Numerical Tools at CERN

Rationale of a choice

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Numerical Tools at CERN

The rationale of a choice

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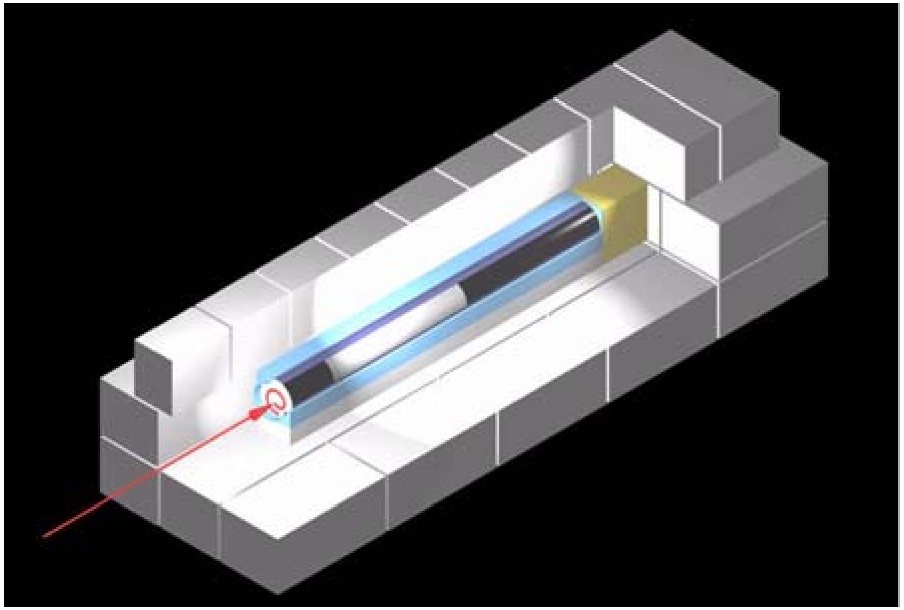
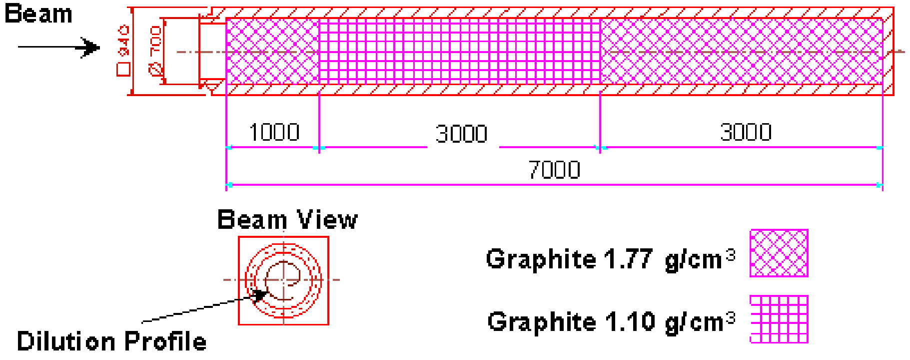
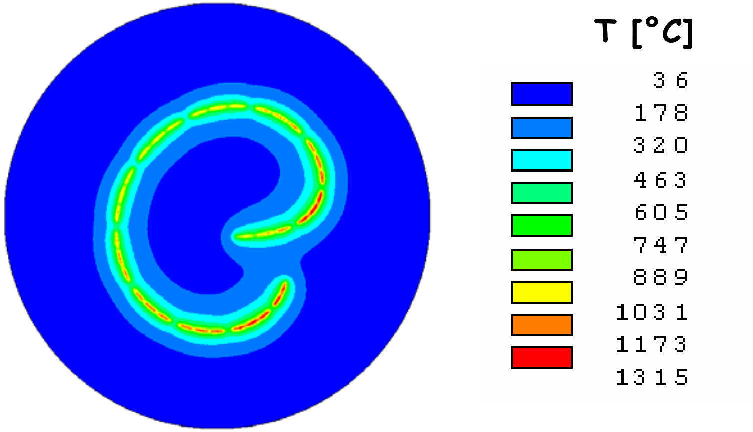
The need of an
Advanced numerical tool



