Neutronic considerations in designing the European Spallation Source (ESS)

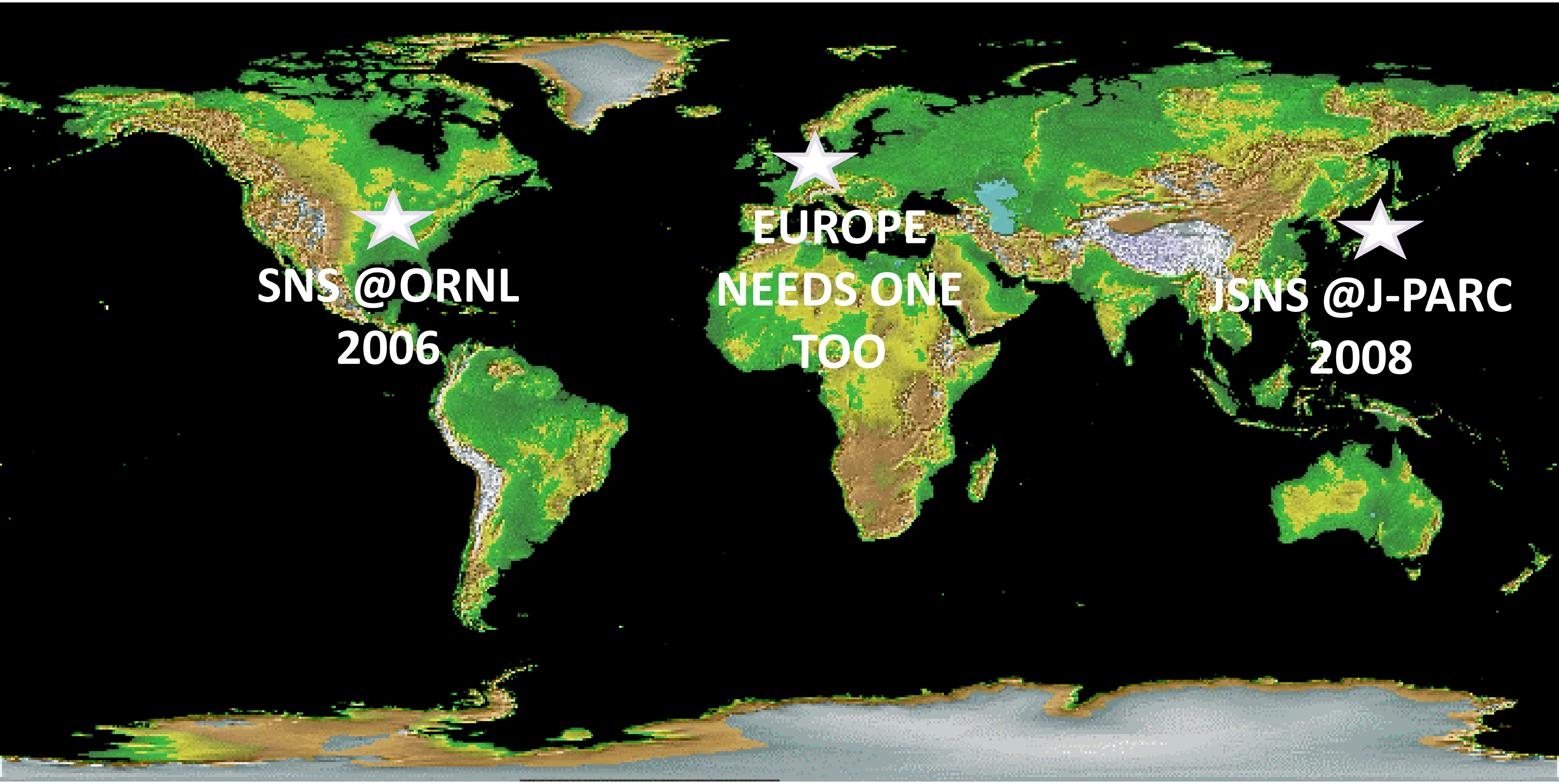
Mary PW Chin

[1] E S S ~~S~~
(European Spallation Source ~~Scandinavia~~)
Lund University
SE-22100 Lund
Sweden

[2] C E R N
(European Centre for Nuclear Research)
Department EN/STI
CH-1211 Geneva 23
Switzerland

as presented at the American Nuclear Society Annual Meeting 2009 (Washington) by me@marychin.org

MEGAWATT SPALLATION NEUTRON SOURCES



28 MAY 2009 Meeting of Research Ministers in Brussels

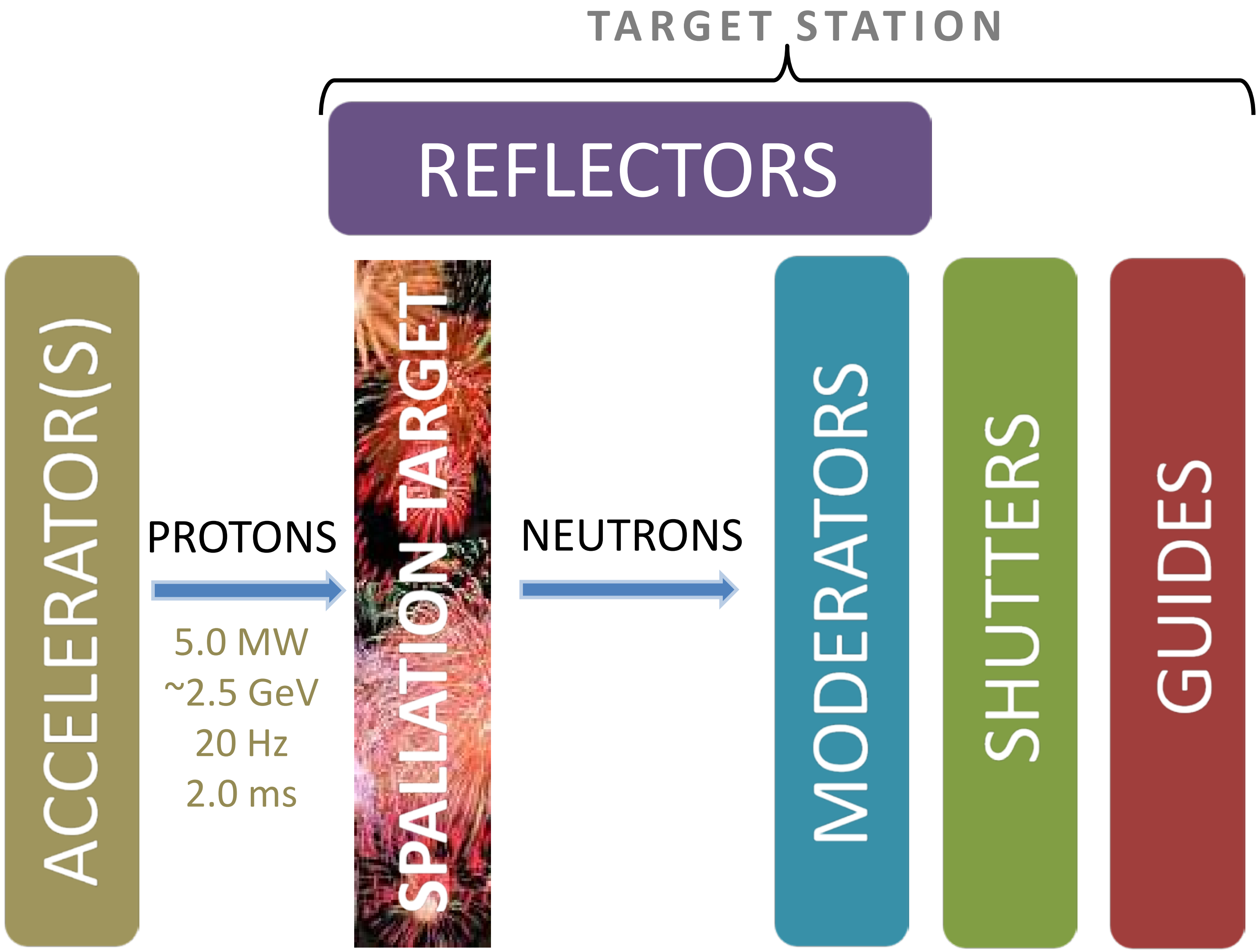
- YES, WE WILL DESIGN AND BUILD ONE
- LUND WINS THE BID TO HOST

