Radiation Safety for High Power Operation

D. Ridikas for Task 5

List of objectives:

- **Shielding against prompt radiation and induced radioactivity**

- **Containment of radioactivity**

- **Characterization of nuclear waste and disposal of spent targets**

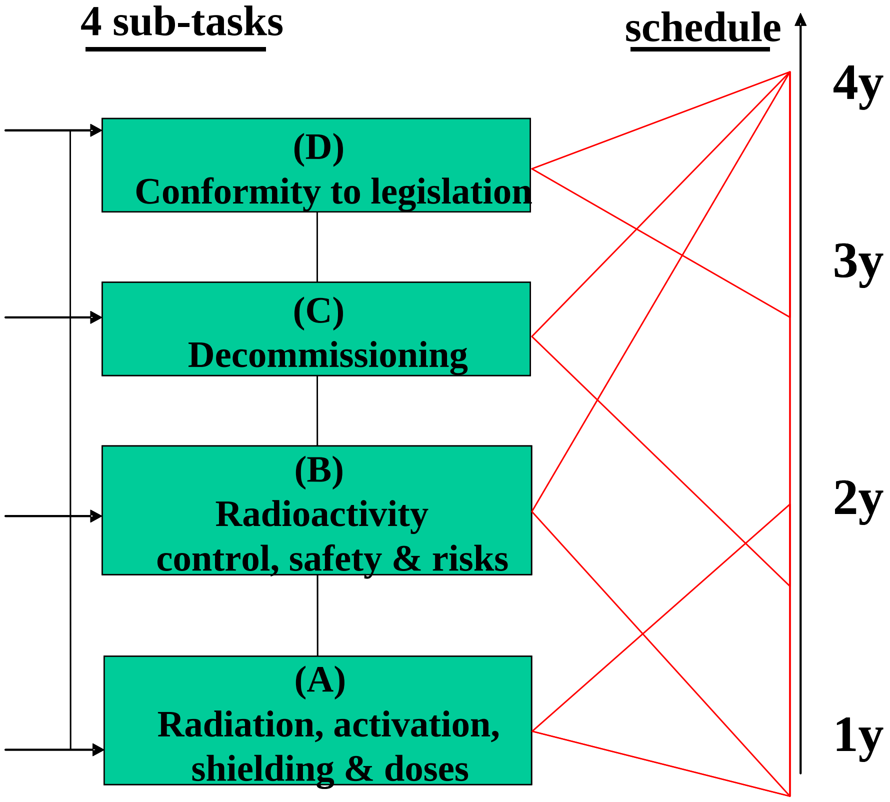
- **Conformity** of the proposed installation **to the legislation**

Major efforts on the 4 MW target station !

27-30 Nov. 2006, CERN, Geneva, Switzerland

Contact: ridikas@cea.fr

Task 5: Participants and work plan

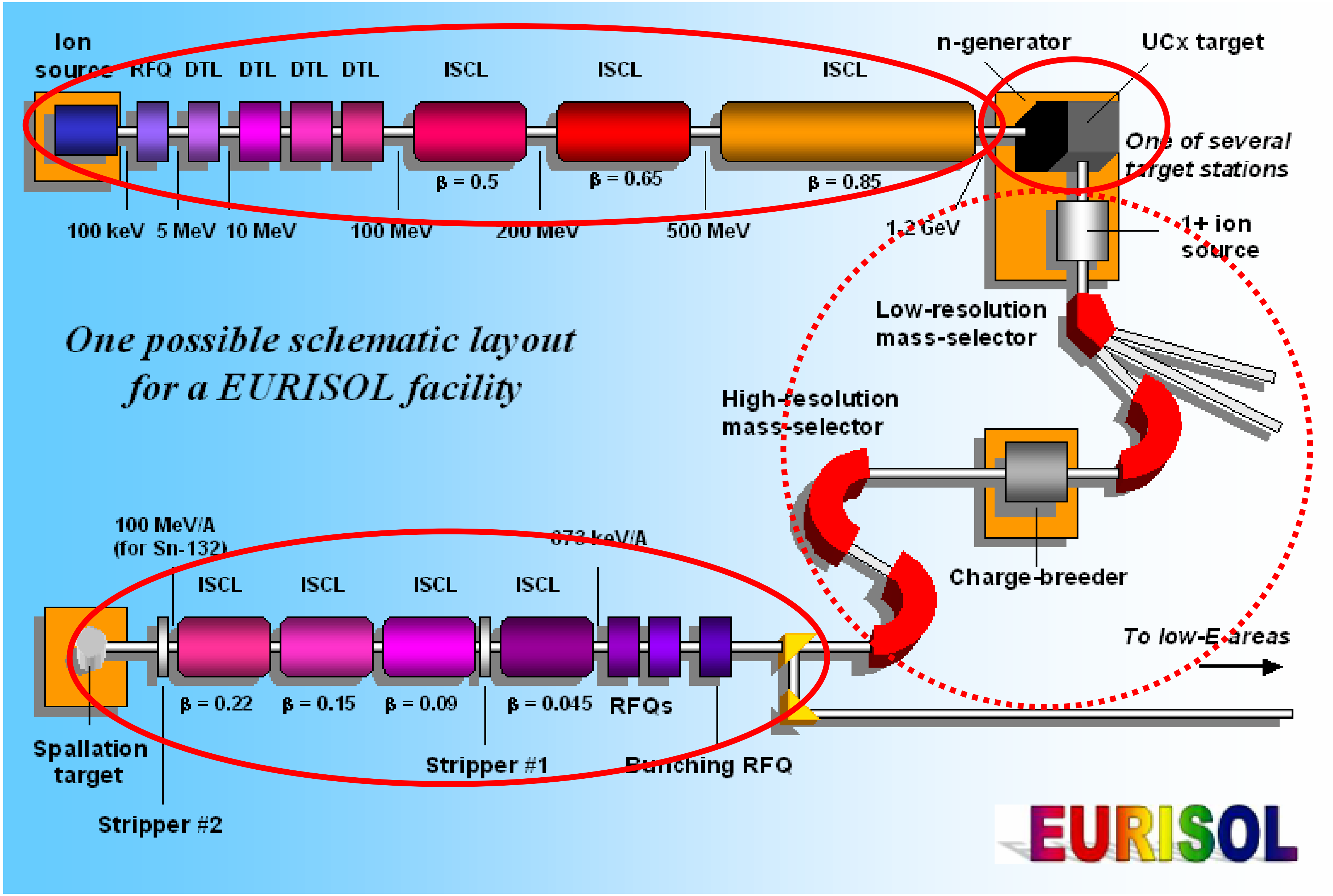


Participants:	role
1. GANIL, France	- sub-task D
2. FZJ, Germany	- sub-task C
3. LMU, Germany	- sub-task B
4. CERN, EU	- sub-task A
5. CEA, France	- coordination
6. NIPNE, Romania	- contribution
7. FI, Lithuania	- contribution
8. Univ. Warsaw, Poland	- contribution

External partners:

ORNL, ANL, TRIUMF, JAEA, KAERI

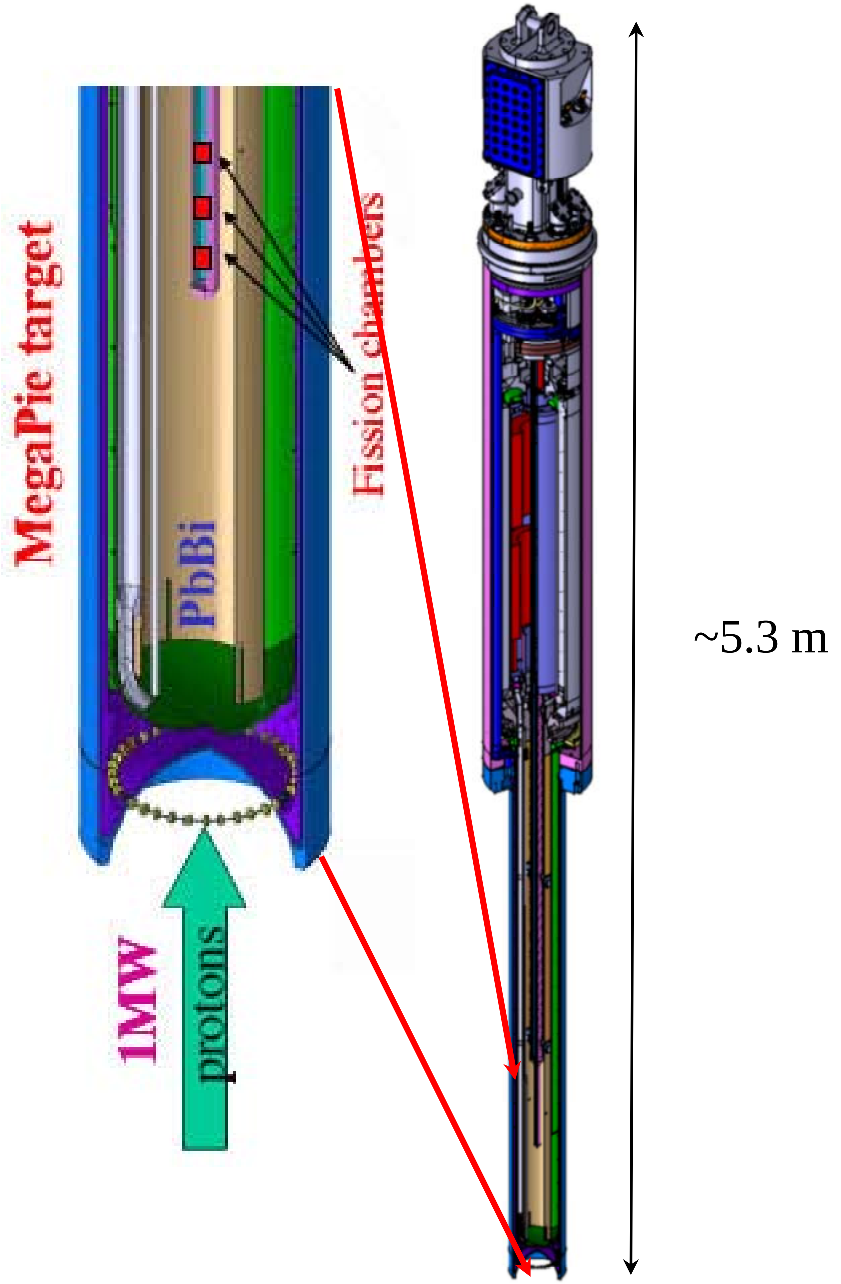
…compared to other projects…



One possible schematic layout for a EURISOL facility

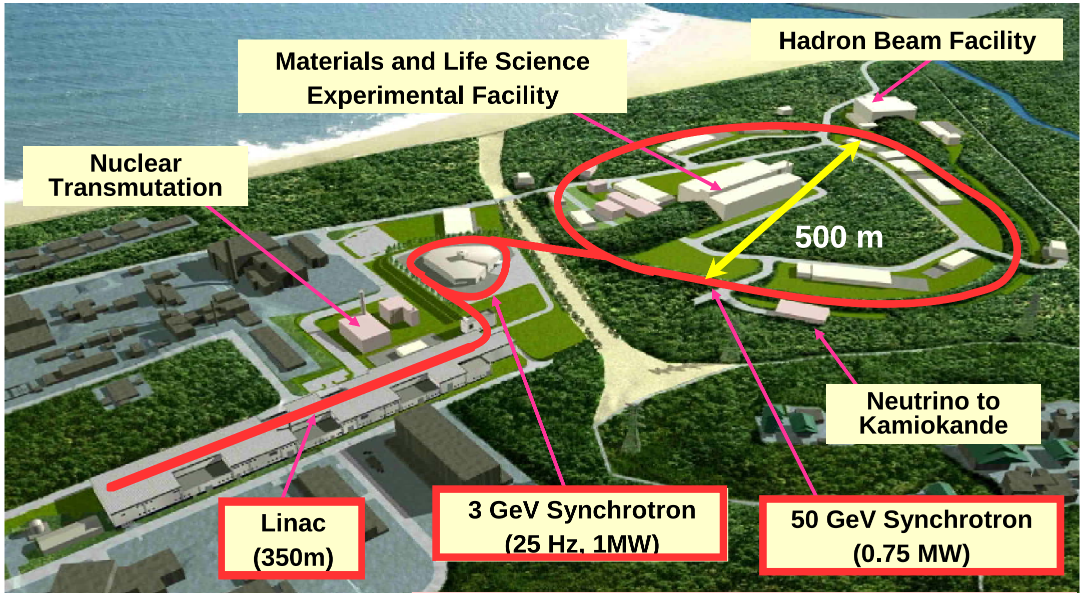
MegaPie/PSI

E_p	570 MeV
I_p	1.2 mA (1.8)
W	0.7MW (1.0)
V_{PbBi}	~ 82 liters
Main pump	~4.00 l/s
$T_{transit}$	~20 s