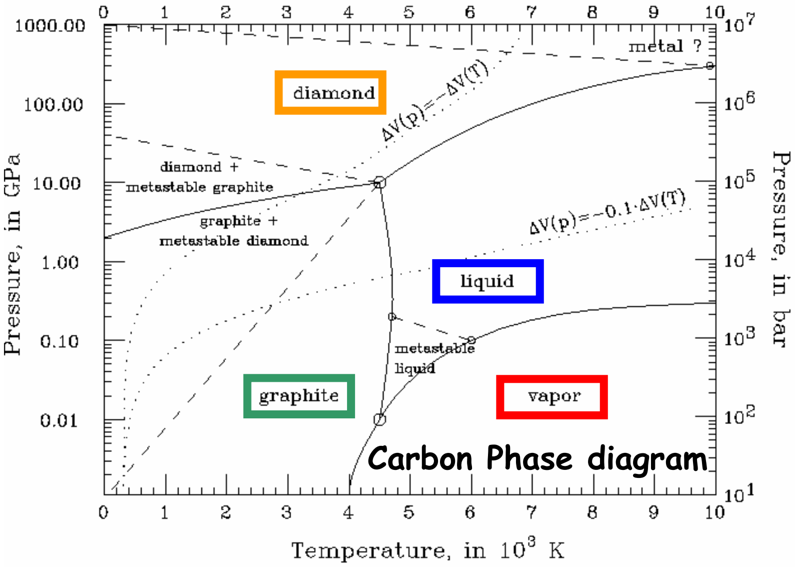
The need for an advanced numerical tool was clearly felt during the design phase of the LHC beam dump, a 8m-long Carbon cylinder contained in a steel jacket (1998).

At that time, ANSYS could simulate (with big efforts) the normal operating conditions, but the faulty cases (undiluted beam focused on the dump axis) were out of reach.

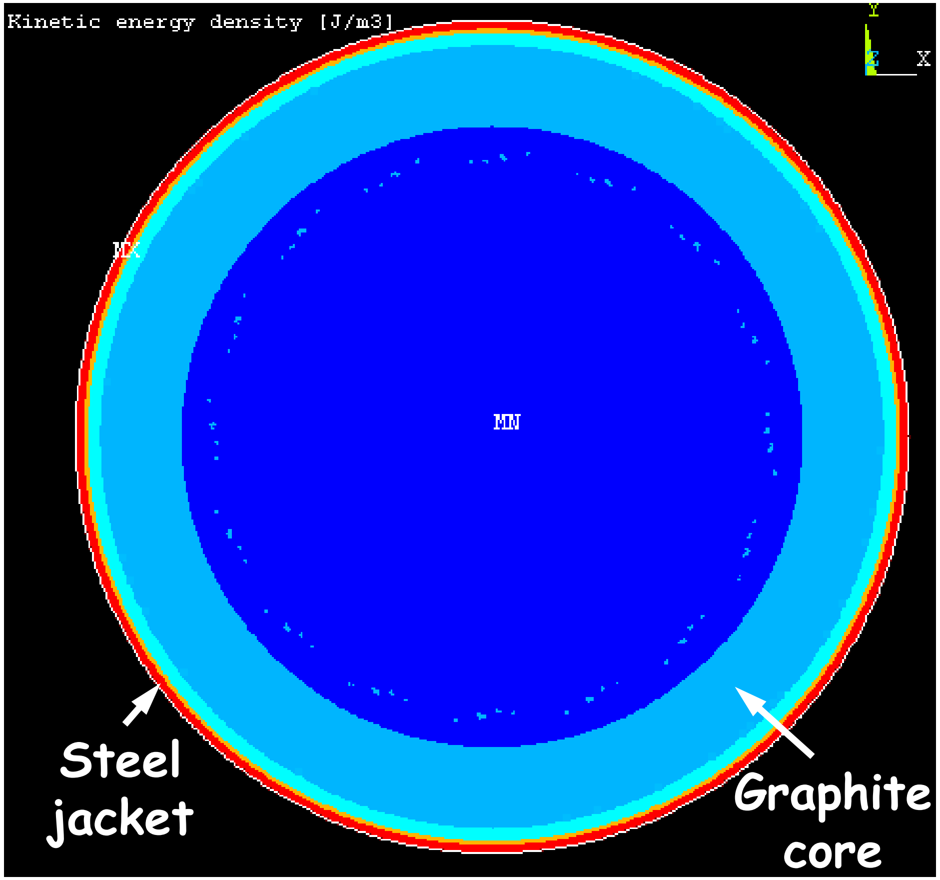




The need of studying
Worst-case scenarios



Carbon Phase diagram



The transient stress waves caused by the sudden absorption of the diluted beam onto the LHC beam dump estimated by ANSYS are shown on the right.