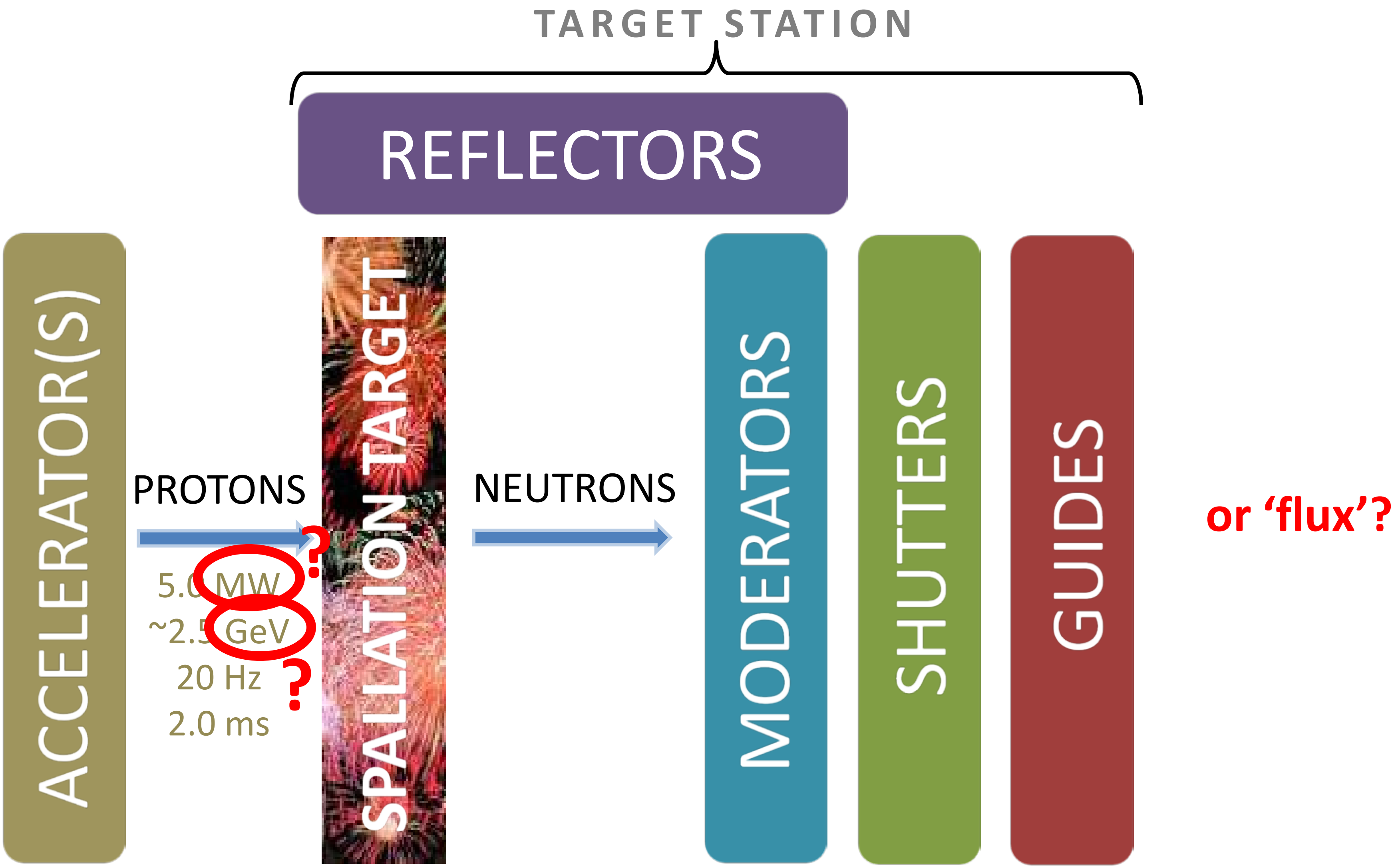
For this to happen, scientists need **engineers** more than ever.

Words of wisdom

The target station will work, no worries. The **pipe** from the gate to the target station won't...

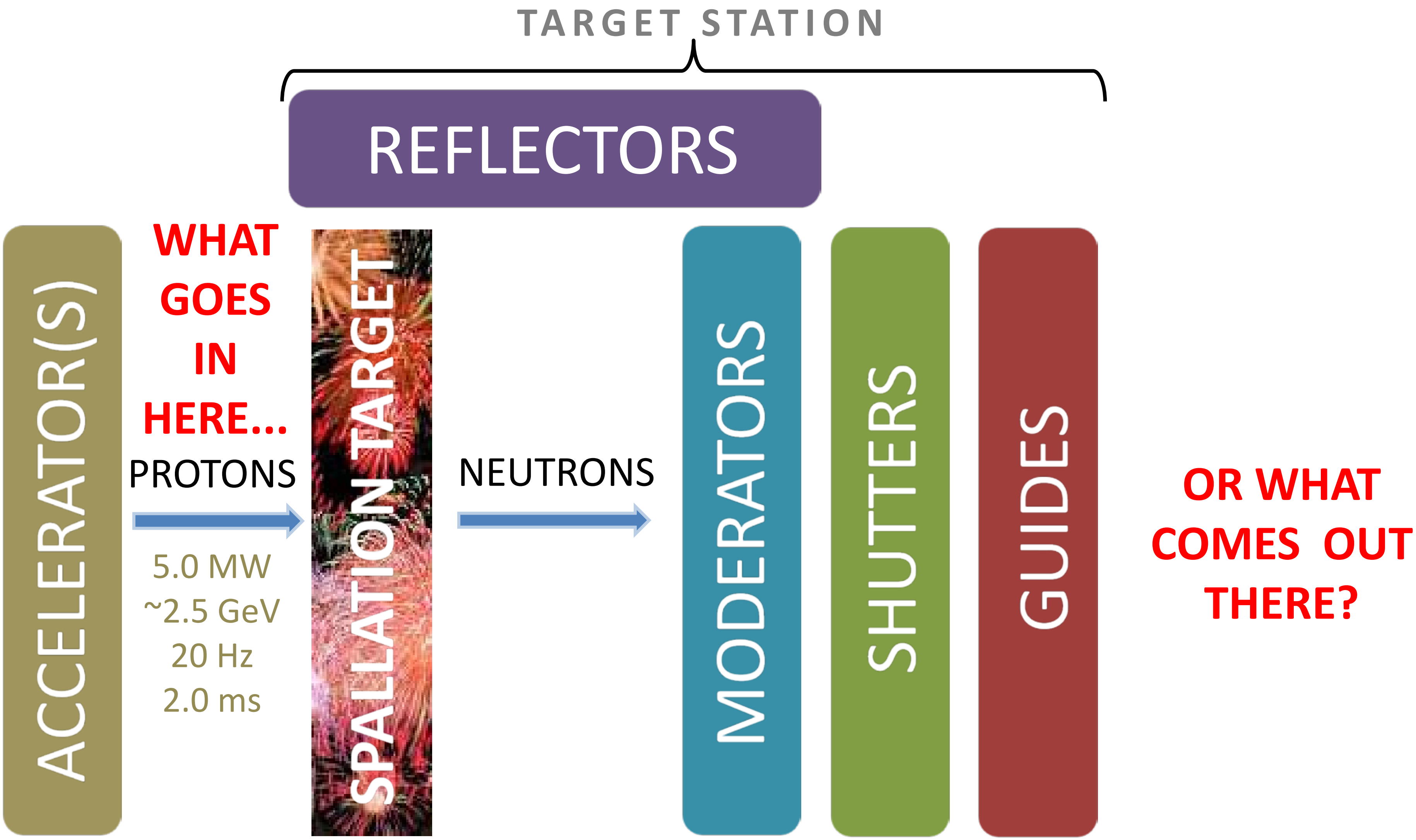
FINAL CONSTRUCT


TARGET STATION
REFLECTORS
ACCELERATOR(S)
PROTONS
5.0 MW
~2.5 GeV
20 Hz
2.0 ms
SPALLATION TARGET
NEUTRONS
MODERATORS
SHUTTERS
GUIDES



NEUTRON FACILITIES ACROSS THE WORLD
HOW WE MEASURE
WHO IS THE KING OF THE JUNGLE?

as presented at the American Nuclear Society Annual Meeting 2009 (Washington) by me@marychin.org