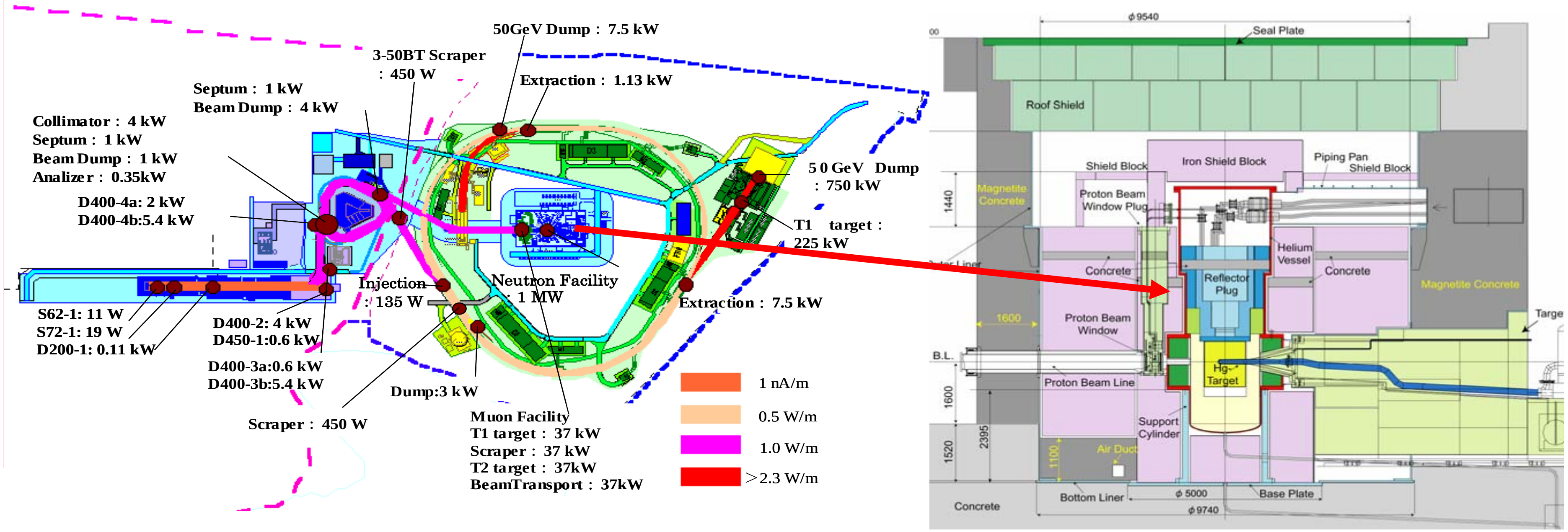
1st beam on the target since 14 August and still running!

J-PARK/JAEA - thanks to H. Nakashima

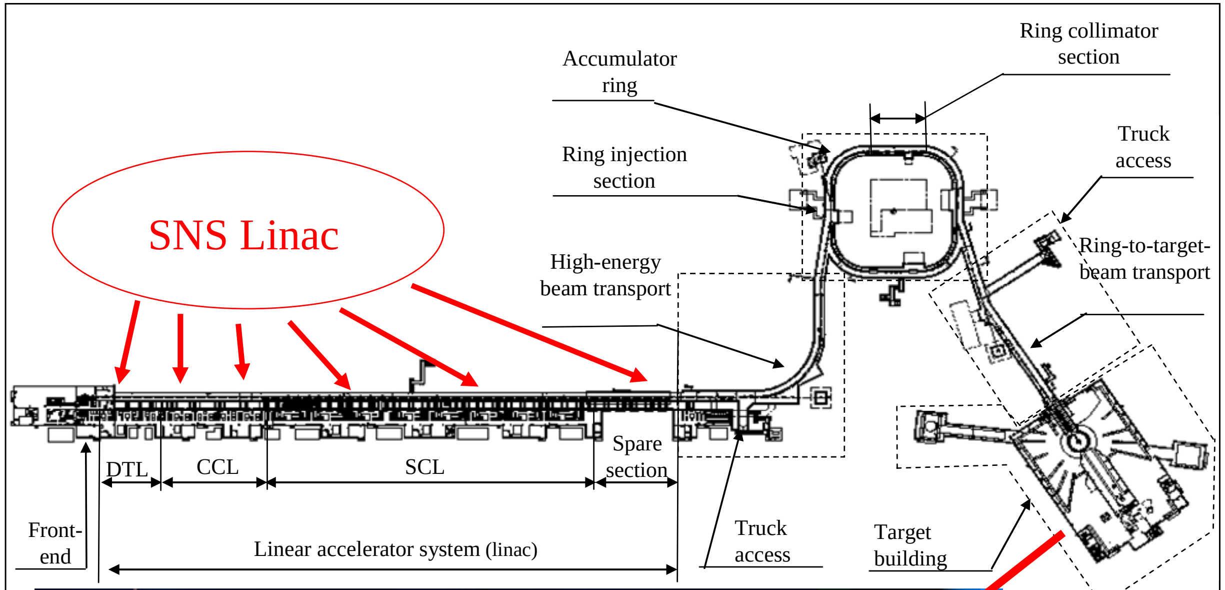


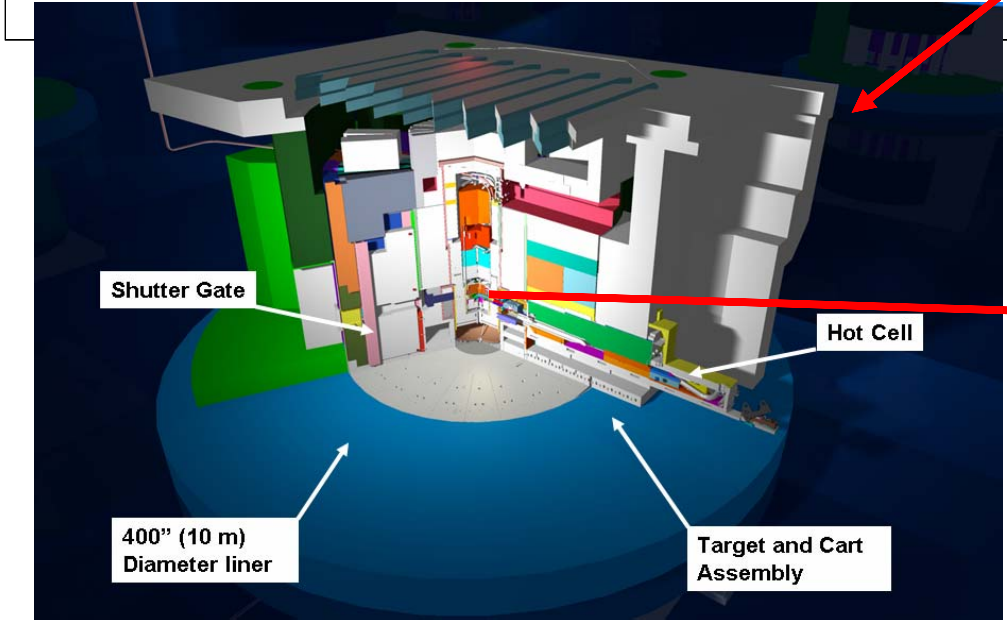
→ Facility Under construction ←

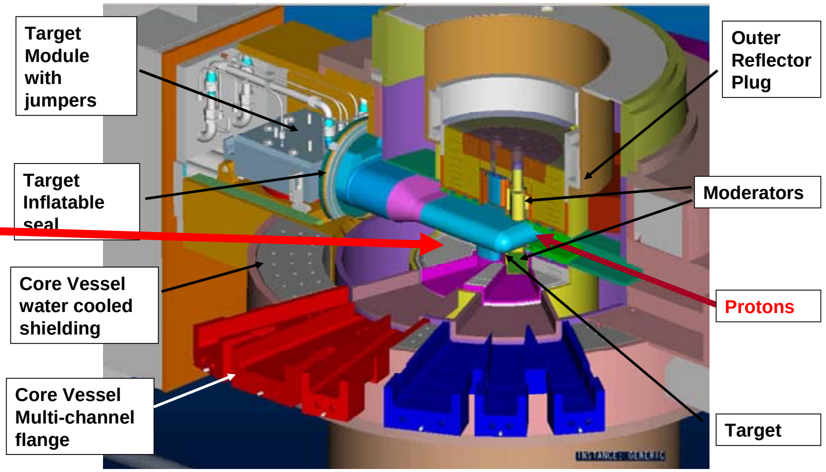
- 3GeV, 1MW, 25Hz, proton beam
- Mercury target of 1.4m^3
- Moderators with liquid H of 260l
- Shield of about 10,000t and movable target structure



SNS/ORNL - thanks to F. Gallmeier

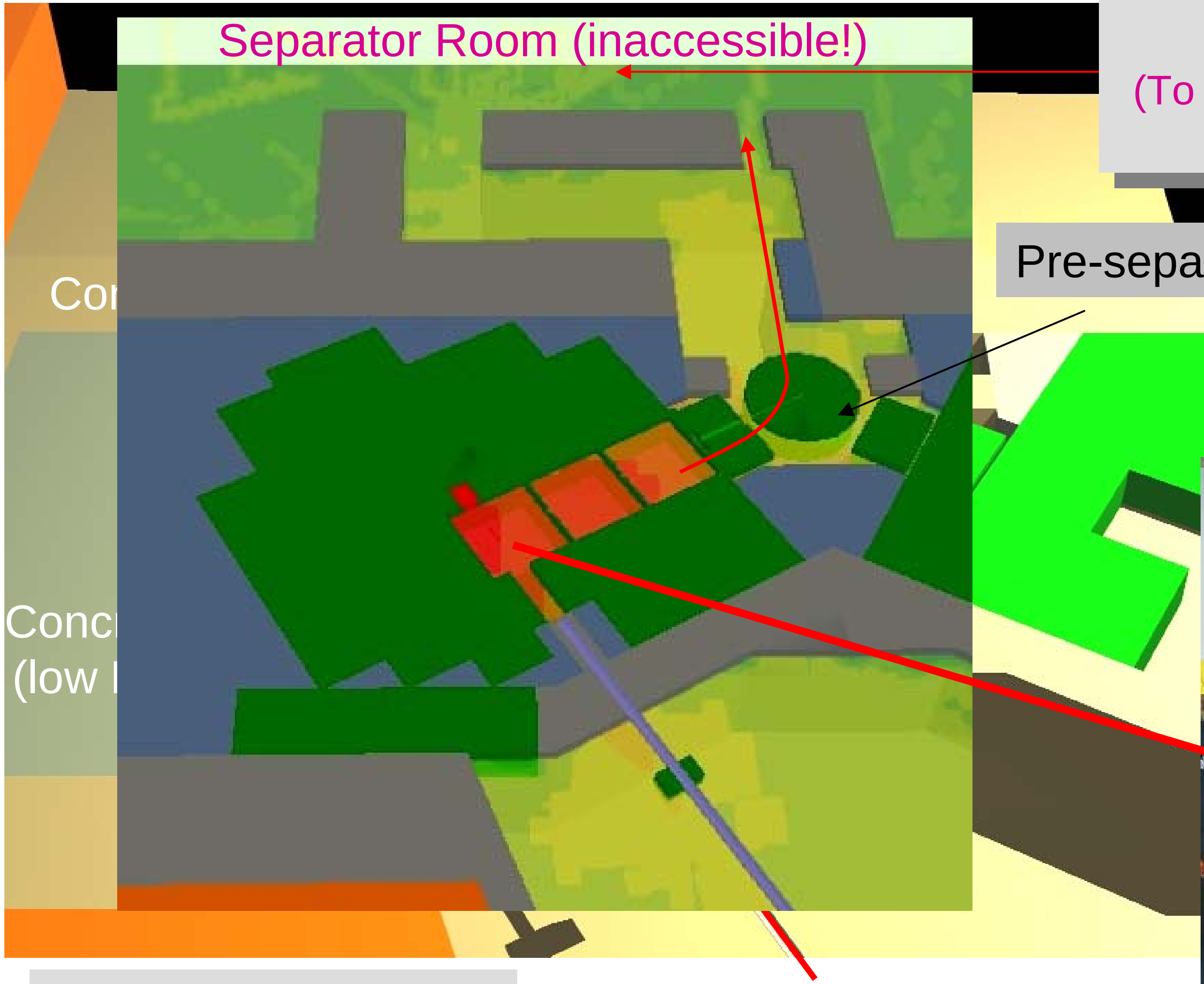






- The SNS has started operation in 2006
- 1GeV protons on liquid Hg (1.4 MW)
- The peak neutron flux ~20–100x ILL
- SNS will be the world’s leading facility for neutron scattering

TRIUMF - thanks to L. Moritz



Separator Room (inaccessible!)