However, to study the worst case scenario (beam perforation induced by melting/vaporization) was mandatory to get the project *approved* !!!

Ten years later
that need is stronger than ever!

CERN R&D Activities…

… are presently aiming at future target facilities based on liquid, cavitating beam targets, which must be safely contained in solid structures. Examples are liquid Pb-pool (Isolde, EURISOL 100kW), Hg-jets (EURISOL Multi-MW, MERIT), or water cooled solid targets (nTOF).

This activities require the simulation of fast thermo-mechanical transients, where a free-surface fluid interacts with a solid structure and eventually changes of phase. Interaction with magnetic fields is potentially envisaged.

This engineering need translates into ***Challenging requirements***

R&D calls for simulating…

… extreme operating conditions, which are still beyond the capabilities of linear-elastic or elastic-plastic material models and standard codes. In particular:

1. **Material models capable of covering the entire thermo-dynamical phase space, material strength and failure are required.**
2. **Access to existing material libraries is an asset;**
3. **Interface with Monte-carlo, CAD and electro-magnetic codes is needed to model complex geometries/phenomena.**

A Technical market survey

has led to the AUTODYN choice

A technical market survey had been performed in 1999 within the LHC beam dump project. This survey has been renewed in 2006 to investigate the state-of-the-art in numerical simulations.

Three softwares have been identified (LS-DYNA, EUROPLEXUS and AUTODYN) and their simulation capabilities have been assessed.

The outcome of both survey has been identical:
AUTODYN is presently the only numerical code combining comprehensive equations of state, strength and failure material libraries, phase transition models and simulation techniques (meshless finite element methods) indispensable to satisfy CERN needs.

AUTODYN Pros

- Large material library already integrated in the code
- Los-Alamos SESAME material library compatible
- Complex geometries can be imported from ANSYS Workbench or CAD tools (AutoCAD, CATIA)
- Beam heat loads can be transferred from Monte-carlo codes (needs user subroutines).
- Magneto-hydrodynamic interactions are being implemented.

AUTODYN Cons

Till now the following nuisances have been found:

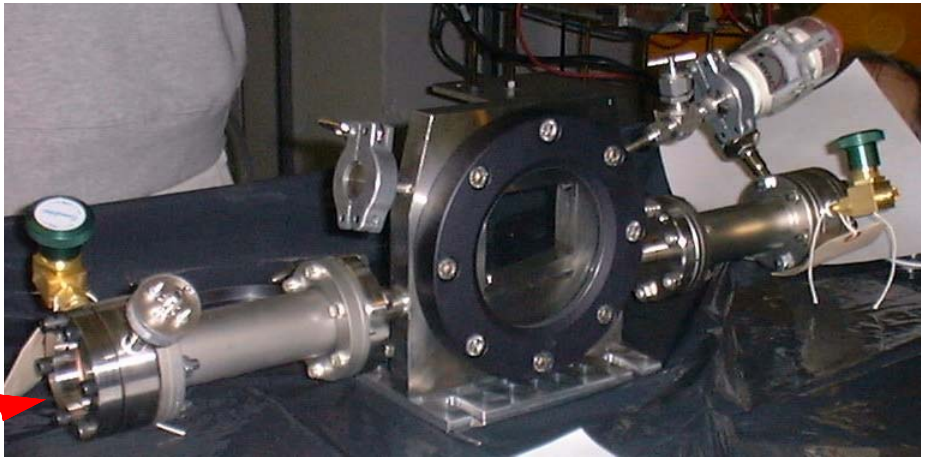
- Additional licenses for Intel FORTRAN 9.0, MS Visual Studio 2003.net and WMPI (Windows only) are needed.
- The graphical interface is available under Windows only. Only batch jobs can be run under Linux.
- The standard on-line help file is unsatisfactory. Additional tutorials are needed.
- Needs training or hot-line support.