NEUTRON FACILITIES ACROSS THE WORLD

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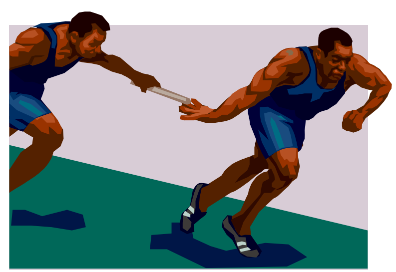
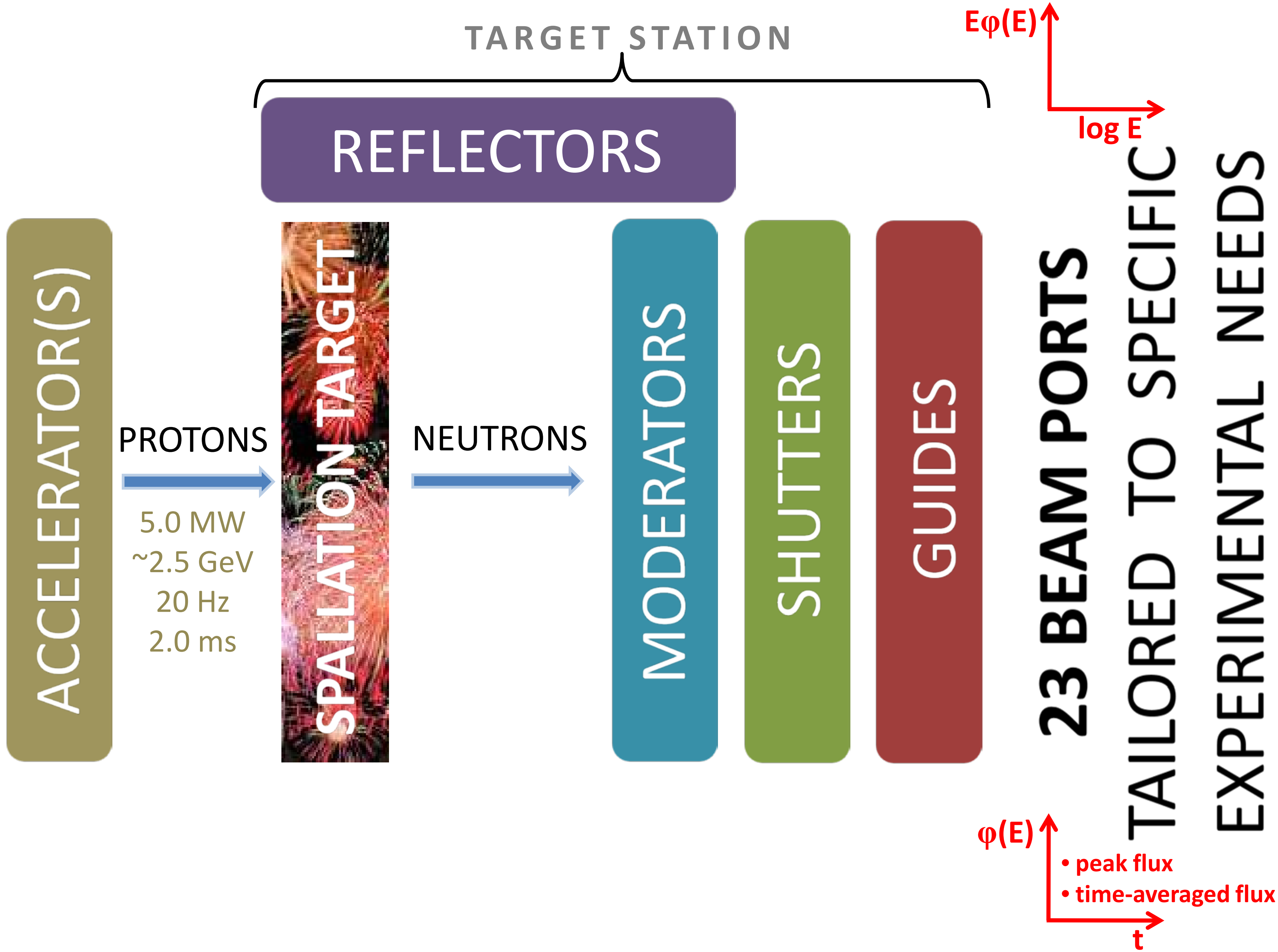
IT IS A MATTER OF RELAY

ACCELERATOR FOLKS – TARGET STATION FOLKS – USERS





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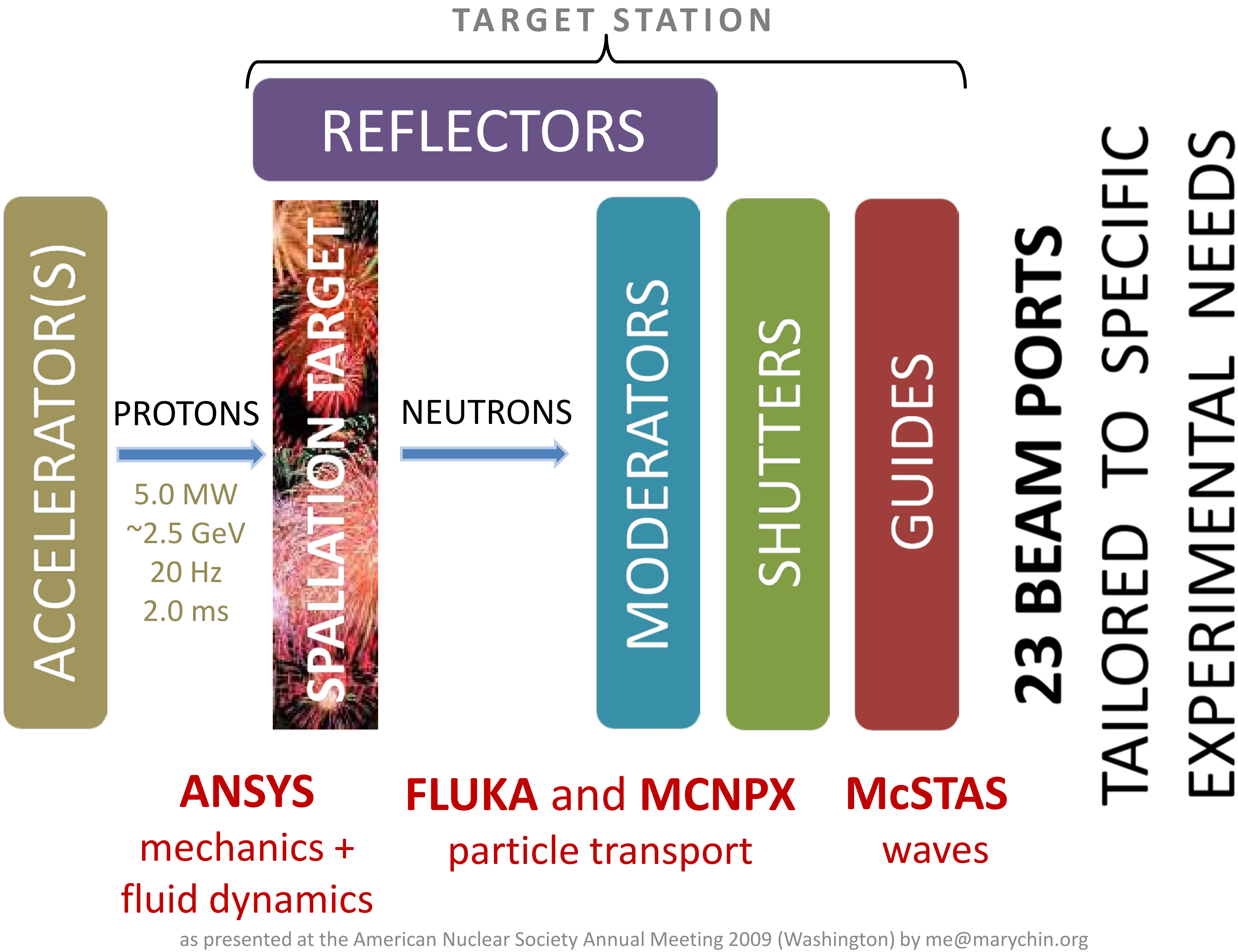
TARGET STATION
REFLECTORS
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5.0 MW
~2.5 GeV
20 Hz
2.0 ms
SPALLATION TARGET
NEUTRONS
MODERATORS
SHUTTERS
GUIDES
23 BEAM PORTS
TAILORED TO SPECIFIC
EXPERIMENTAL NEEDS
ANSYS
mechanics +
fluid dynamics
FLUKA and MCNPX
particle transport
McSTAS
waves
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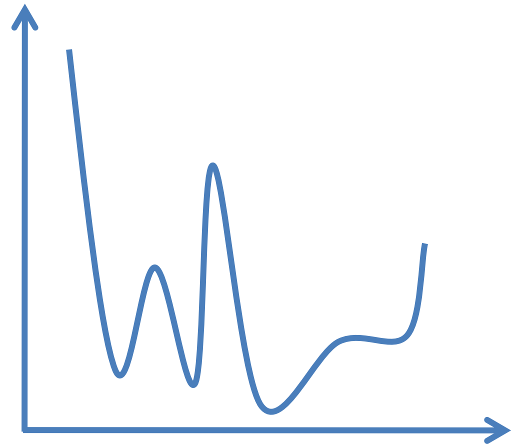
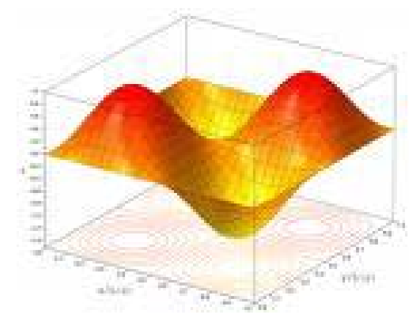
1-D OPTIMISATION: N1 SIMULATIONS NEEDED