~ 1 mSv h^{-1}

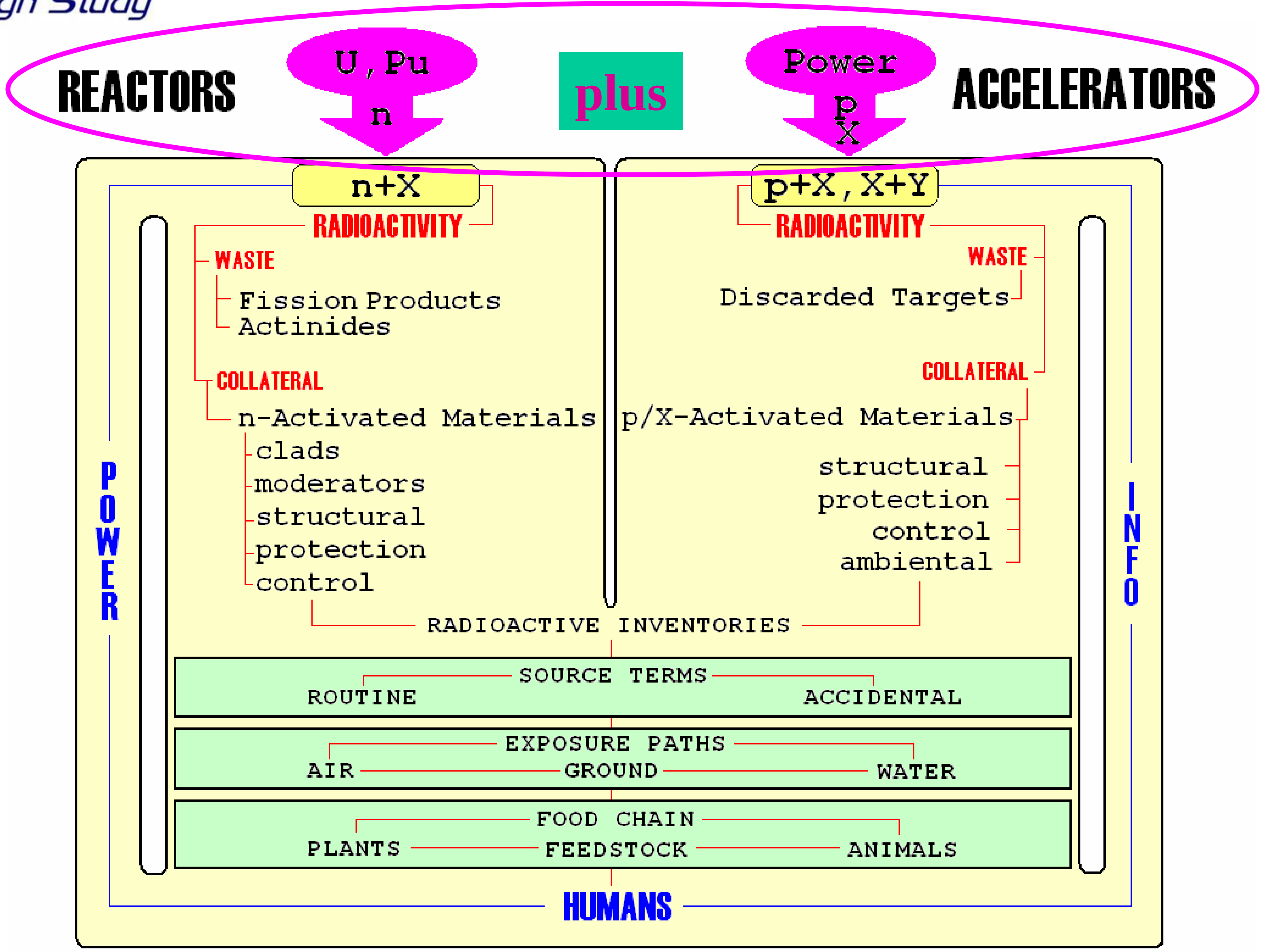
(To prevent radiation damage)

Pre-separator

Proton beam

Target: 50 g cm^{-2} UC_2
E_p = 500 MeV
I_p = 100 μA

No license so far!



REACTORS U, Pu → n **plus** Power → p, X **ACCELERATORS**

n+X

RADIOACTIVITY

WASTE
- Fission Products
- Actinides

COLLATERAL
- n-Activated Materials
  - clads
  - moderators
  - structural
  - protection
  - control

p+X, X+Y

RADIOACTIVITY

WASTE
- Discarded Targets

COLLATERAL
- p/X-Activated Materials
  - structural
  - protection
  - control
  - ambiental

RADIOACTIVE INVENTORIES

SOURCE TERMS: ROUTINE, ACCIDENTAL

EXPOSURE PATHS: AIR, GROUND, WATER

FOOD CHAIN: PLANTS, FEEDSTOCK, ANIMALS

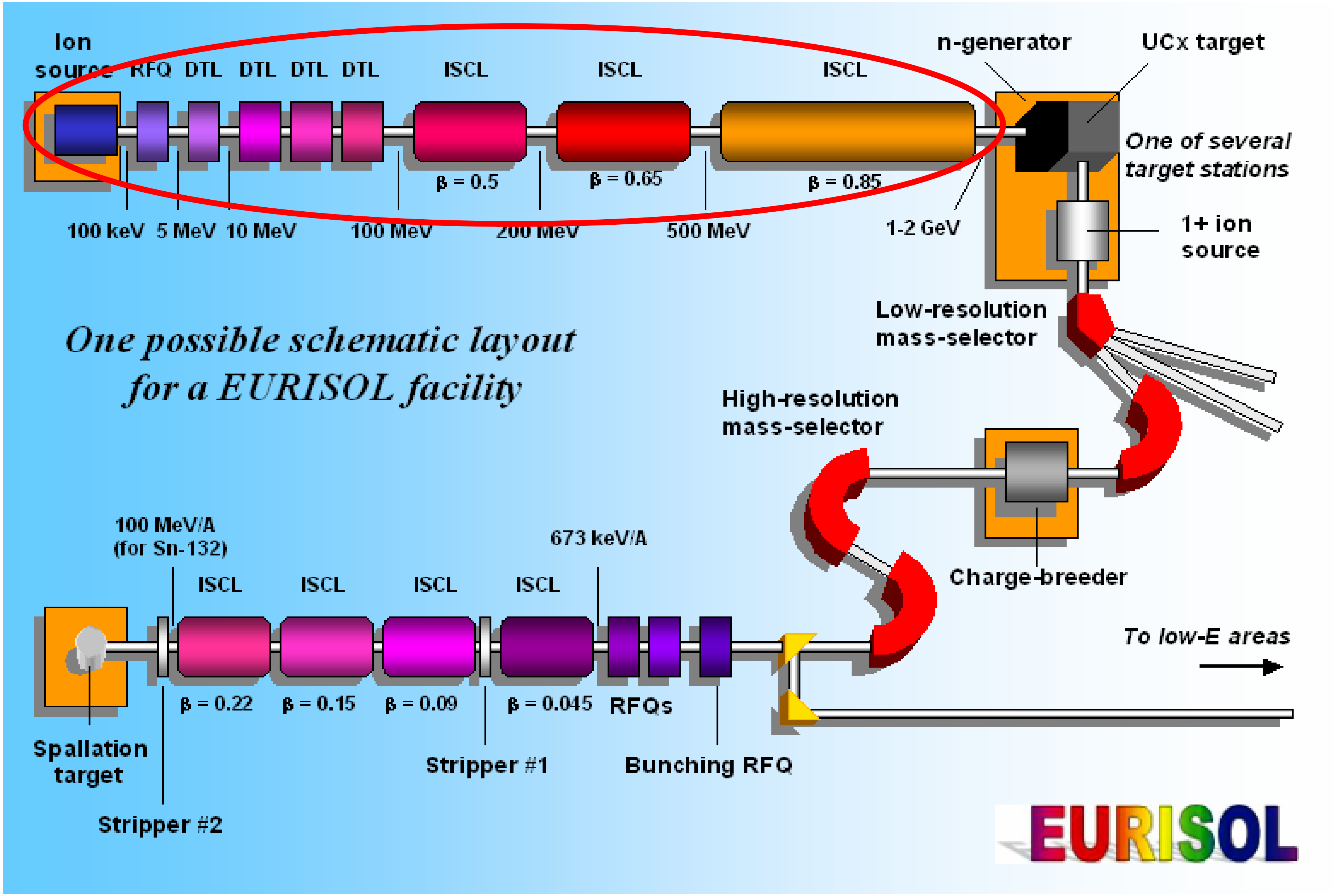
HUMANS

POWER

INFO

EURISOL → combination of both!

A) Shielding of the proton driver



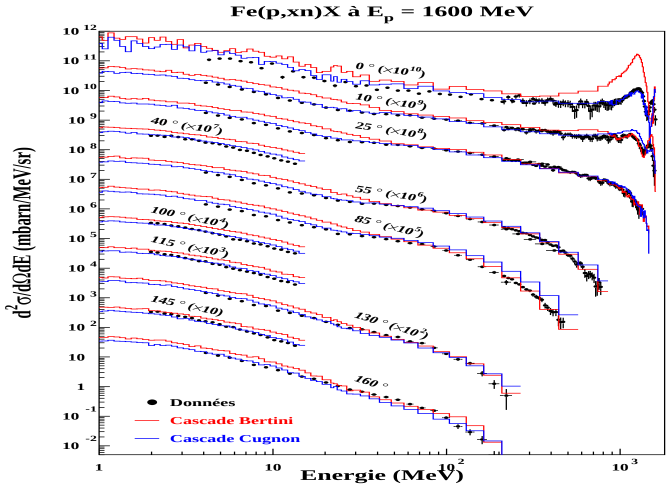
One possible schematic layout for a EURISOL facility

EURISOL Design Study

A) Shielding benchmarks

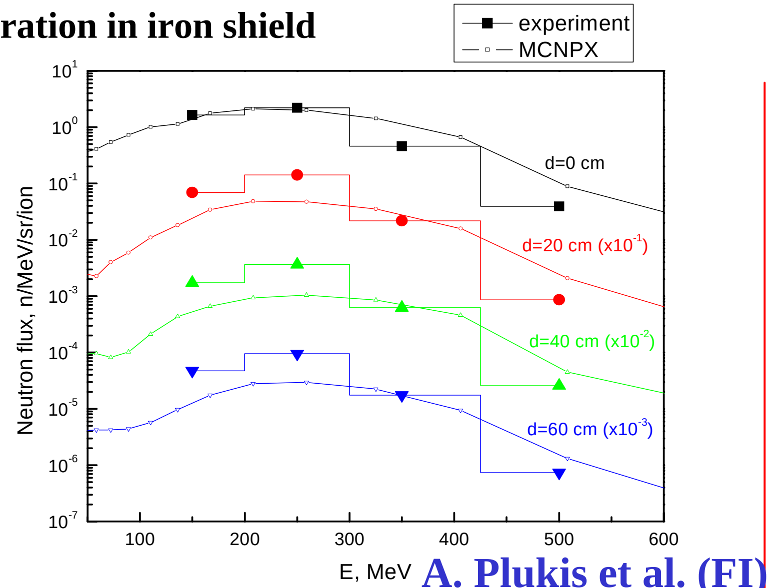
T5: Safety & Radioprotection

p(1.6 GeV) + Fe → neutrons



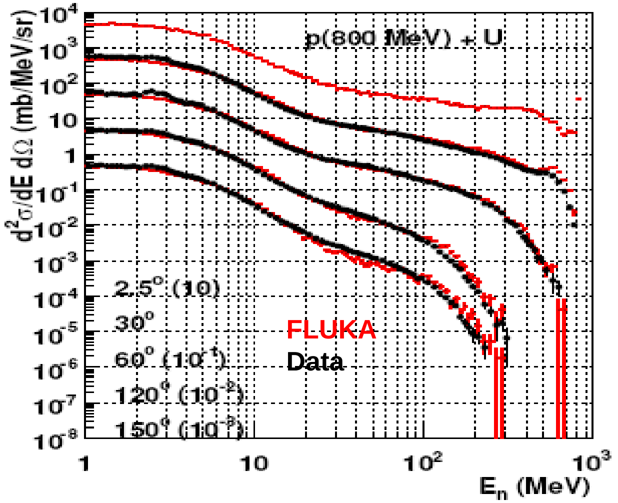
J.-C. David et al. (CEA)

Neutron penetration in iron shield



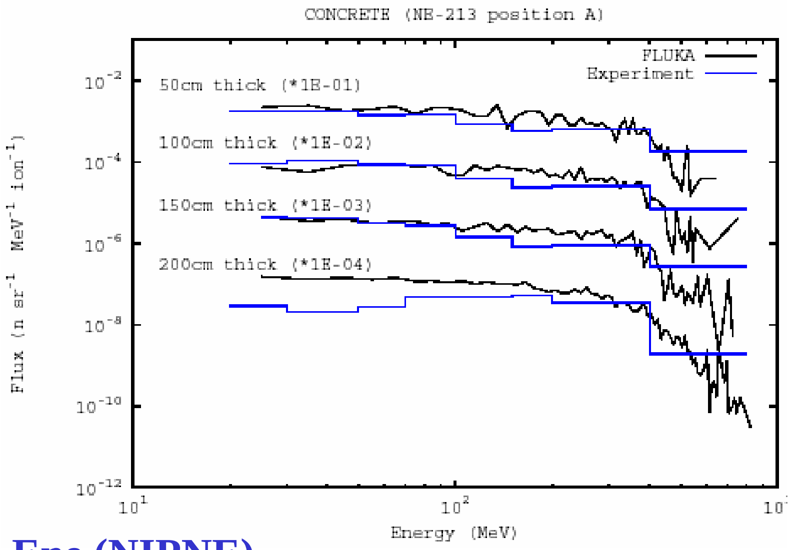
A. Plukis et al. (FI)

p(0.8 GeV) + U → neutrons



M. Felcini et al. (CERN)

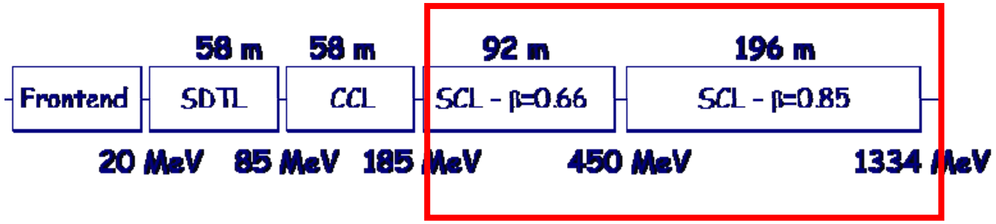
Neutron penetration in concrete shield



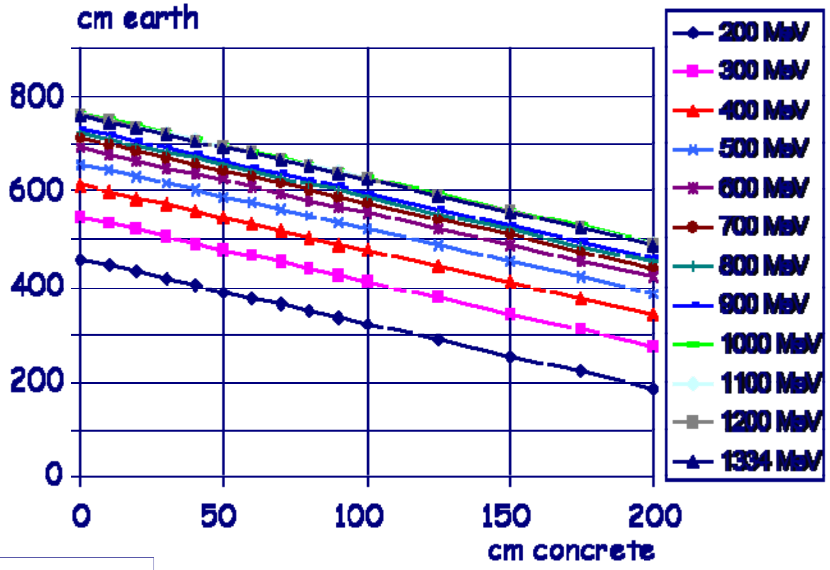
D. Ene (NIPNE)