BNL-CERN Hg-thimble test

A. Fabich, J. Lettry, H. Kirk, K. Mc Donald, T. Tsang

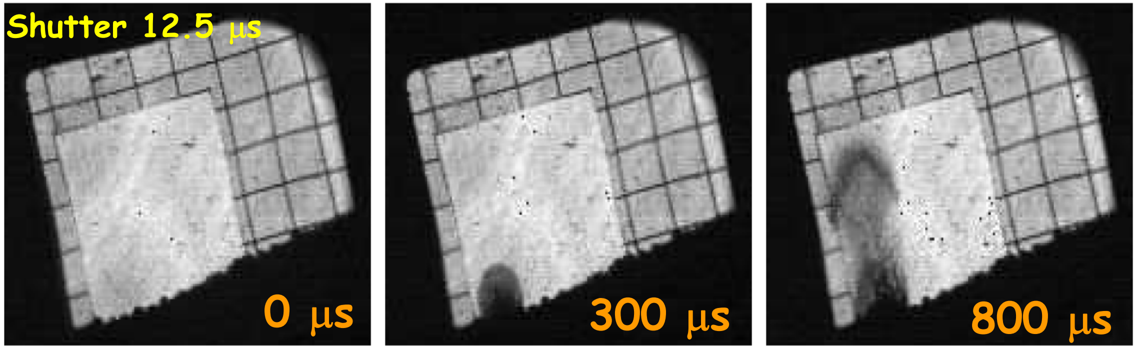
The capabilities of reliably simulating complex phenomena have been qualitatively benchmarked with a Hg-thimble experiment performed at BNL and repeated at CERN-ISOLDE.

0.6×10^{12}
24-GeV-protons
Δt: 100 ns



Ref.1: A. Fabich, J. Lettry, Proc. NuFact01, Japan, 2001.

Ref.2: H. Kirk et al., Proceedings PAC01, Chicago, 2001.