2-D OPTIMISATION: N1*N2 SIMULATIONS NEEDED



multi-D OPTIMISATION: N1*N2*N3*N4*N5… SIMULATIONS NEEDED

THINGS CAN GET PRETTY OUT OF CONTROL

DESIGN

ANSYS

THERMO / MECHANICS
FLUID DYNAMICS

FLUKA and MCNPX

HADRONS and CHARGED
PARTICLES TRANSPORT

McSTAS

WAVE NATURE OF
NEUTRONS

FINAL CONSTRUCT

DESIGN

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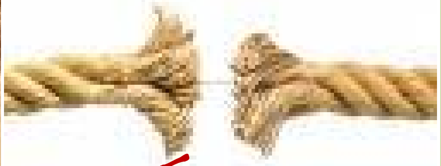


THE GRAND CHALLENGE

FINAL CONSTRUCT

DESIGN

ANSYS

THERMO / MECHANICS
FLUID DYNAMICS

FLUKA and **MCNPX**

HADRONS and **CHARGED PARTICLES TRANSPORT**

McSTAS

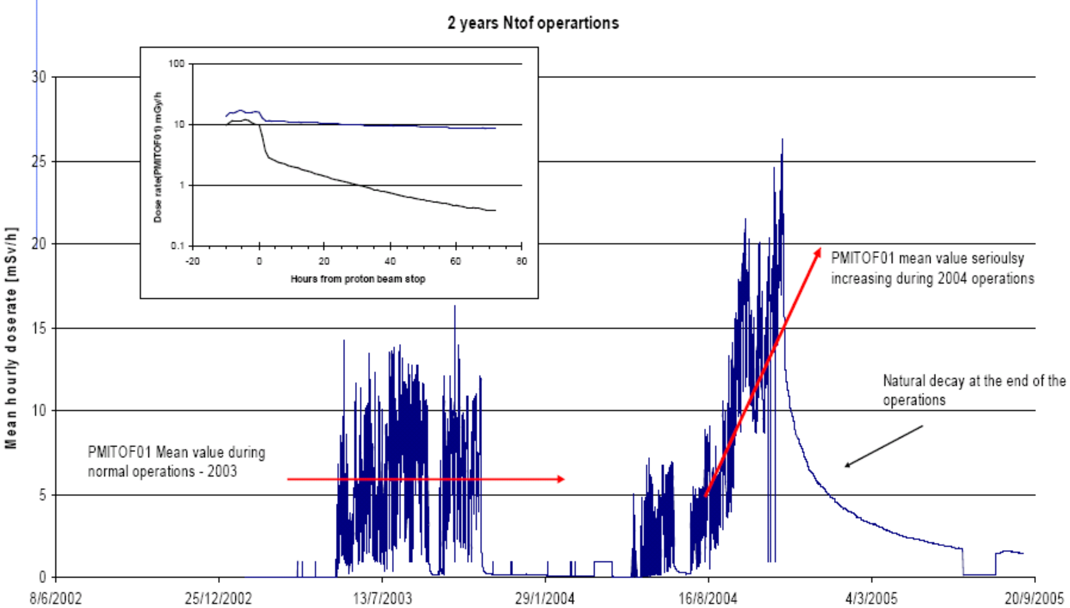
WAVE NATURE OF NEUTRONS

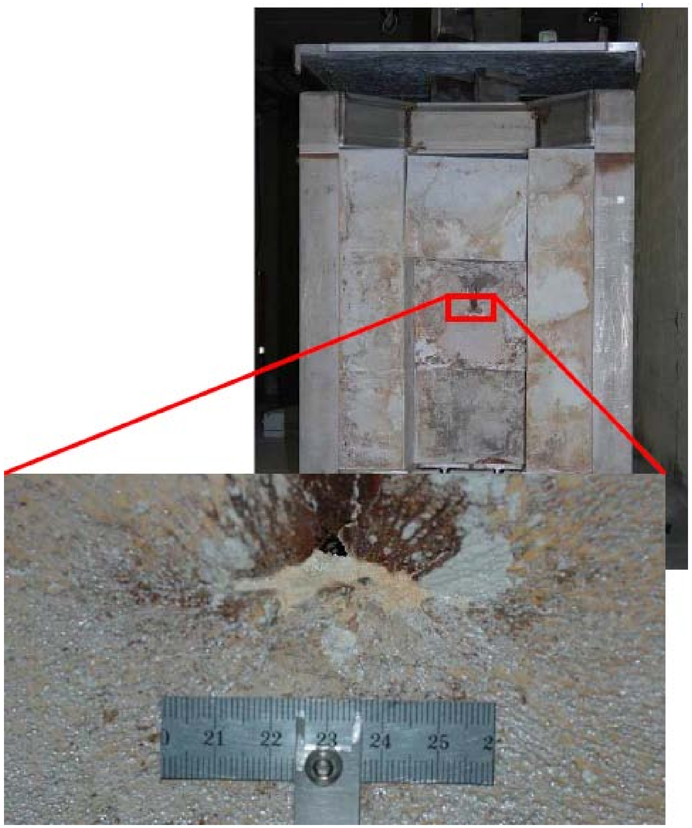
less worrying

most worrying
BITS
LURKING IN THE BACKGROUND
eg. corrosion

CORROSION STORY @ n_TOF
extensive detective work

RP: Cooling circuit activation in 2004





CERN-SC-2005-034-RP-TN

RIDDLE SOLVED @ n_TOF

POOR WATER FLOW
MECHANICAL INSTABILITY

WATER TEMPERATURE ↑

WATER O_2 CONTENT ↑

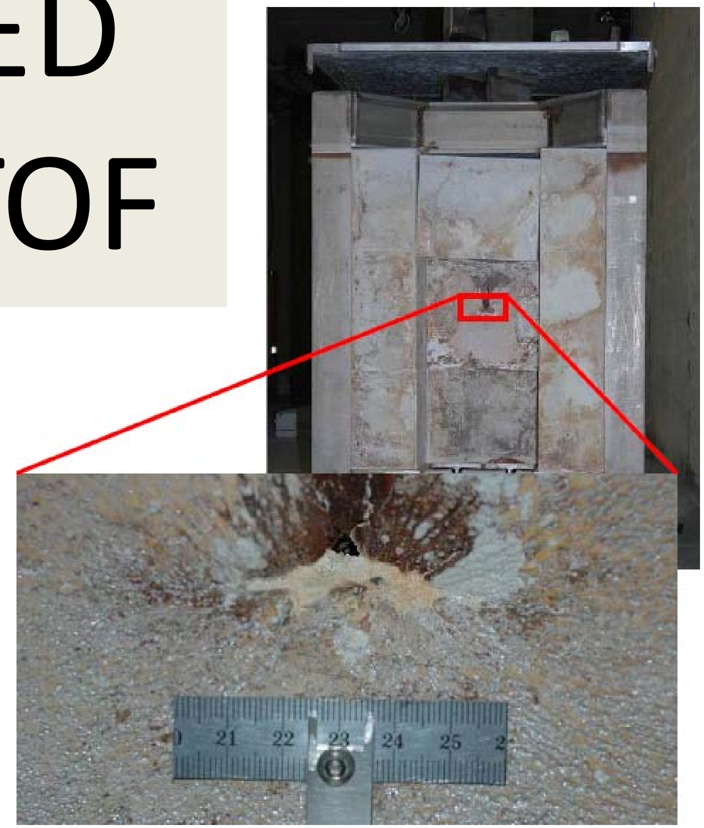
$Pb \rightarrow Pb^{2+} + 2e^-$

$Pb \rightarrow Pb^{4+} + 4e^-$

$Pb^{2+} + 2H_2O \rightarrow Pb(OH)_2 + 2H^+$

$Pb^{4+} + 2H_4O \rightarrow Pb(OH)_4 + 2H^+$

Local acid attacks metals



analysis at CERN and CIEMAT

PROCESSES BEYOND MONTE CARLO RADIATION TRANSPORT

POOR WATER FLOW
MECHANICAL INSTABILITY

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Local acid attacks metals

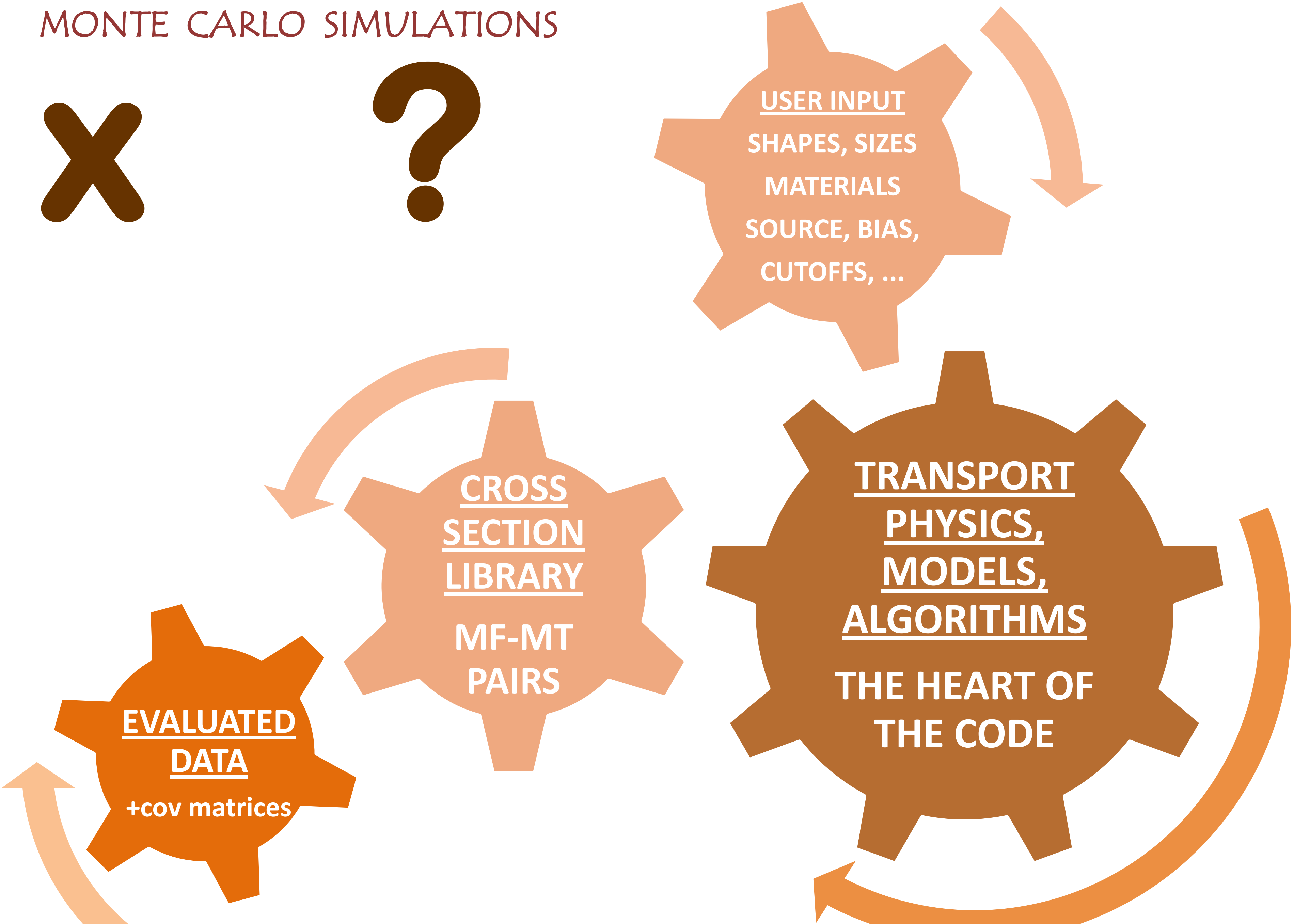
HEATR:
Heating and Radiation Damage

Nuclear heating results from the slowing down of energetic charged particles produced in nuclear reactions, including the recoil nucleus from scattering reactions. It is a very important quantity. Sometimes it is the product being sold (as in power reactors), and sometimes it is a damaging corollary of the nuclear reactions (as in melting of important structural elements). The HEATR module of NJOY can be used to compute estimates of energy-deposition cross sections for neutrons that can be combined with calculations of neutron fluxes in nuclear systems to compute the neutronic contributions to nuclear heating. The heating due to the photon flux in a nuclear system is usually even more important; it is computed in the GAMINR module.

The same energetic charged particles and recoil nuclei that lead to heating can also cause damage to the crystalline structure of the materials that they pass through. An important case of this is the embrittlement of power reactor containment vessels that is one of the main limiting factors in the useful life of a commercial reactor. HEATR computes the damage-production energy, which can be correlated to macroscopic damage, such as tensile strength, ductility, or resistivity, through phenomenological factors like DPA (displacements per atom).