Contact: ridikas@cea.fr

A) Shielding of the proton driver



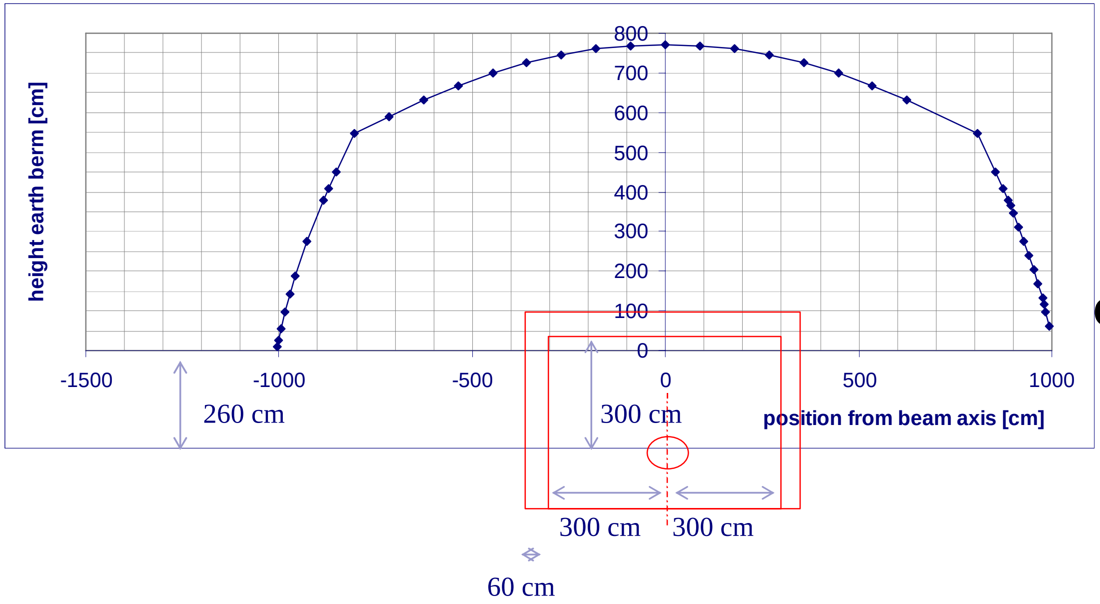
Guidelines for ESS by P. Berkvens et al. (2006)



Shielding criteria:

- Normal losses of 1W/m
- Dose rates < 1.0 µSv/h

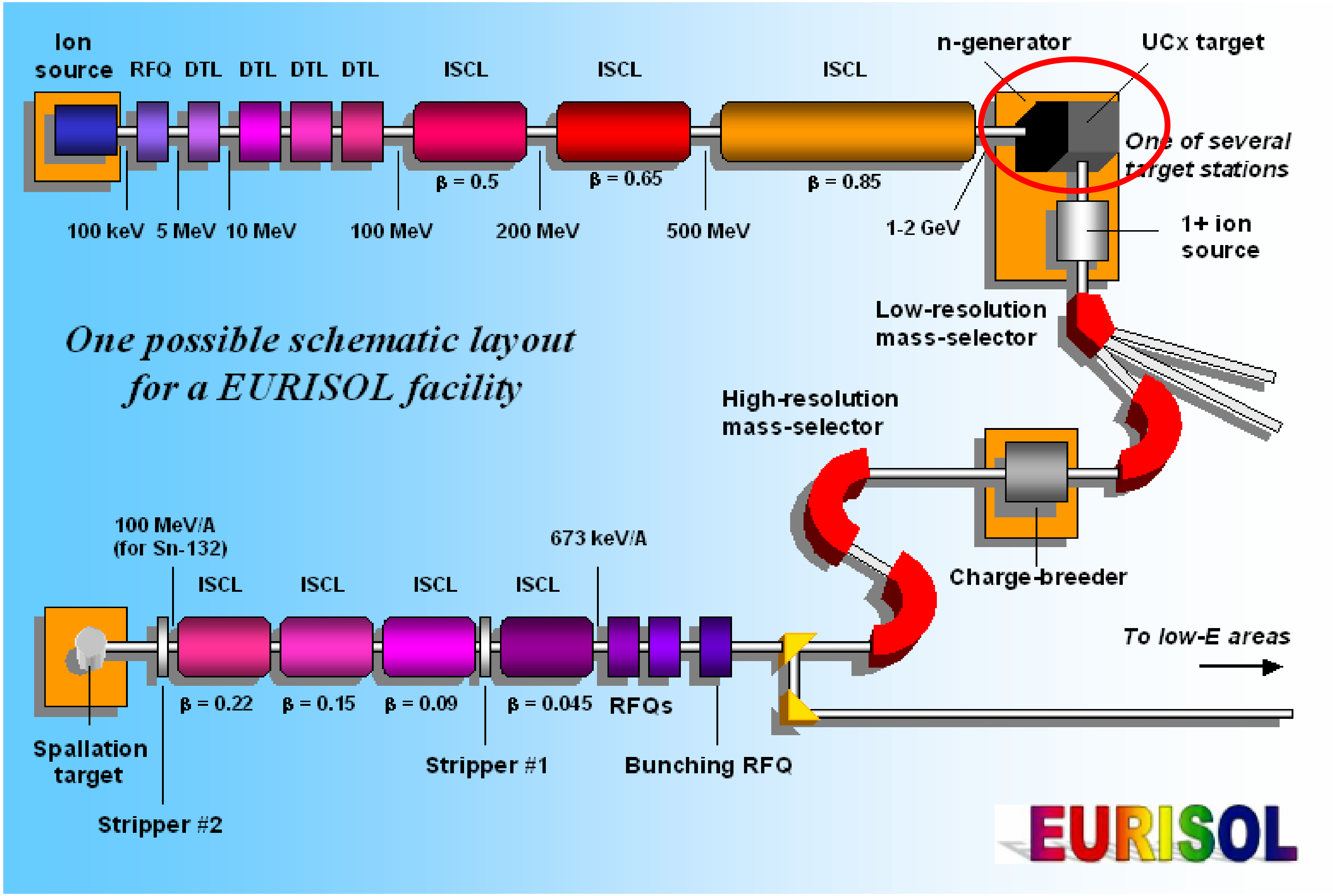
Definition of earth shielding for a given concrete thickness



Cross check: MC versus deterministic

Shielding thickness	Monte Carlo	Moyer model
45 cm concrete + 4.75 m earth	2.5 µSv/h	3.8 µSv/h

A) Shielding of the 4 MW target

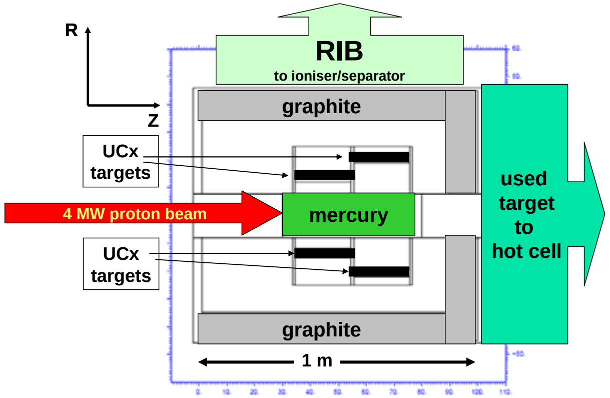


One possible schematic layout for a EURISOL facility

A) Shielding of the 4 MW target

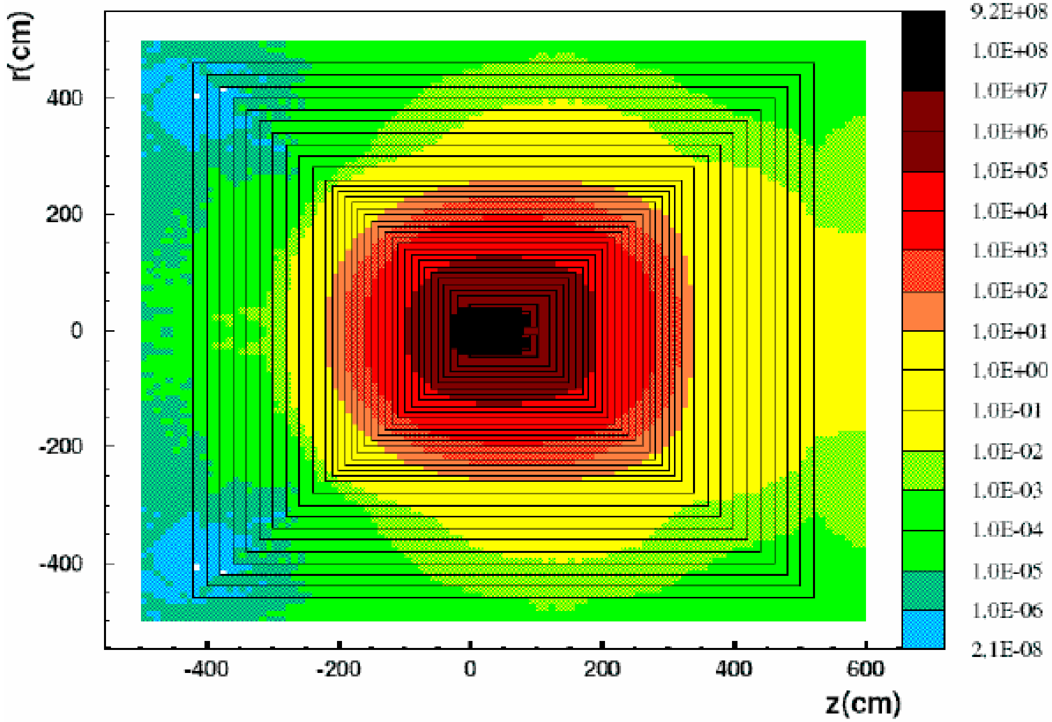
T5: Safety & Radioprotection

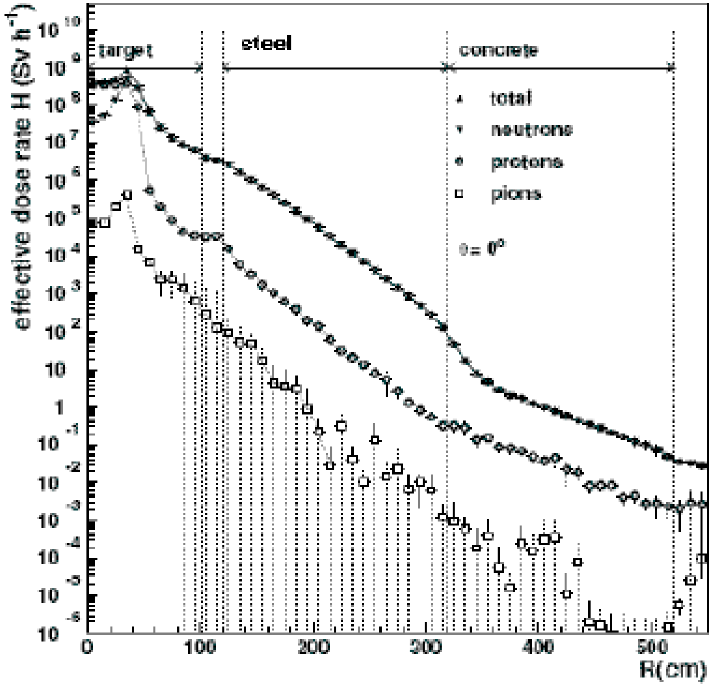
T. Otto & M. Felcini (CERN)



Condition for dose rates < 1 μSv/h

- 2 m of iron
- For θ = 0, 90 &180° → 9.0, 8.0 & 5.5 m of concrete
- To be complemented with earth