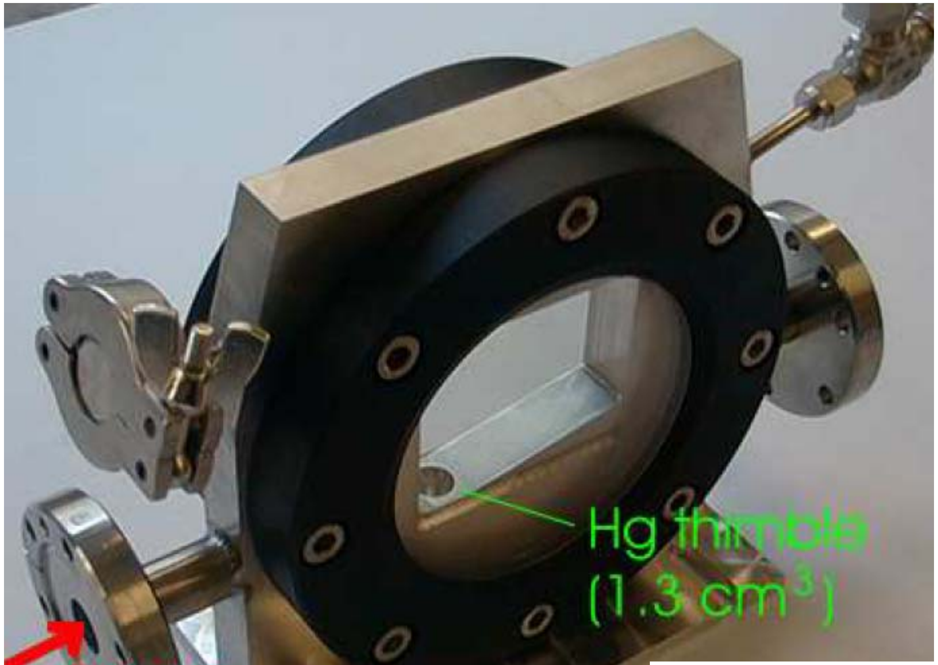
ISOLDE Hg-thimble test

A. Fabich, M.Benedikt, J. Lettry

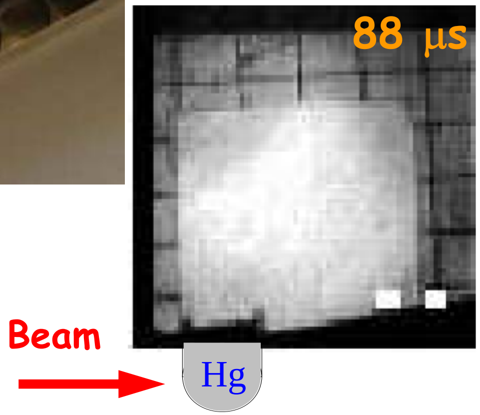
Hg-thimble set-up. Two quartz windows make it possible to view the p^+-Hg interaction process.

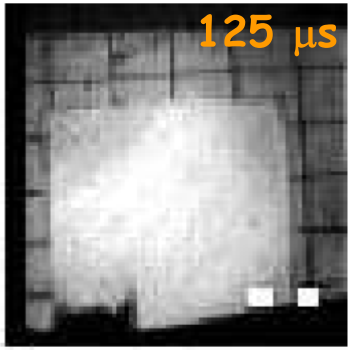
The Hg receptacle consists of a half sphere (r = 6mm), a vertical cylinder (r = h = 6mm), and a meniscus .The mercury has a free surface, where it can expand into an atmosphere of 1 bar Argon.

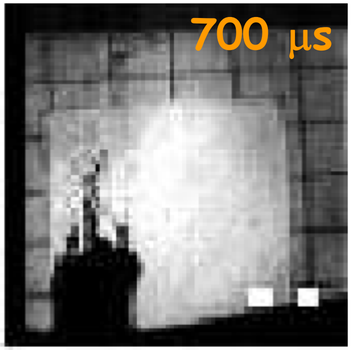
The Hg interaction with 1.4 GeV, 4 10^{12} p^+ is shown below.



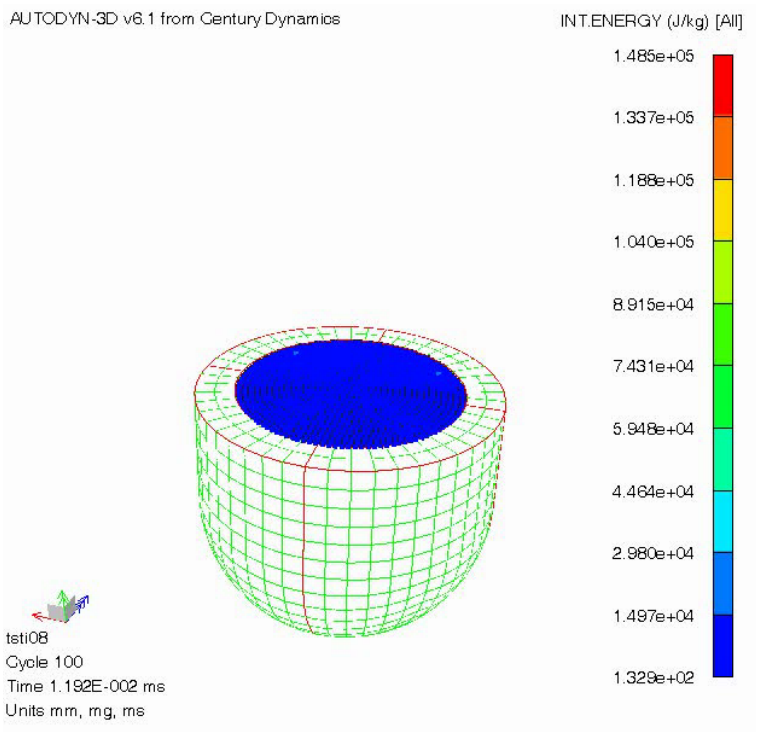
Ref.3: Journal of Nuclear Materials 318 (2003) 109–112