EVEN HEATR and DPA CAN'T PROVIDE SUCH ANSWERS

MONTE CARLO SIMULATIONS



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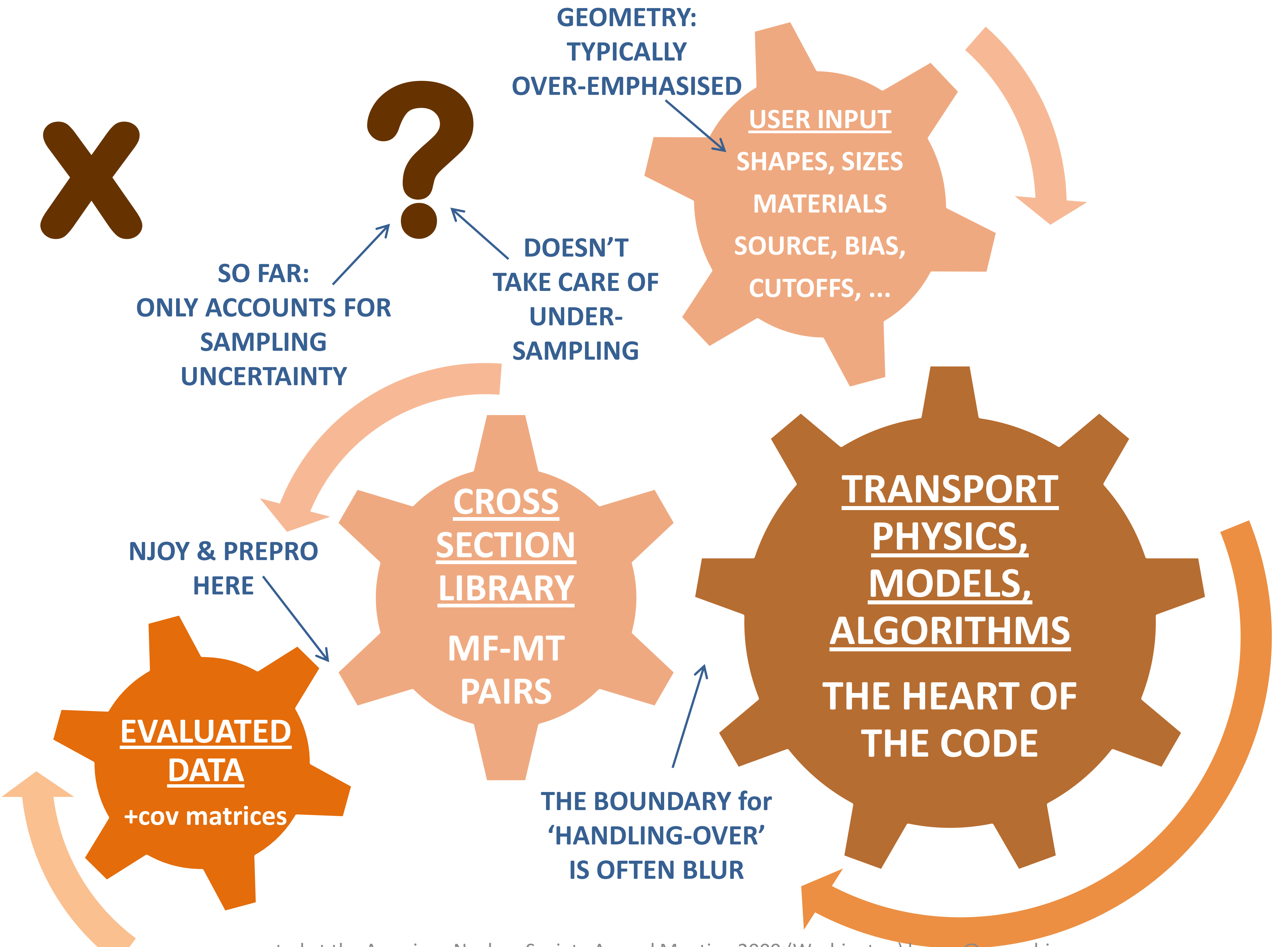
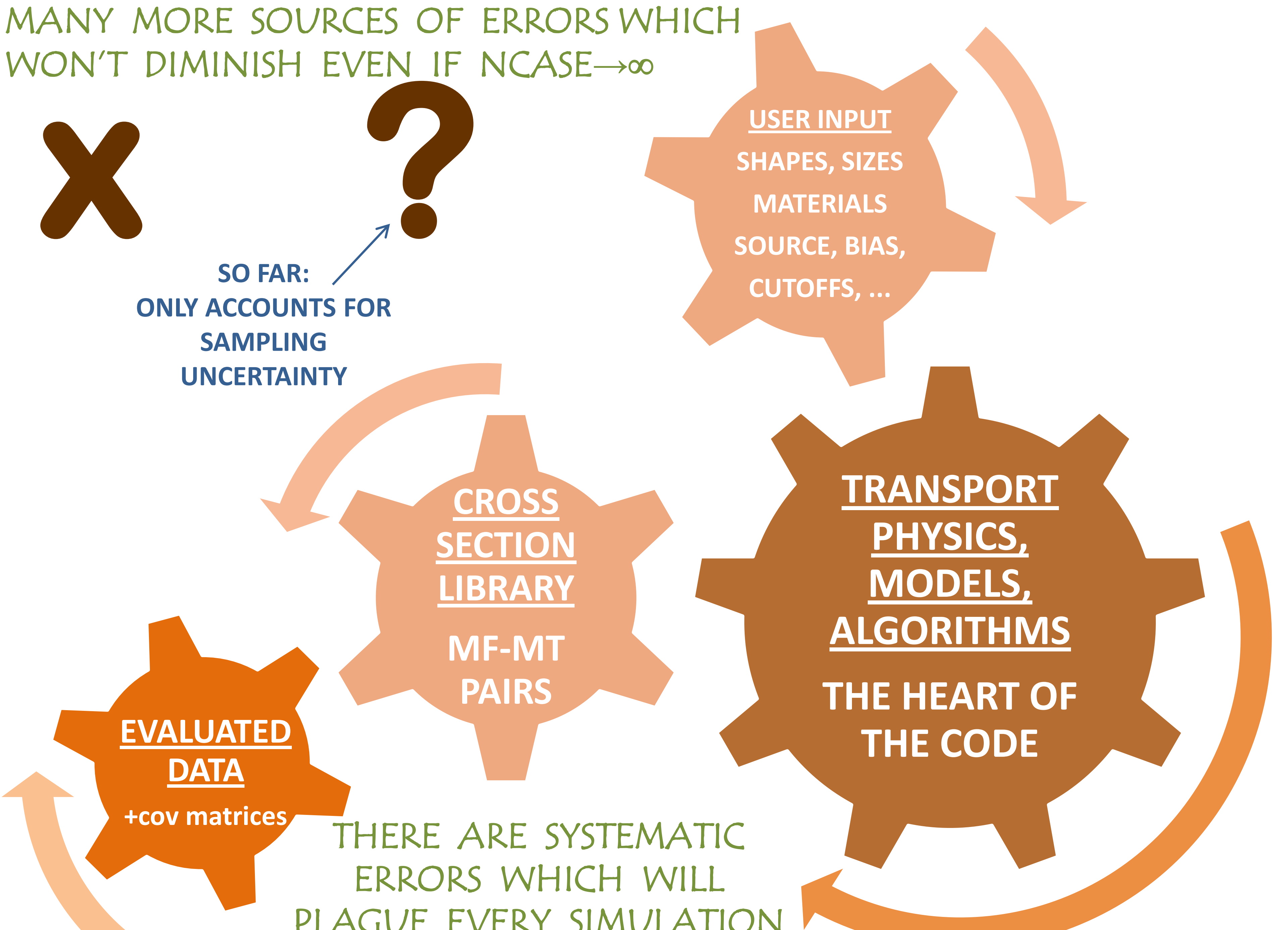

GEOMETRY:
TYPICALLY
OVER-EMPHASISED
USER INPUT
SHAPES, SIZES
MATERIALS
SOURCE, BIAS,
CUTOFFS, ...
SO FAR:
ONLY ACCOUNTS FOR
SAMPLING
UNCERTAINTY
DOESN'T
TAKE CARE OF
UNDER-
SAMPLING
CROSS
SECTION
LIBRARY
MF-MT
PAIRS
NJOY & PREPRO
HERE
TRANSPORT
PHYSICS,
MODELS,
ALGORITHMS
THE HEART OF