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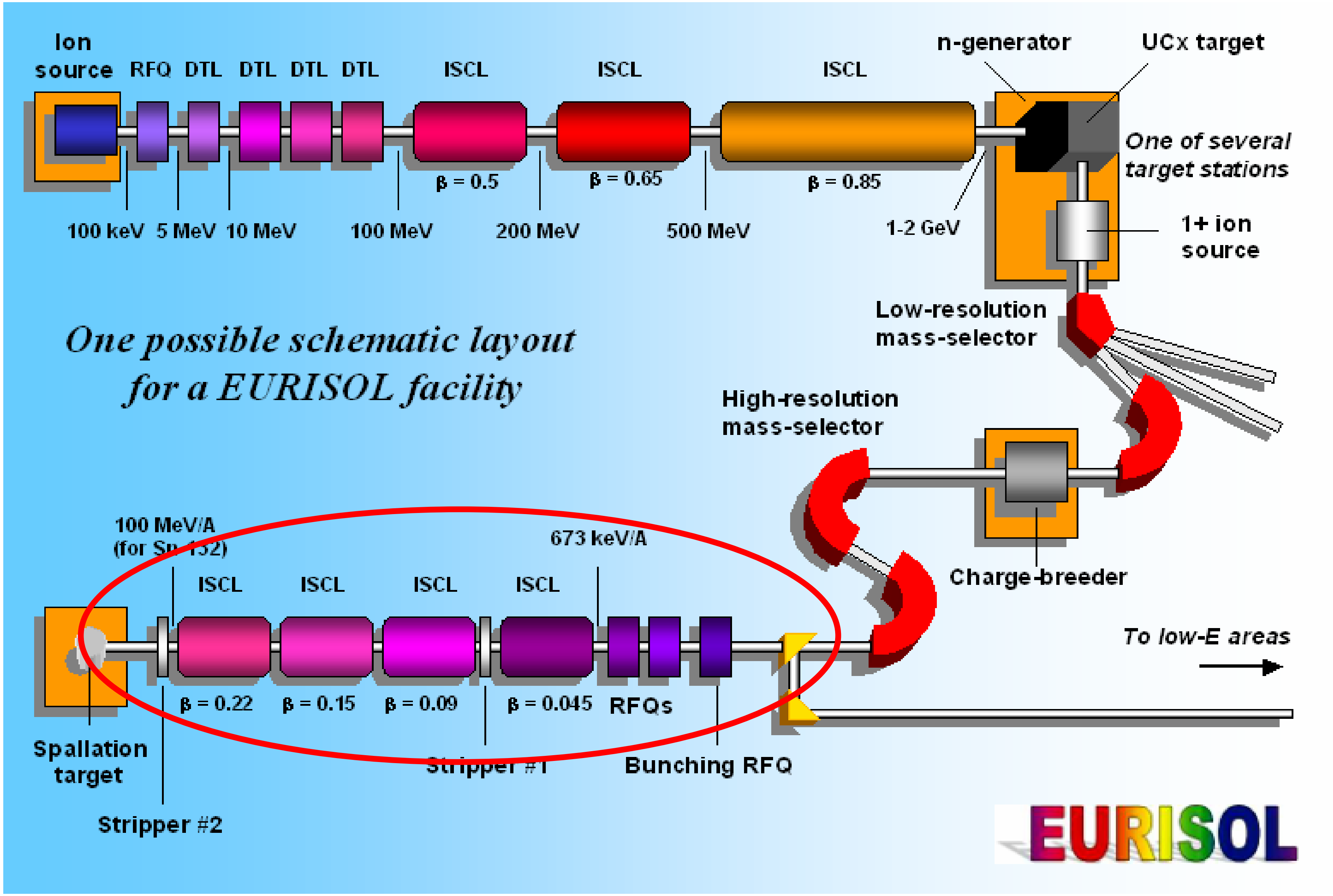
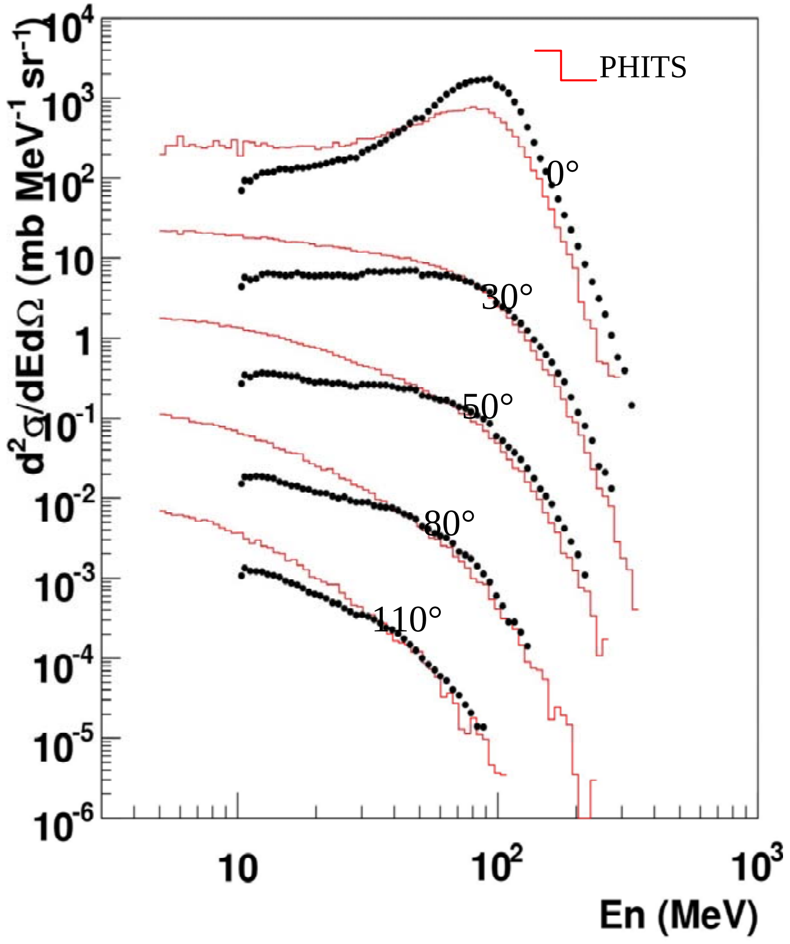
A) Shielding of the postaccelerator



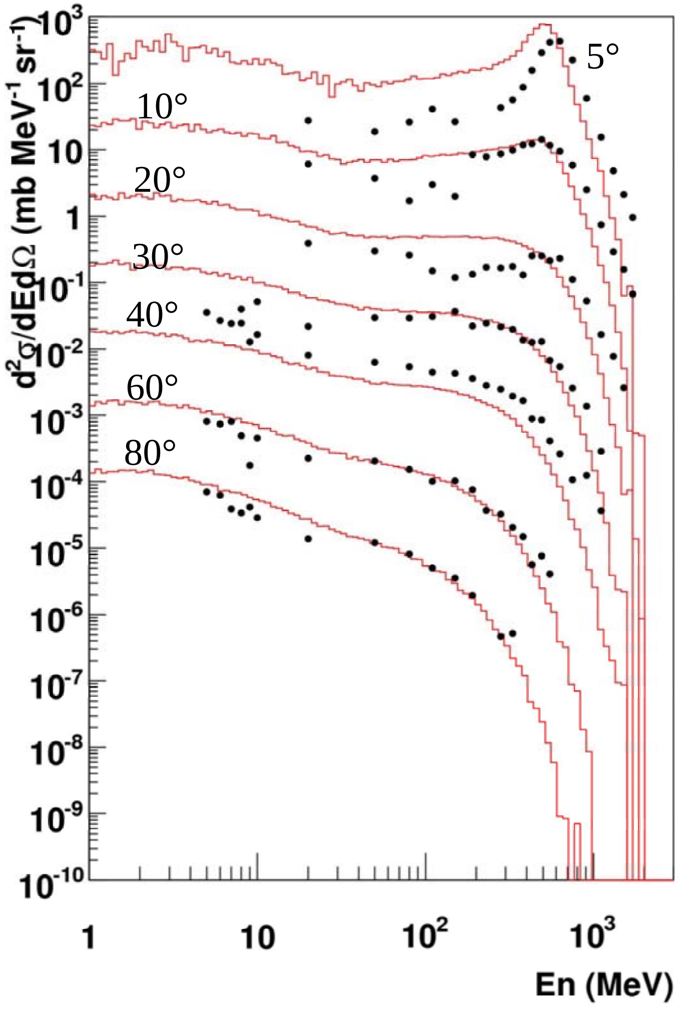
One possible schematic layout for a EURISOL facility

A) Shielding benchmarks

Production of neutrons
RIKEN data : Ar(95MeV/u)+Cu



Production of neutrons
HIMAC data : Ar(560MeV/u)+Cu

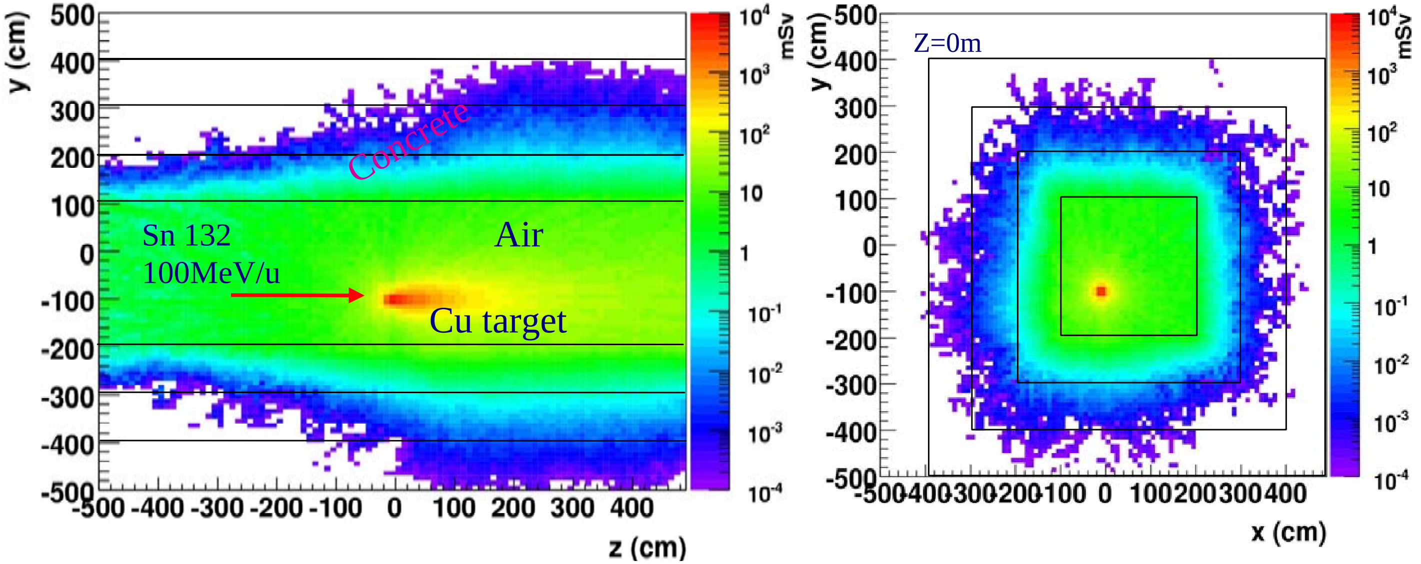


B. Rapp et al. (CEA)

A) Shielding of the postaccelerator

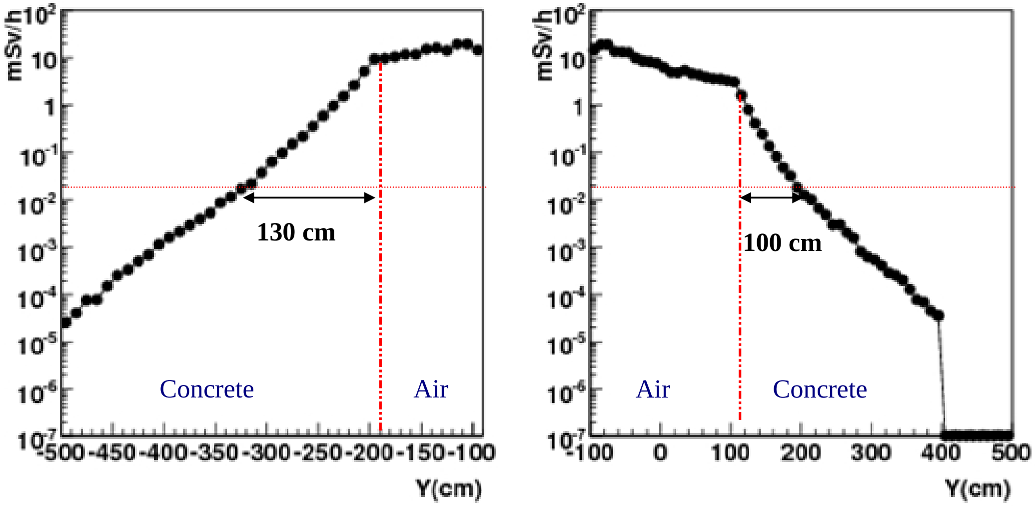
Assumption: 100 MeV/u ^{132}Sn + Cu at I = 6x10^{12} pps; beam loss of 1 second

Resulting Dose Map



Condition for dose rates:

