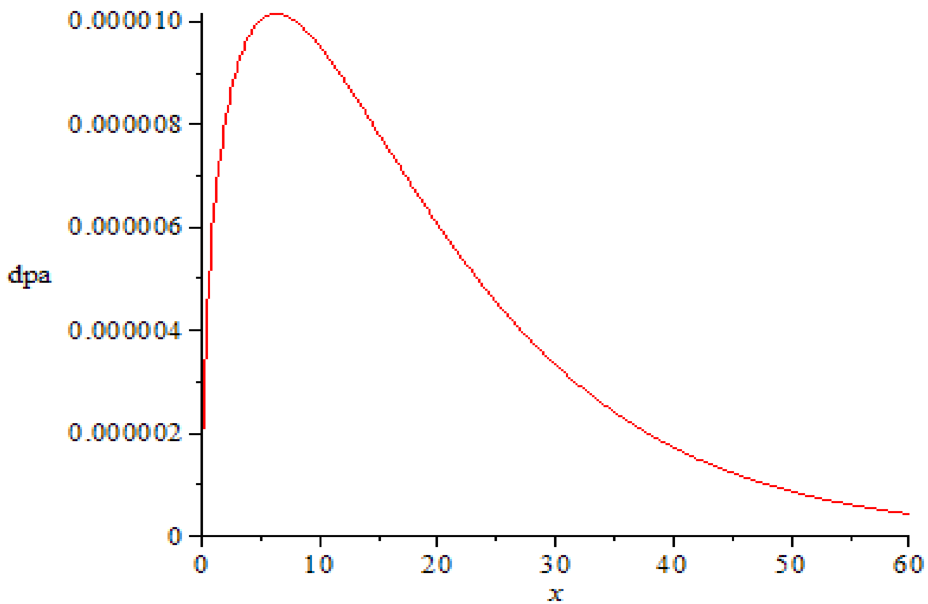
„The target and horn for the SPL-based Super Beam: preliminary design report", EUROnu WP2 Note 11-01



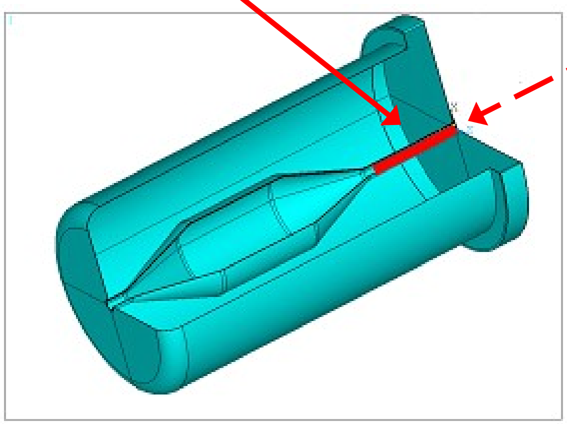
Maximum energy deposition in the proximity of target → maximum NIEL → maximum dpa → maximum micro-damage D_{r0}

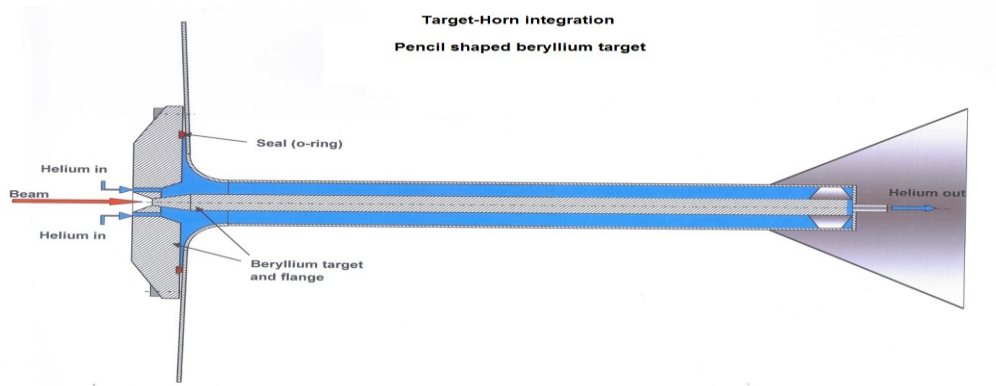
Parametric „dpa" distribution along the horn bore