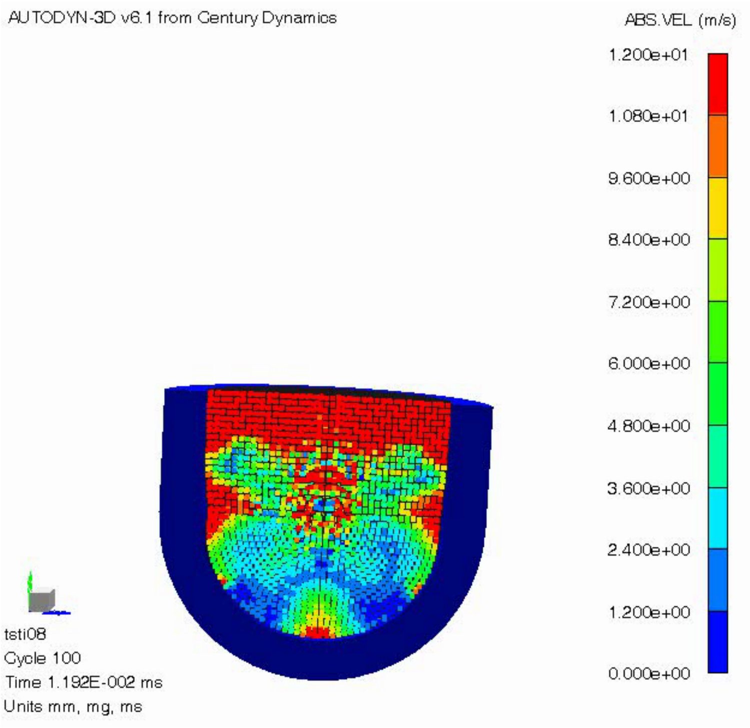






The AUTODYN Model

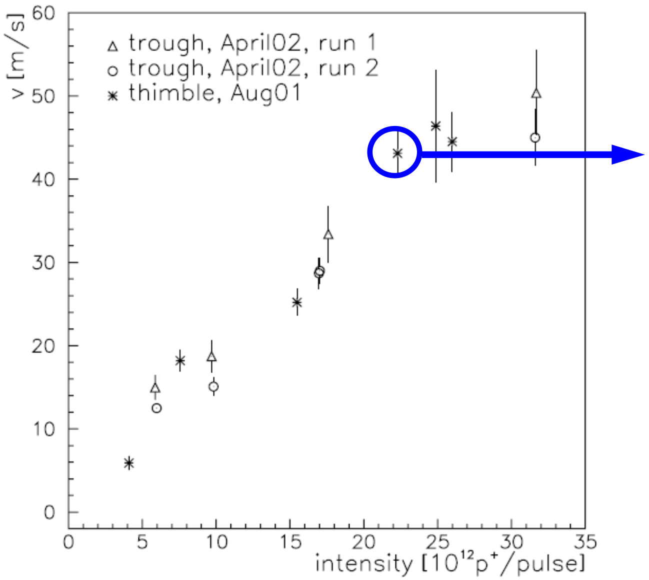




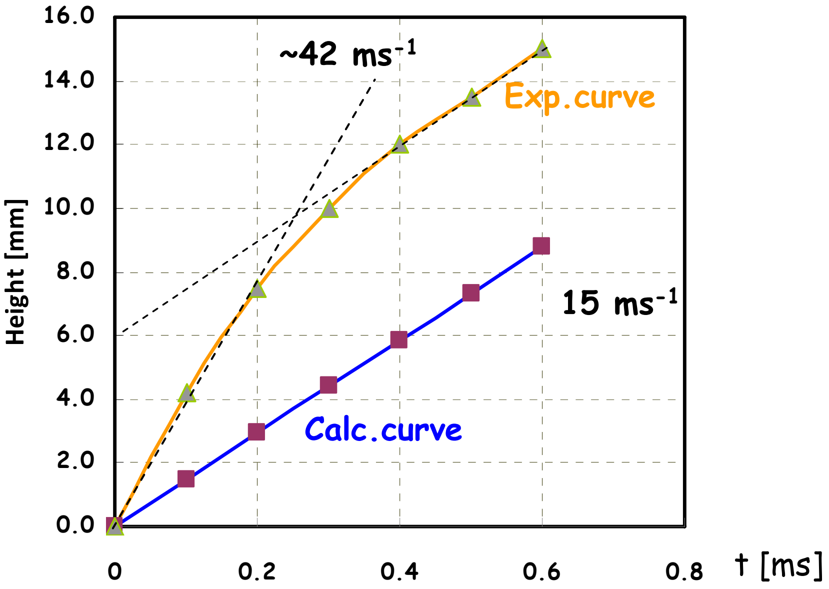
The numerical model has been built directly by AUTODYN standard features only: standard, ready-to-use material properties and numerical technique. Only a FORTRAN90 interface to import FLUKA data has been written.