20mSv /2000 h → < 10 µSv/h

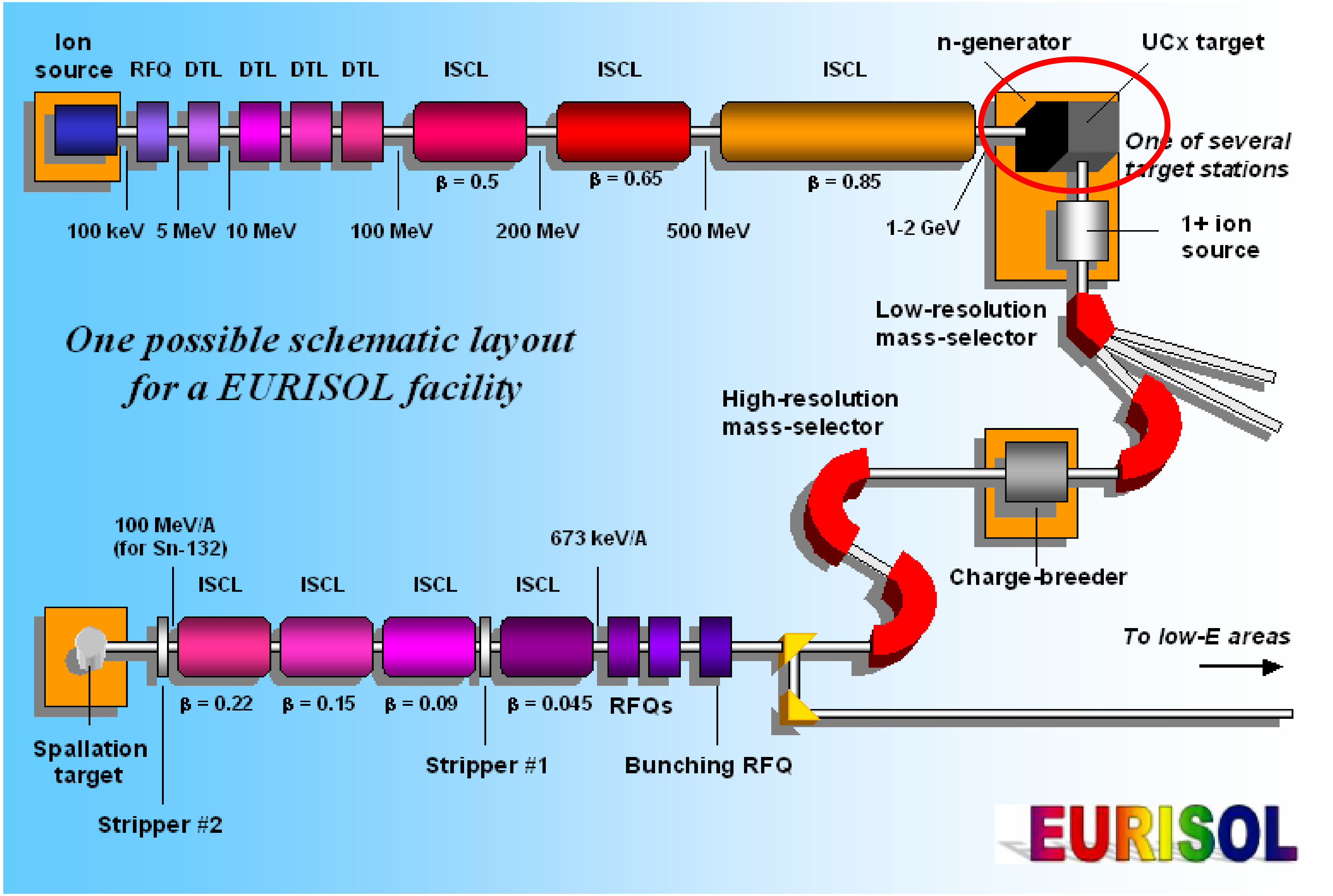


Assumption for losses:

1 s beam loss once a day with probability of 10^{-5}/m

B. Rapp et al. (CEA)

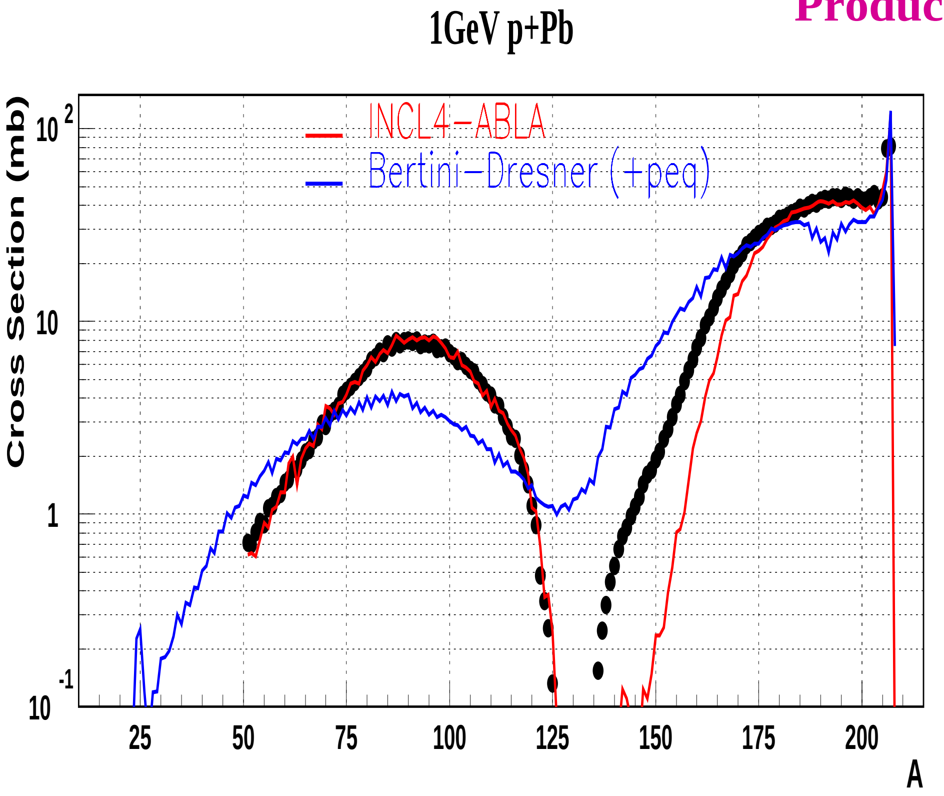
A) Activation of the 4 MW target



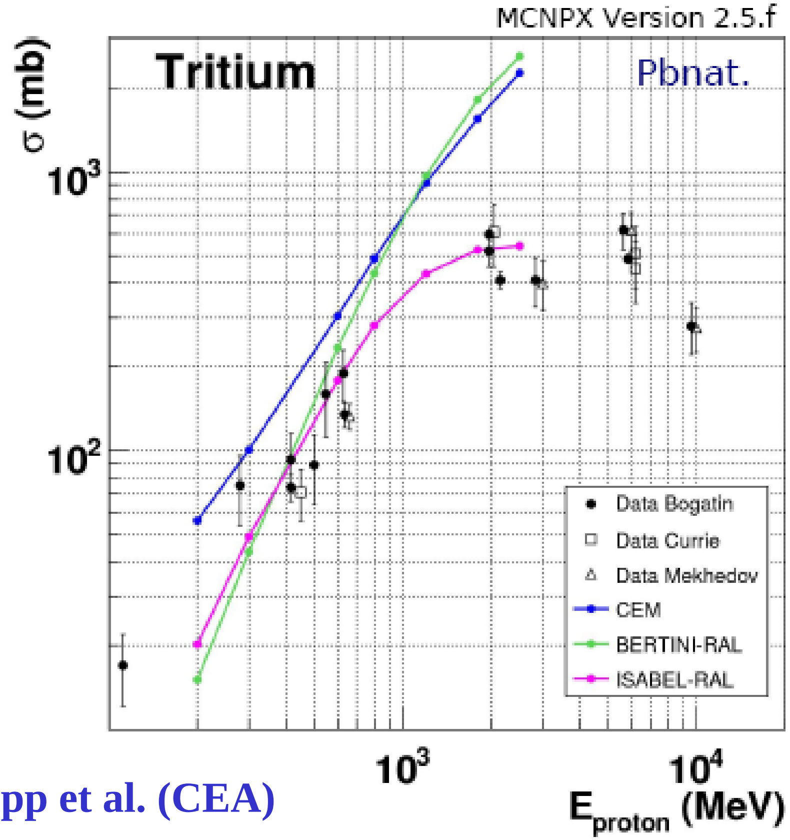
One possible schematic layout for a EURISOL facility

A) Activation benchmarks

Production of Residual Nuclei



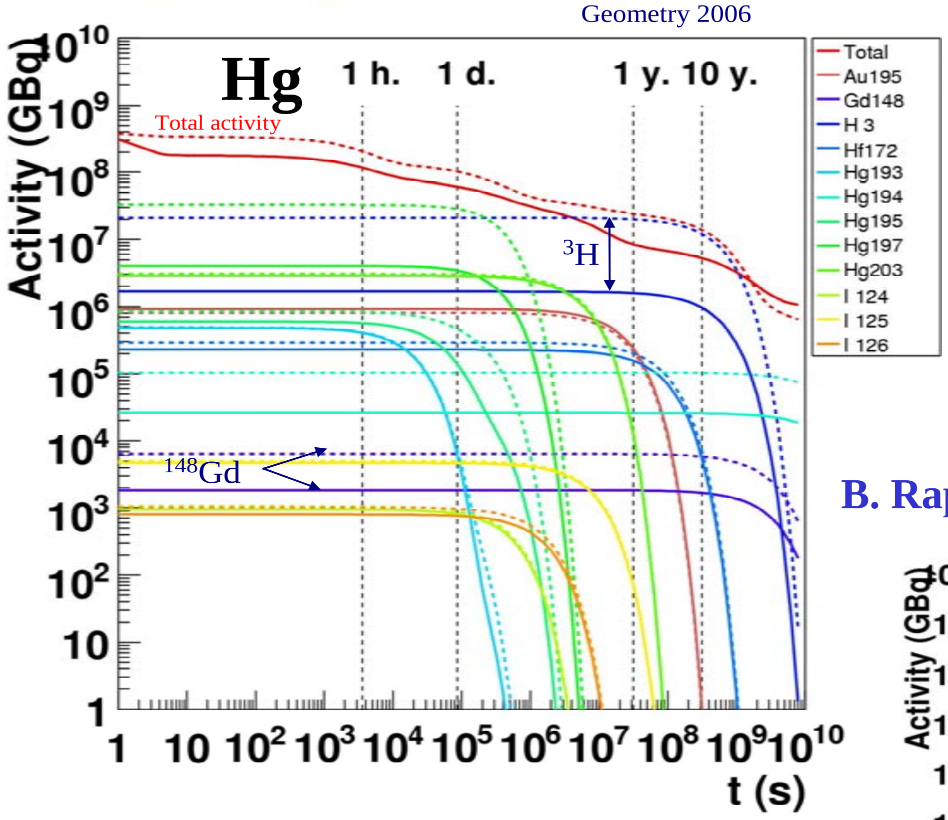
J.-C. David et al. (CEA)

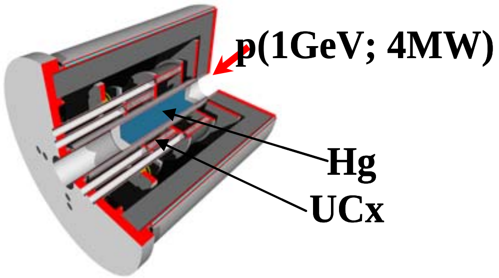


B. Rapp et al. (CEA)

A) Activation of Hg and UCx

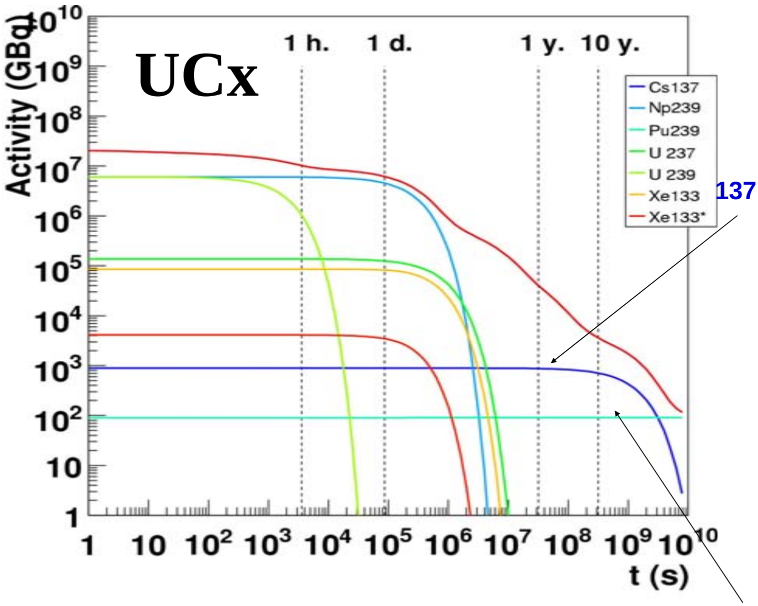
T5: Safety & Radioprotection





- Irradiation : 40 years operation, 5000 h/year, 4MW beam power
- Important differences appears in nuclide yield production, and consequently in Hg target activity