$$dpa(x) = ax^b e^{cx}$$



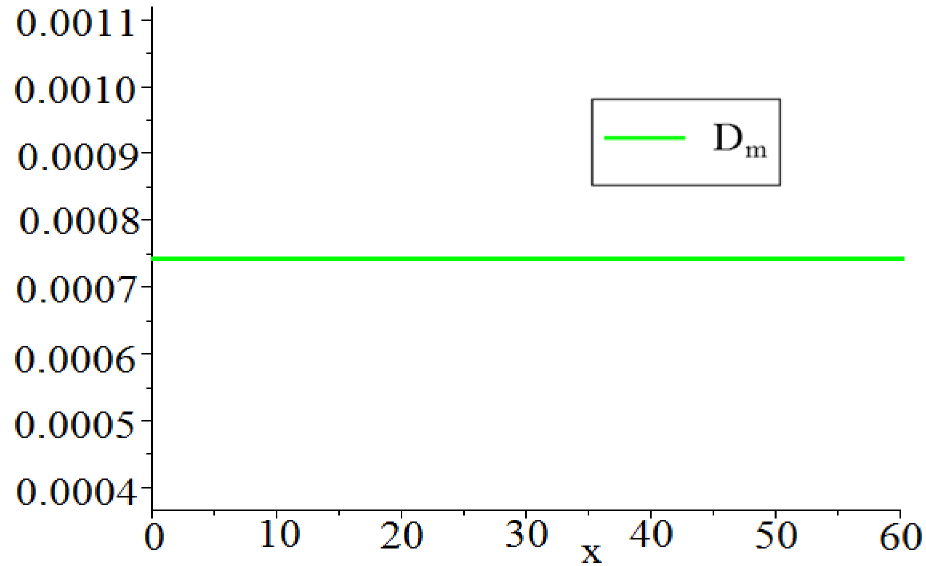
NIEL
⇓
dpa
⇓
D=Dr+Dm

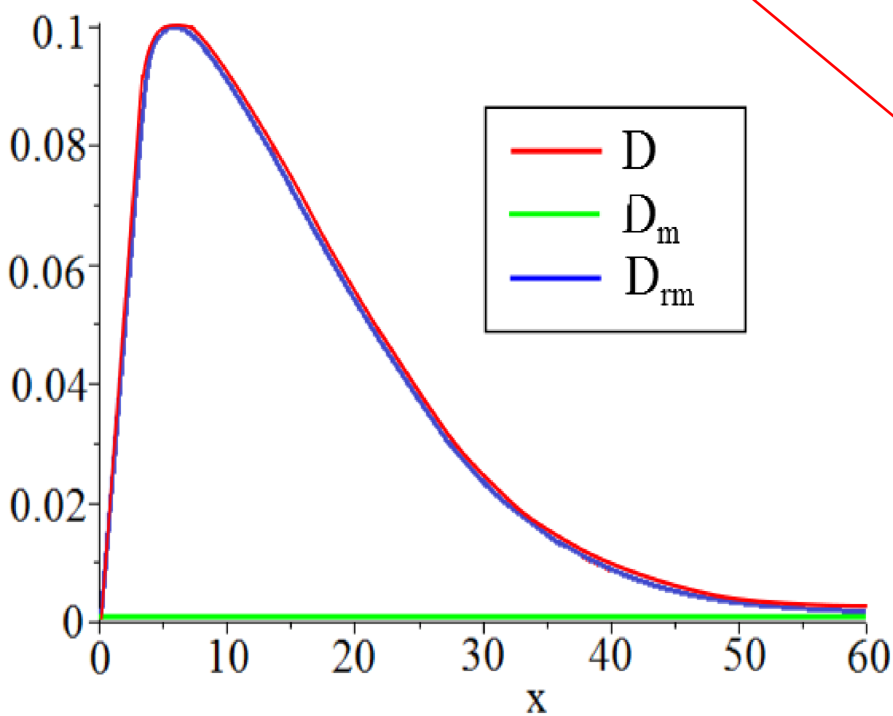


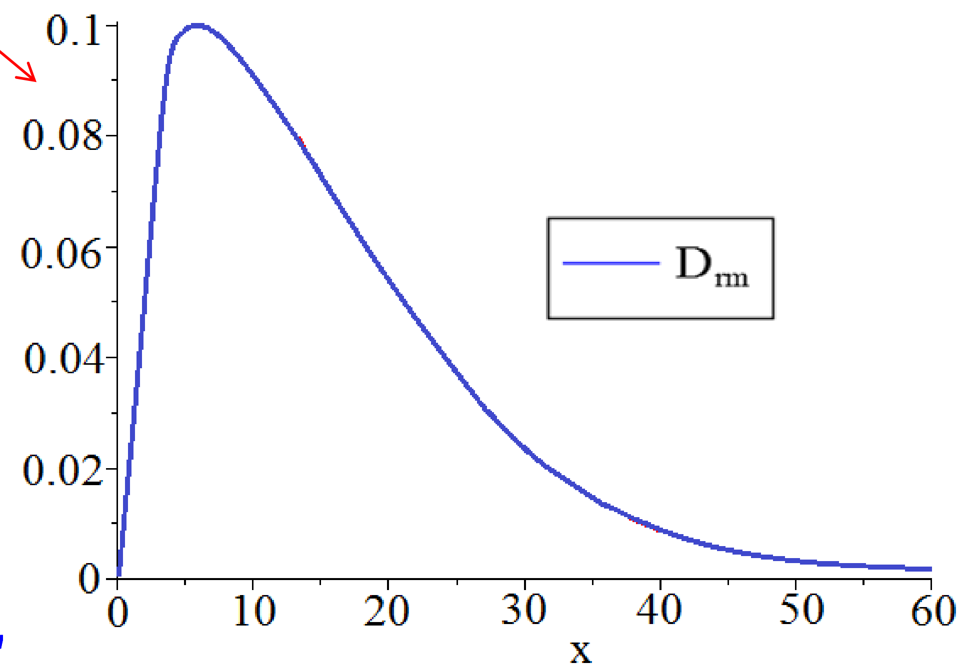


Superposition of radiation induced and mechanical damage

$$D^i = D^i_m + D^i_{rm}$$



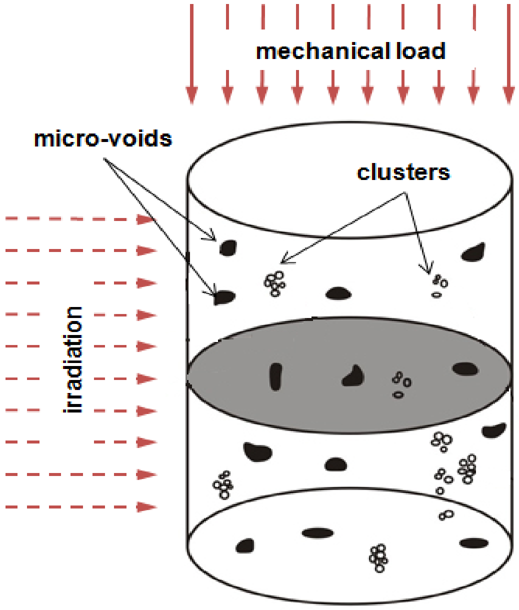


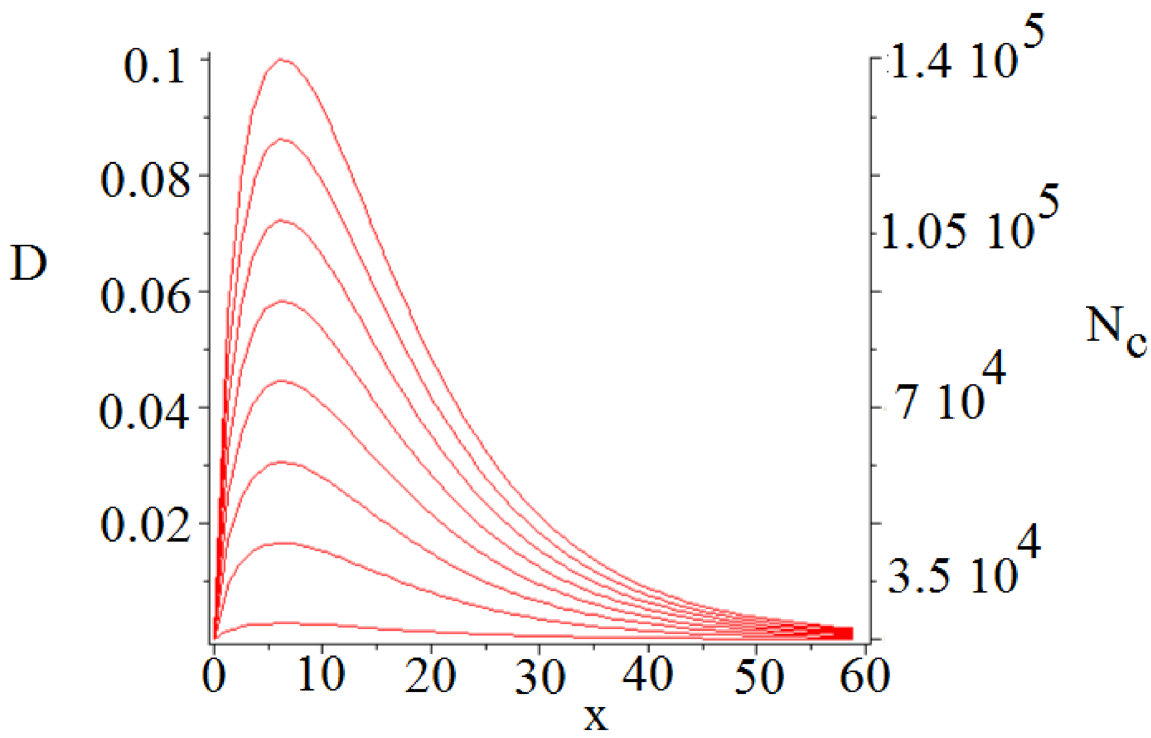


Evolution of damage parameter in the course of horn operation

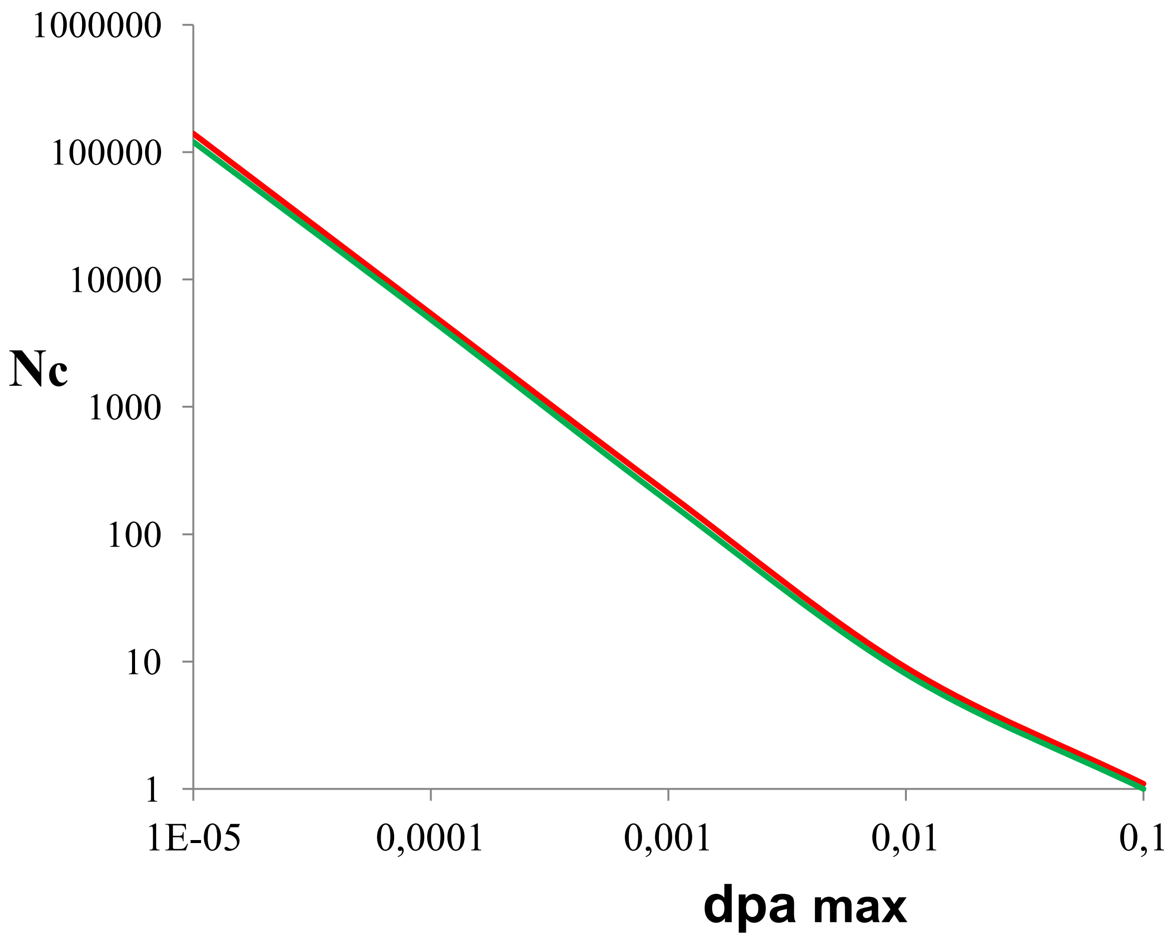
$$D = \sum_{i=1}^{N} D^i$$

$$D^i = D^i_m + D^i_{rm}$$





Number of cycles to failure as a function of maximum dpa on cycle



Conclusions

1. Removing the beam heating of the target and the Joule heating of the horn are feasible,
2. Separation of the target from the horn increases modularity (assembly, maintenance, replacement) and permits efficient cooling solutions for both of them,
3. The thermal stresses in the horn inner conductor are fully acceptable, also for the Joule heating induced by the horn current pulses (efficient cooling),
4. It is possible to adjust the target and the horn geometry separately, including the radial and the longitudinal alignment of both of them,
5. Failure modes of the target and the horn result mainly from irradiation (dpa) and thermo-mechanical cyclic loads and are only partially coupled,
6. Target can be easily removed and reinstalled inside the horn bore, thus reducing the cost of repair and the quantity of radioactive waste.