Experimental vs. numerical results

Preliminary qualitative benchmark



Max splash velocity vs. proton intensity (Fig 3 of ref. 3)

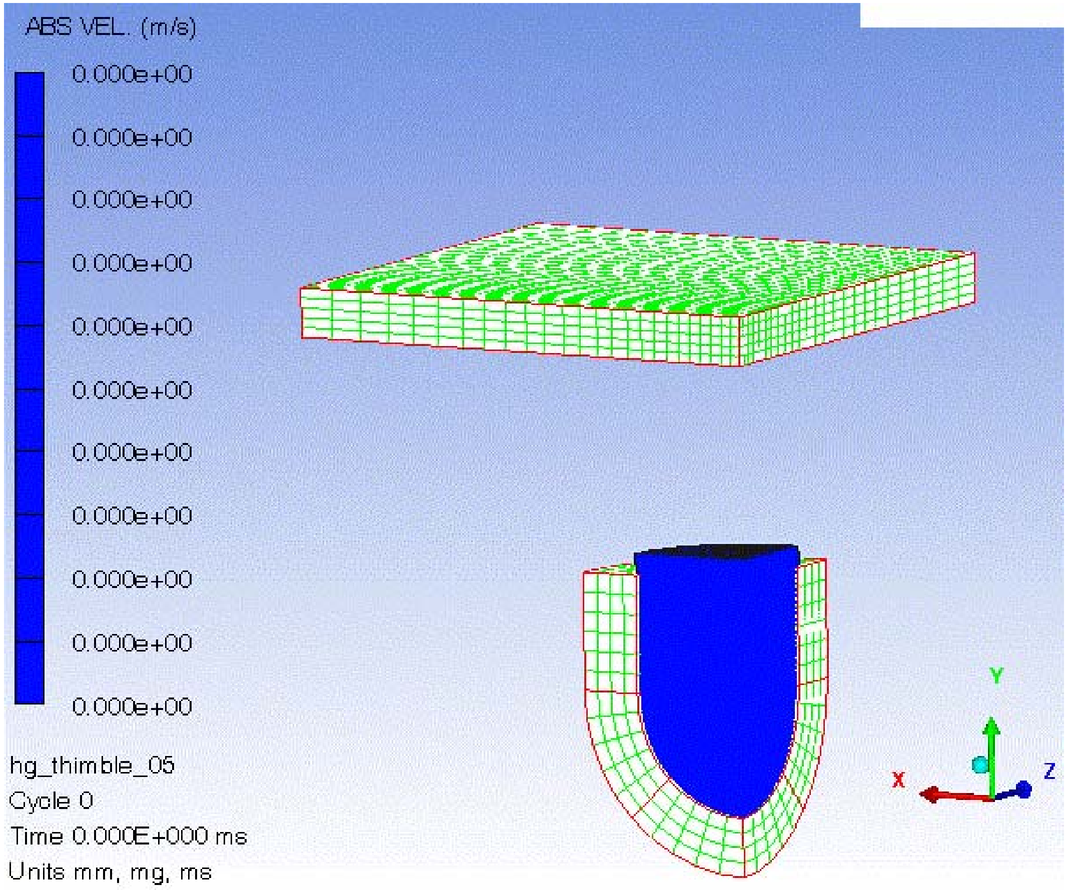


Splash height vs. time

The numerical model shows a constant calculated splash velocity which is close to the experimental „asimptotic“ one estimated from the pictures.

Having some fun…

Would reinforced glass resist the Hg splash ?