THE CODE
EVALUATED
DATA
+cov matrices
THE BOUNDARY for
'HANDLING-OVER'
IS OFTEN BLUR



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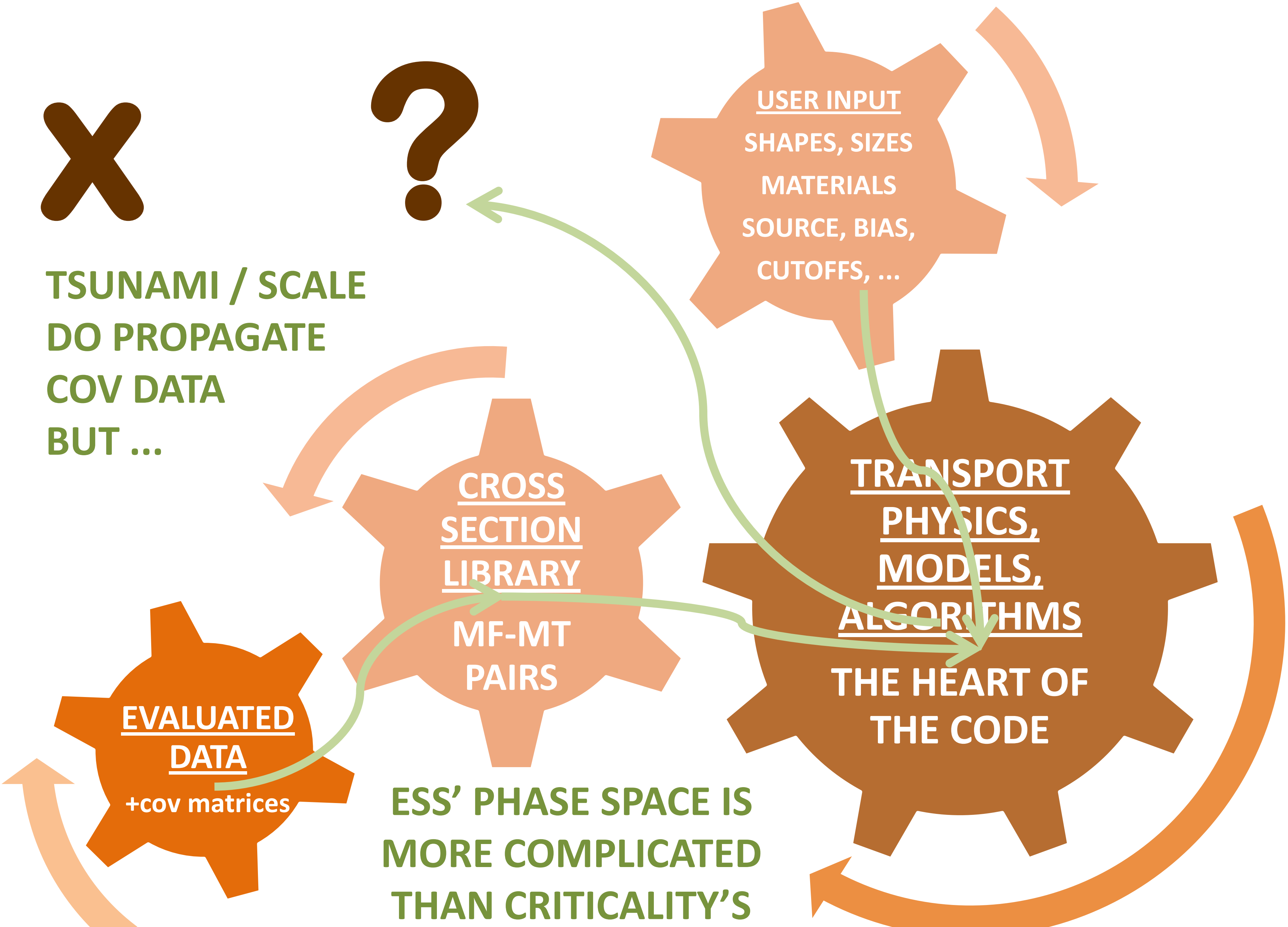


as presented at the American Nuclear Society Annual Meeting 2009 (Washington) by me@marychin.org

NOTE: MCNPX's PERT <u>does not</u> propagate covariance data

MCNPX User's Manual
Version 2.5.0, April. 2005
LA-CP-05-0369

TALLY SPECIFICATION

5.6.21 PERT Perturbation

Form: PERT*n*:<*pl*> KEYWORD=*value(s)* ...