B. Rapp et al. (CEA)



^{137}Cs, $T_{1/2}$=30y

^{239}Pu, $T_{1/2}$=24110y

→ induced activity comparable to the research reactor + α emitters

→ production of ^{239}Pu: ~50 g/year

T. Otto et al. (CERN)

A) Activation of MW target shielding

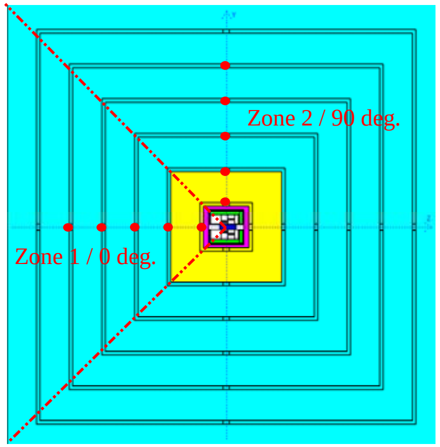
40 years irradiation at 2.28 MW

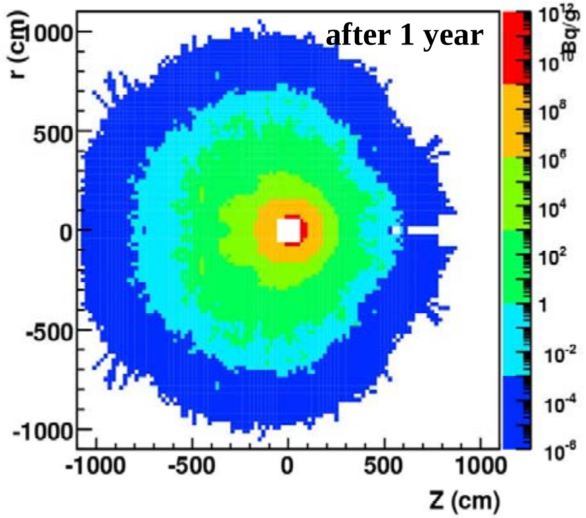
1 MBq/g < A < 1GBq/g

1 kBq/g < A < 1MBq/g

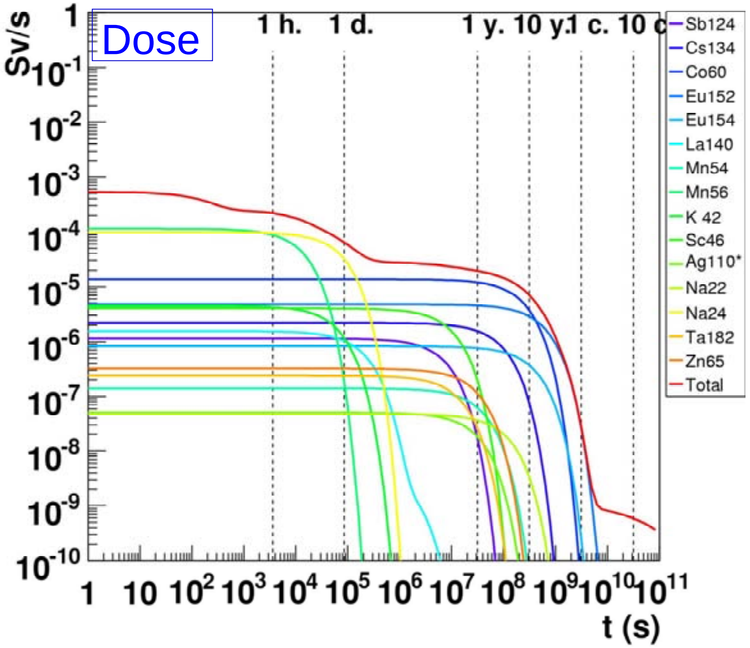
1 Bq/g < A < 1kBq/g

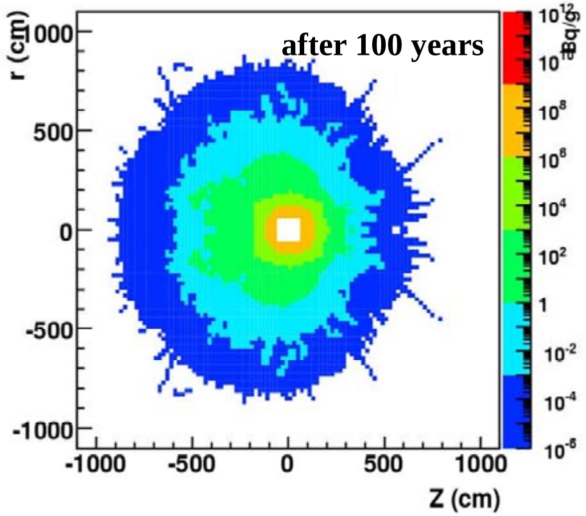
A < 1Bq/g





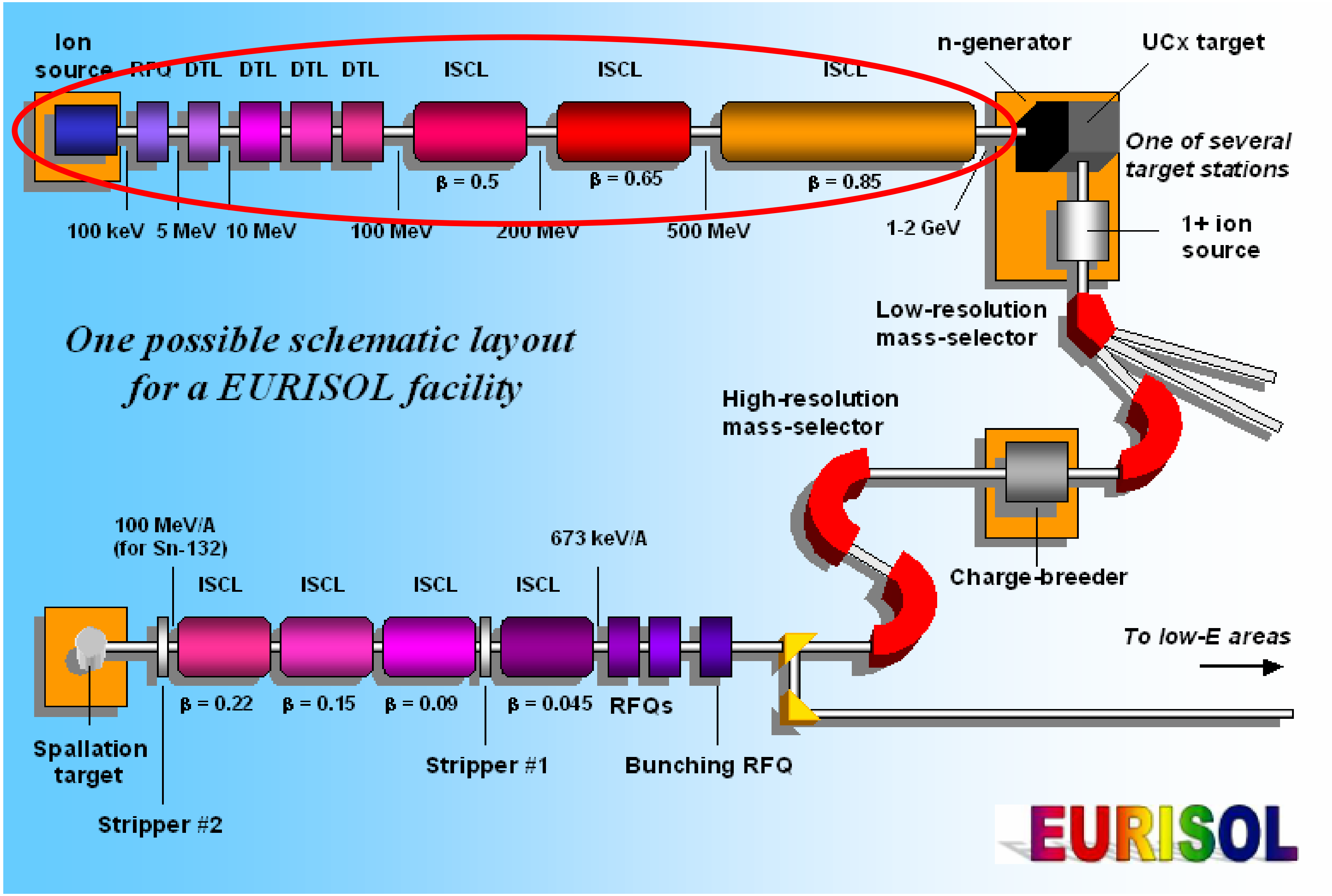
Concrete, 0 degree, at 1m70





B. Rapp et al. (CEA)

B) Activity transport in ground water



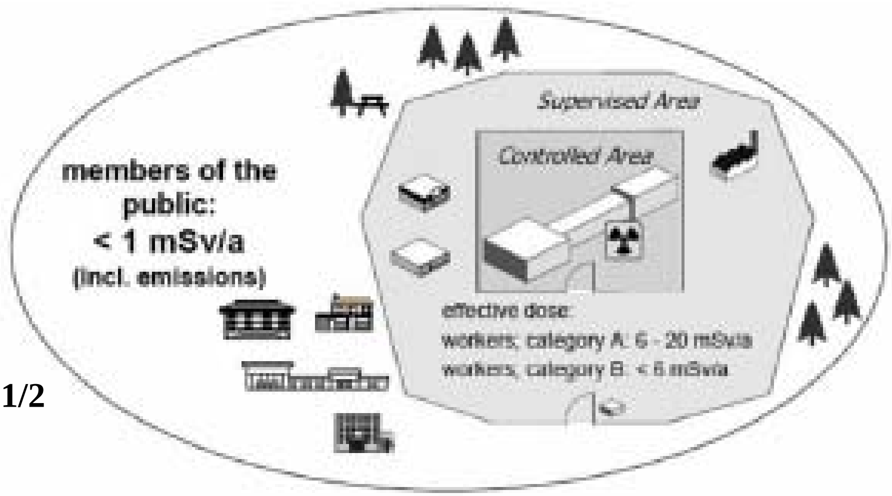
One possible schematic layout for a EURISOL facility

B) Activity transport in ground water

Goal: prediction of radioactivity at the boundary of the supervised area

Conservative assumptions:

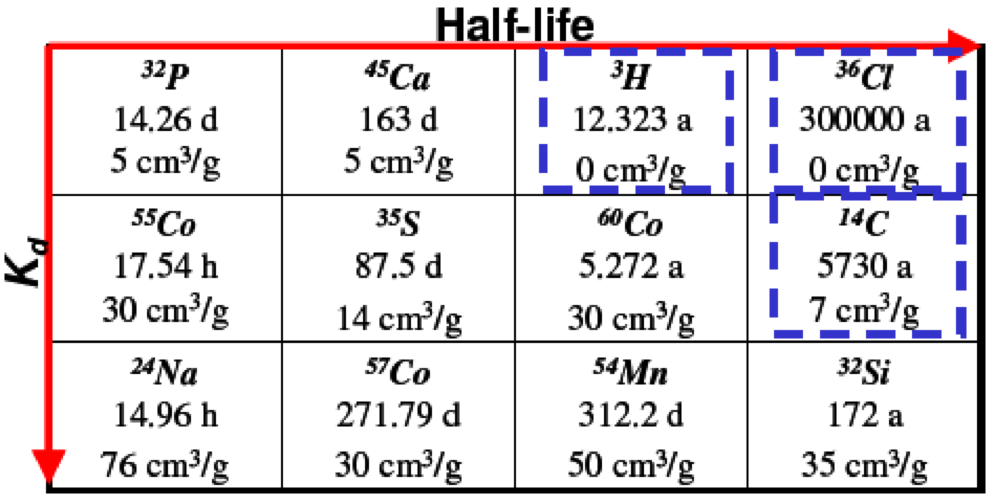
- maximum concentration at the source
- saturated water flow
- small partition coefficient K_d & high $T_{1/2}$
- …



Tools used:

TRACE
water flow simulations needed for

PATRACE
particle tracking (includes sorption & decay)

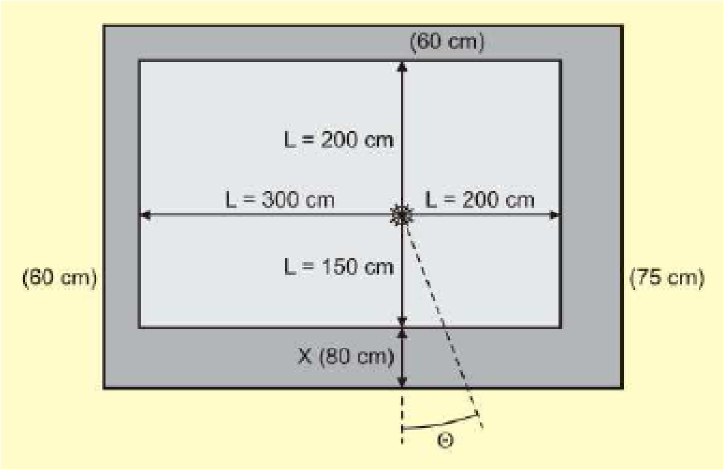


^{32}P 14.26 d 5 cm³/g	^{45}Ca 163 d 5 cm³/g	^{3}H 12.323 a 0 cm³/g	^{36}Cl 300000 a 0 cm³/g
^{55}Co 17.54 h 30 cm³/g	^{35}S 87.5 d 14 cm³/g	^{60}Co 5.272 a 30 cm³/g	^{14}C 5730 a 7 cm³/g
^{24}Na 14.96 h 76 cm³/g	^{57}Co 271.79 d 30 cm³/g	^{54}Mn 312.2 d 50 cm³/g	^{32}Si 172 a 35 cm³/g

Prolingheur et al. (FZJ)