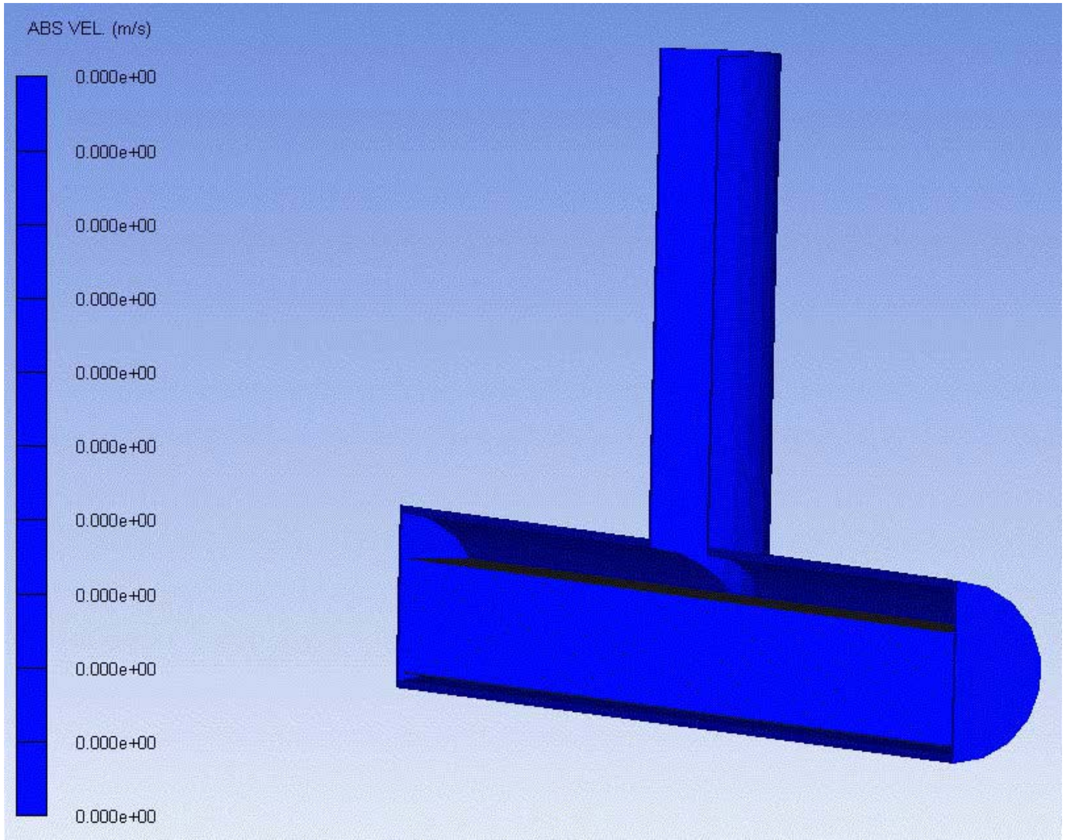
A toy model was built to test the AUTODYN capabilities to model extreme conditions.

A reinforced glass slab was located on top of the Hg thimble and the beam load amplified.

Failed material elements were removed from the model. Their inertia could have been retained to model the effects of flying fragments on neighboring objects.

The ISOLDE Liquid Pb Target

by E. Noah



Presently, the transient behavior of ISOLDE liquid Pb targets is being investigated at CERN.

The main concern is given by cavitation and internal splashes leading in the past to failures and clogging due to solidification on cold surfaces.

A publication is in preparation by E.Noah.

Summary

At CERN a new numerical tool is available…

- … capable of simulating today's challenging designs
  - Key physical phenomena are included (strength, failure, cavitation, free-surface tracking, change of phase, beam load input by FLUKA to AUTODYN interface);
  - MHD is being developed in the UK;
  - AUTODYN to FLUKA interface should be developed to address coupled beam-failure effects
- … running on a Windows CERN server
  - Two users working at the same time;
  - Up to 6 parallel tasks possible (needs computer upgrade);
  - Available CERN-wide;
- … waiting for those who dare to
  - Go into the details of the physical/numerical models;
  - Face classified material data and "delicate" documentation.