Basic Keywords	Description
CELL	Comma or space delimited list of cells, c_1 ... c_K, to which to apply perturbation. Required.
MAT	Single material number, m, with which to fill all cells listed in CELL keyword.† Must have a corresponding M card.

Use: Optional.

Note: Allows perturbations in cell material density, composition, or reaction cross-section data. Uses the first and second order differential operator technique. Perturbation estimates are made without actually changing the input material specifications. Multiple perturbations can be applied in the same run, each specified by a separate PERT card.

It only estimates perturbation if ZAID were replaced by another

The nuclide identification number with the form ZZZAAA.nnX
where
ZZZ is the atomic number,
AAA is the mass number (000 for elements),
nn is the unique table identification number, and
X=U for continuous-energy photonuclear tables.

A solo ZAID would have its own cov data, independent of another ZAID

GENERIC 'FORMAT' FOR REPORTING MONTE CARLO RESULTS

SOMETIMES THERE JUST TO SATISFY THE REFEREES

NUMBER OF HISTORY = ...

RESULTS = x ± y

GENERIC 'FORMAT' FOR REPORTING MONTE CARLO RESULTS

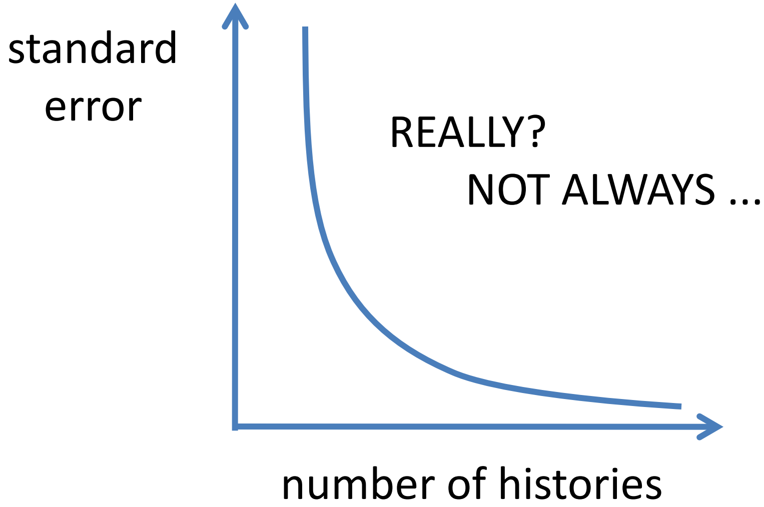
SOMETIMES THERE JUST TO SATISFY THE REFEREES

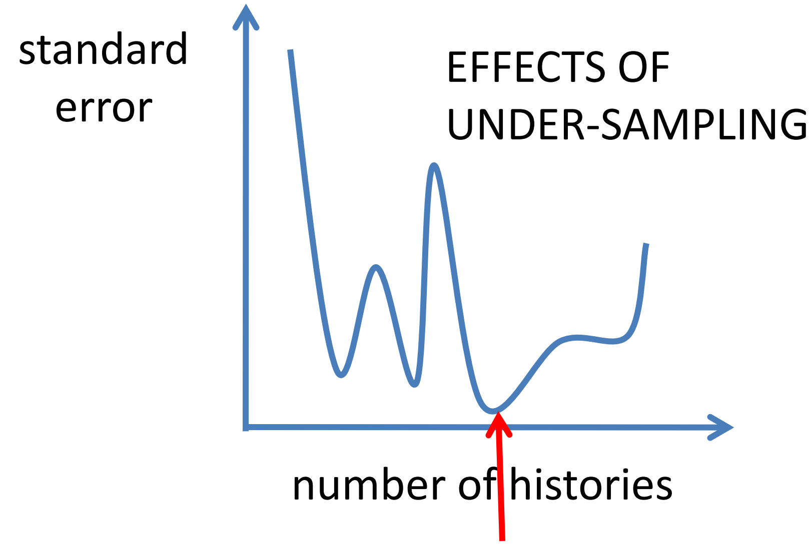
NUMBER OF HISTORY = ...

USEFUL FOR REPRODUCIBILITY BY OTHERS IN THE COMMUNITY BUT REALLY DOESN'T TELL MUCH ABOUT THE GOODNESS OF THE SIMULATION

RESULTS = x ± y

A SINGLE VALUE OF STD ERROR DOESN'T TELL MUCH UNLESS AND UNTIL WE CHECK HOW THE STD ERROR EVOLVED AS SIMULATION PROGRESSED

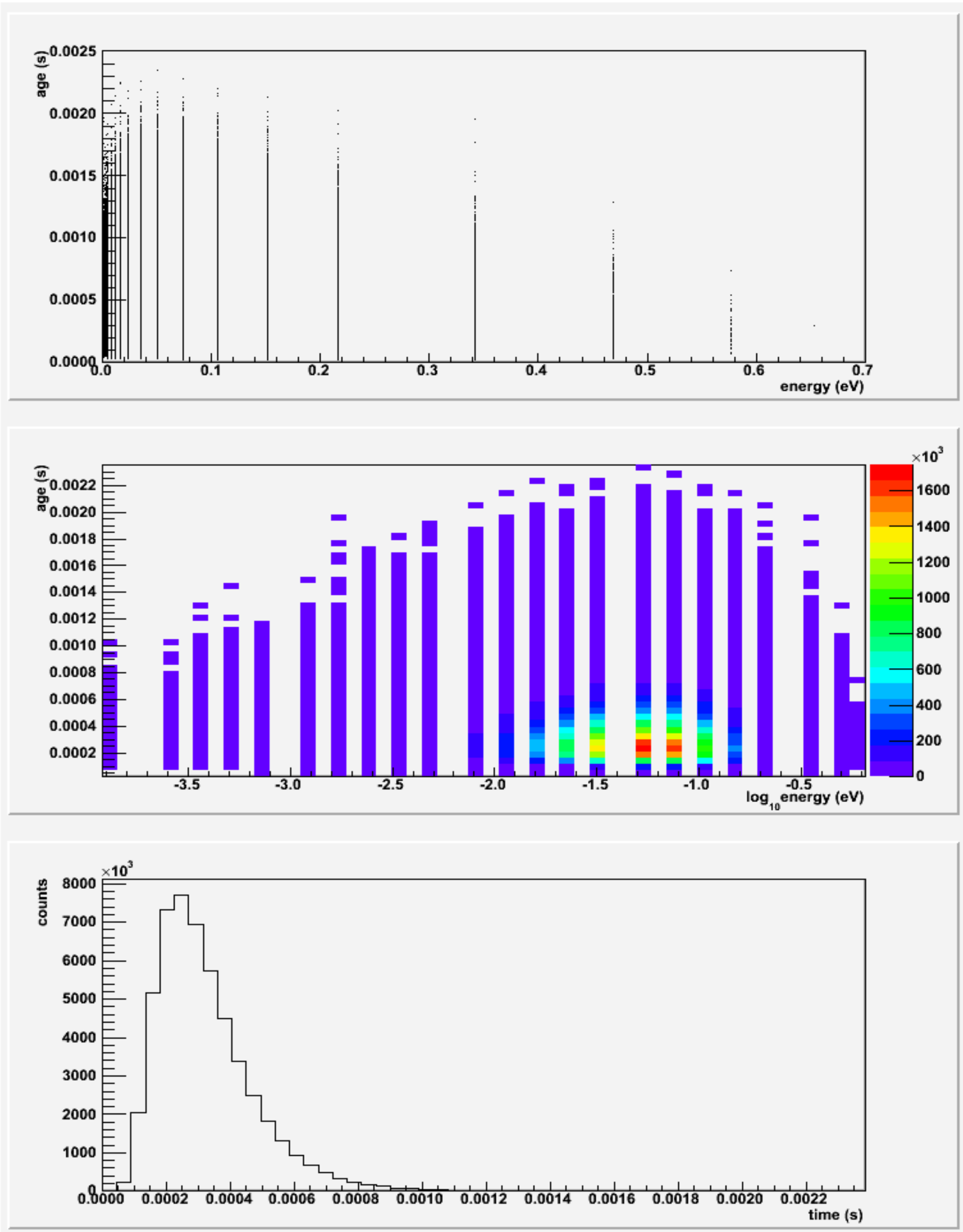




Stopping the simulation here quoting the standard error would be a <u>lucky deception</u>

A SINGLE VALUE OF STD ERROR DOESN’T TELL MUCH UNLESS AND UNTIL WE CHECK <u>HOW THE STD ERROR EVOLVED</u> AS SIMULATION PROGRESSED

RESULTS = x ± y



FLUKA SIMULATION OF LOW-ENERGY NEUTRONS TRAVERSING WATER
(AS A TOY MODERATOR)

BEHIND THE SCENES

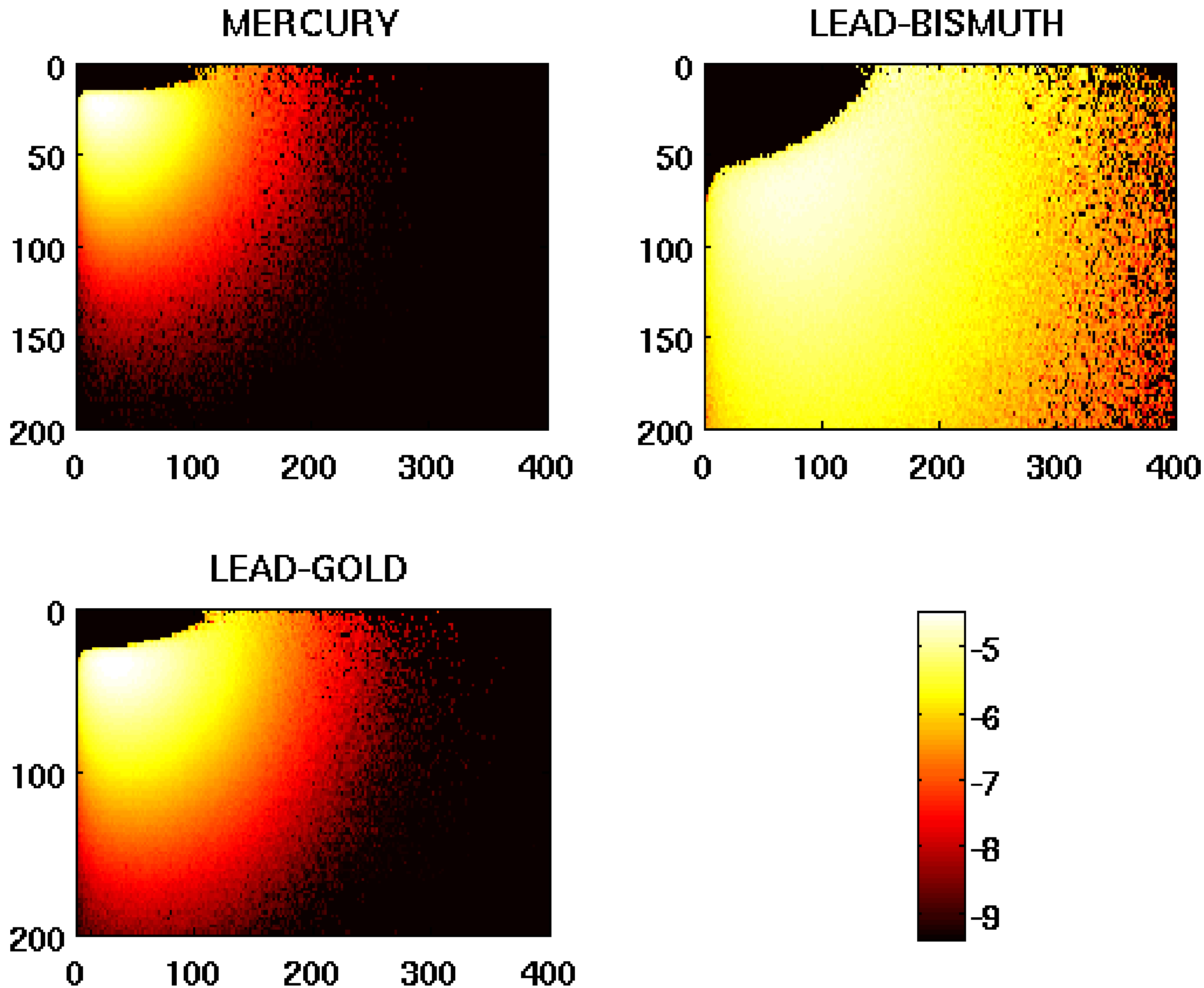
fluka : less

File Edit View Scrollback Bookmarks Settings Help

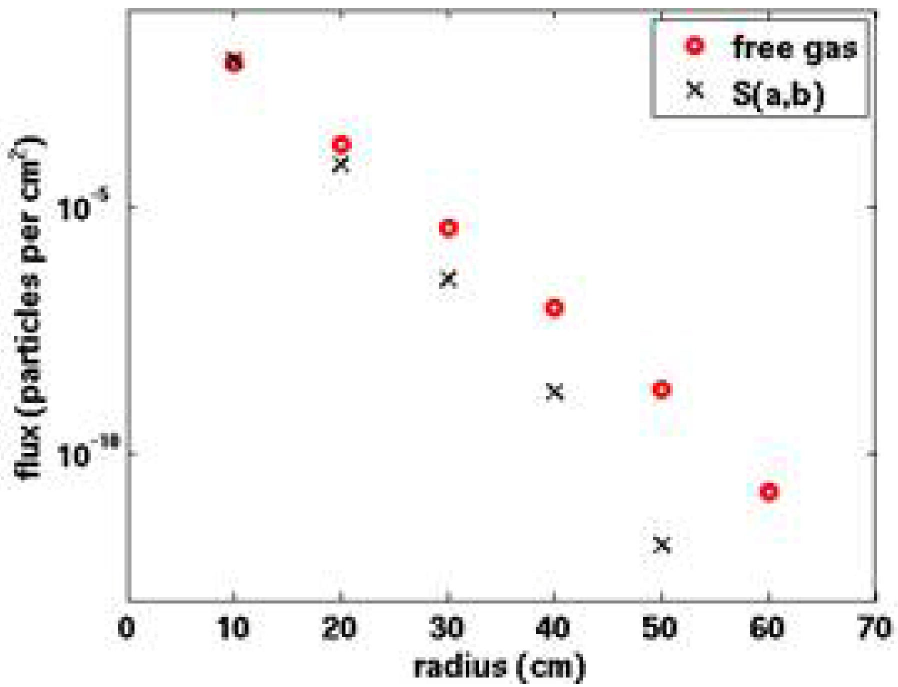
```
*               49: boundary crossing                                        *
*      Icode = 5x: call from Kasoph                                          *
*               59: boundary crossing                                        *
*                                                                            *
*============================================================================*
*                                                                            *
      ENTRY BXDRAW ( ICODE, MREG, NEWREG, XSCO, YSCO, ZSCO )
       IF ( .NOT. LFCOPE ) THEN
         LFCOPE = .TRUE.
         IF ( KOMPUT .EQ. 2 ) THEN
            FILNAM = '/'//CFDRAW(1:8)//' DUMP A'
         ELSE
            FILNAM = CFDRAW
         END IF
         OPEN ( UNIT = IODRAW, FILE = FILNAM, STATUS = 'NEW', FORM =
     &          'UNFORMATTED' )
      END IF
      IF (JTRACK.EQ.8) THEN
         WRITE (IODRAW) SNGL(ETRACK-Amntrn),SNGL(ATRACK)
      END IF
      RETURN
*
*============================================================================*
*                                                                            *
*     Event End DRAWing:                                                     *
:_
```

fluka : less   flutil : bash

fluka : less   rdesktop - cernts   10:09



FLUKA SIMULATION OF
NEUTRON PRODUCTION AND SINK FOLLOWING (p,xn)



Free gas vs **S(α,β)** thermal treatments. MCNPX2.5.0 simulations were started with 10^6 5 eV neutrons in concentric spheres of polyethylene, passing all 10 statistical tests. Thermal data at 300 K was taken from the tmccs library, which provides scattering data for ^1H only; ^{12}C was still represented by the default free-gas treatment.

OUR LEGOLAND

GPS N 55° 44,013 E 013° 14,829

CURRENTLY AN OLD FARMLAND

TOWARDS

THE 1ST NEUTRON

IN 10 YEARS' TIME

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ROCK-SOLID FACILITIES + INFRASTRUCTURE

WE CAN DO EXPERIMENTS THERE

BUT WE CAN'T GO BACK IN TIME

TO DESIGN & BUILD CERN

SHALL BE AS GREEN AS IT CAN BE

CERTAINLY NOT AS GRAY

SHALL EMULATE CERN'S

FREEDOM TO DO SCIENCE

ROCK-SOLID FACILITIES + INFRASTRUCTURE

WE CAN DO EXPERIMENTS THERE

BUT WE CAN'T GO BACK IN TIME

TO DESIGN & BUILD CERN