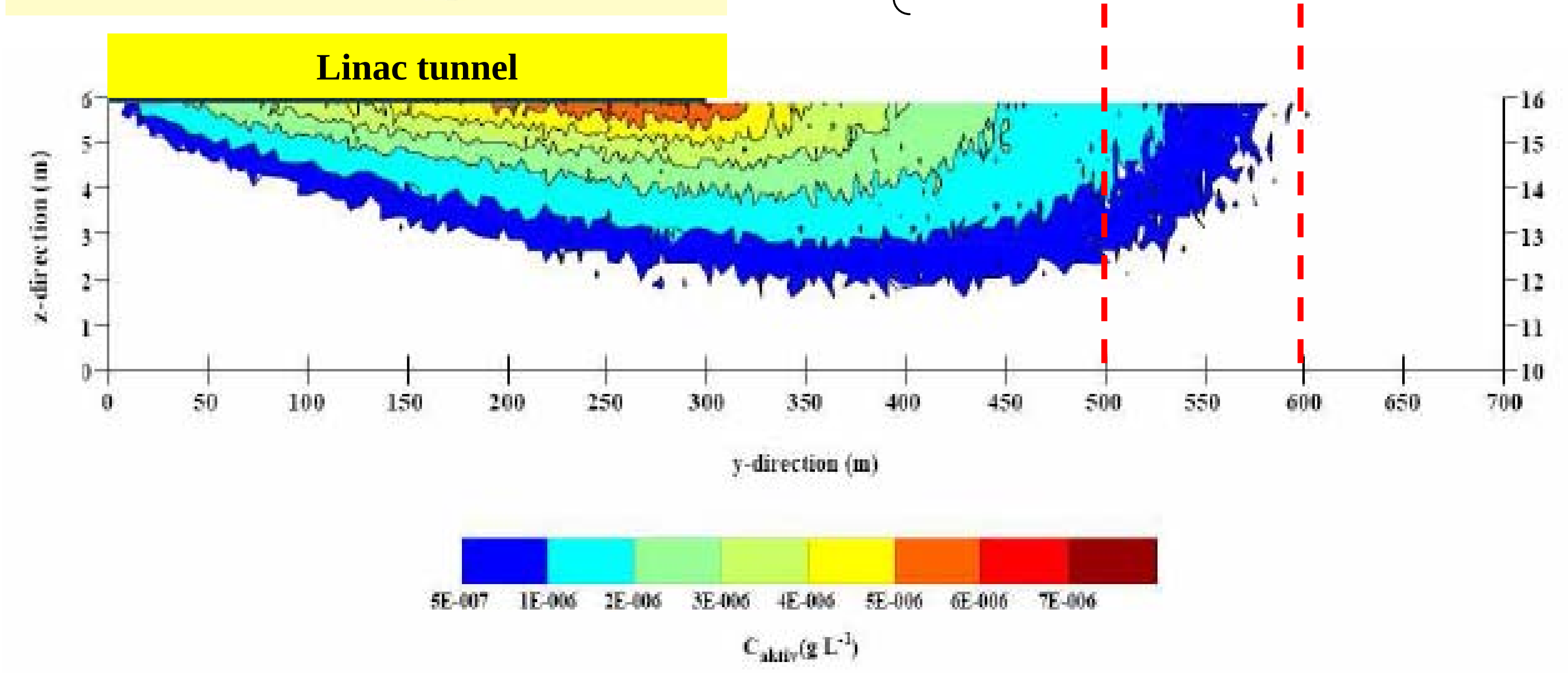
B) Activity transport in ground water

Linac tunnel



Final goal:

- **Committed effective doses**
- **Effectiveness of the shielding**
- Generalization of the method
- **Extension of the boundary area**

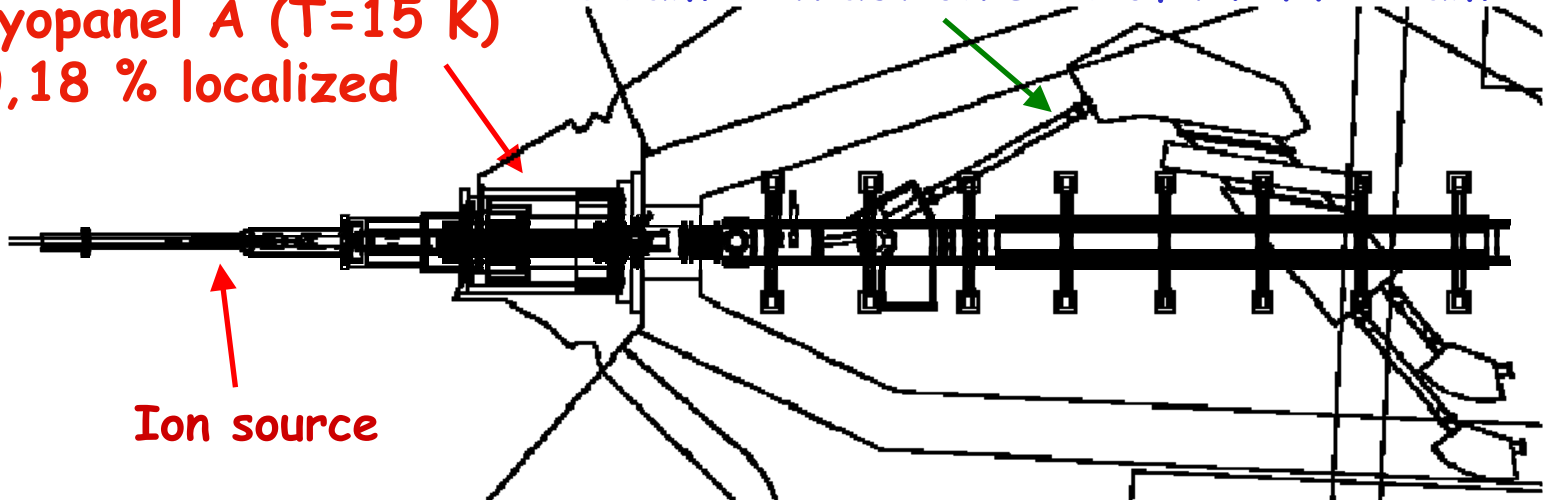


Prolingheur et al. (FZJ)

B) Containment of volatile radioactivity

Thirolf et al. (LMU)

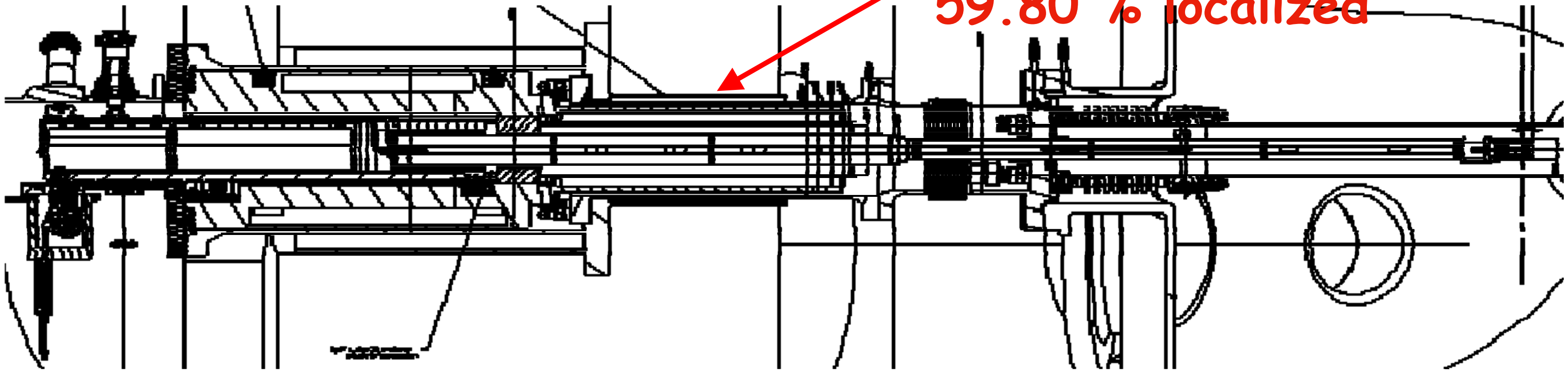
Activity Distribution (MOVAK 3D)



Beam extraction side of MAFF beam-line:

Cryopanel A (T=15 K)
40,18 % localized

Ion source



Source exchange side of MAFF beam-line:

Cryopanel B (T=15 K)
59.80 % localized

Simulations: cryopanels will localize 99.98% of volatile radioactivity

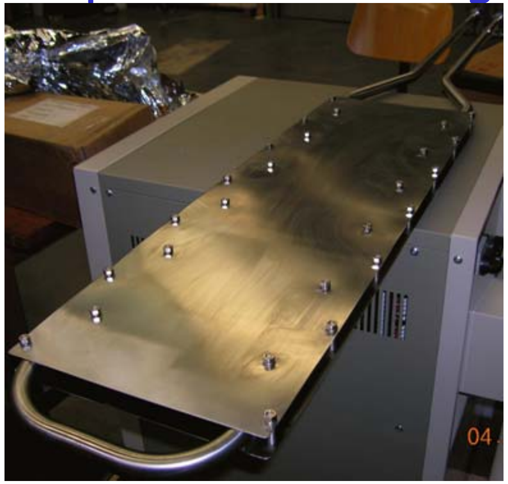
B) Containment of volatile radioactivity

Thirolf et al. (LMU)

Comparison: 2 cryotrap designs

'large' panel (GP):
- double-walled tube
- 6 spiral gas channels
- no passive shield

'small' panel (SP):
- only for comparative tests
- 1 bent tube
- 2 passive shielding paddles



- turbulent regions of gas flow with compression/expansion
  -> anisotropic temperature distribution

- unambiguous gas flow characteristics
- simple mechanical design, no weldings

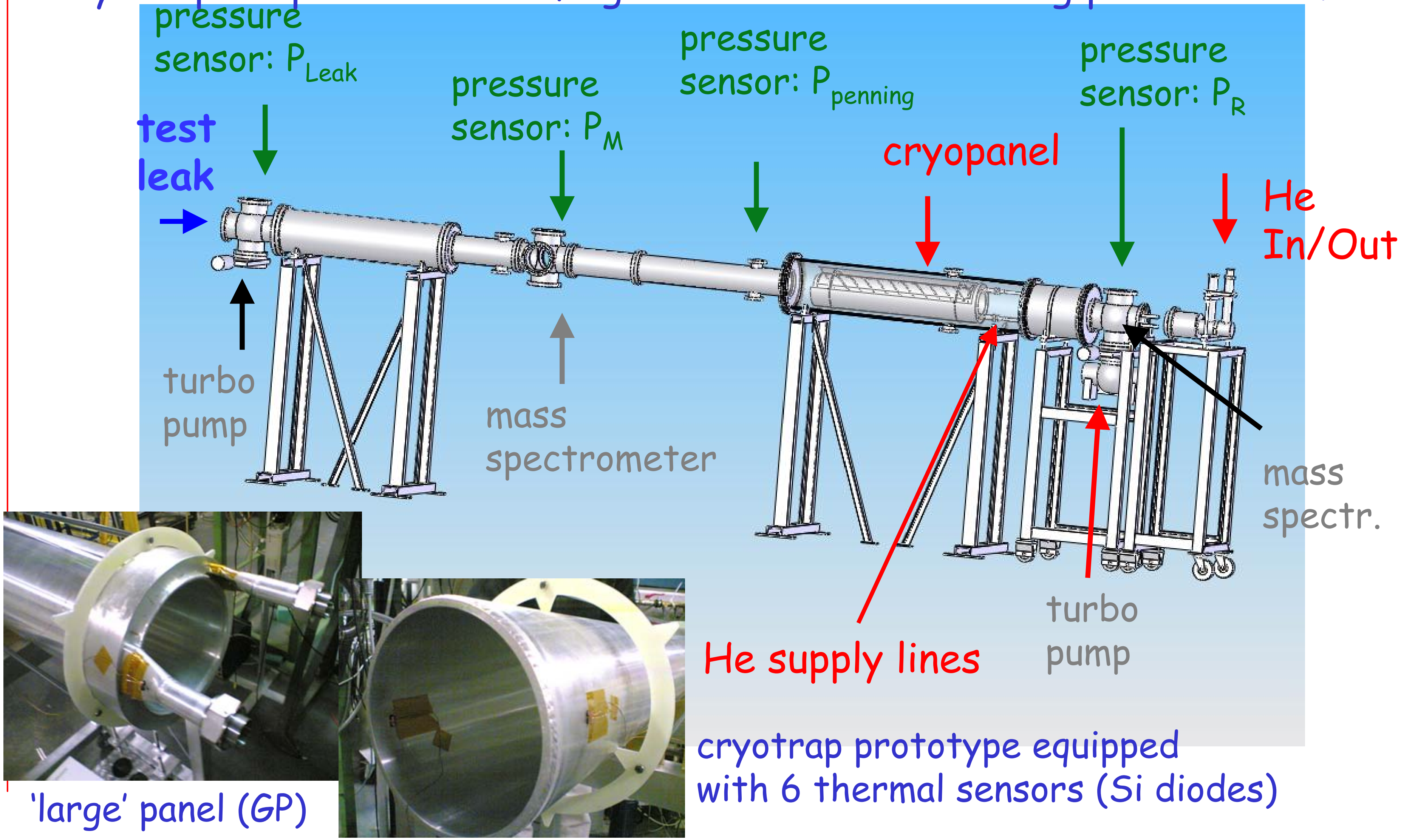
Surface ratio: A(GP)/A(SP) ~ 18 (without shield)

B) Containment of volatile radioactivity

Thirolf et al. (LMU)

Cryotrap Testbench at MLL/Garching

cryotrap coupled to lHe refrigerator: ~ 600 W cooling power at 12 K



'large' panel (GP)

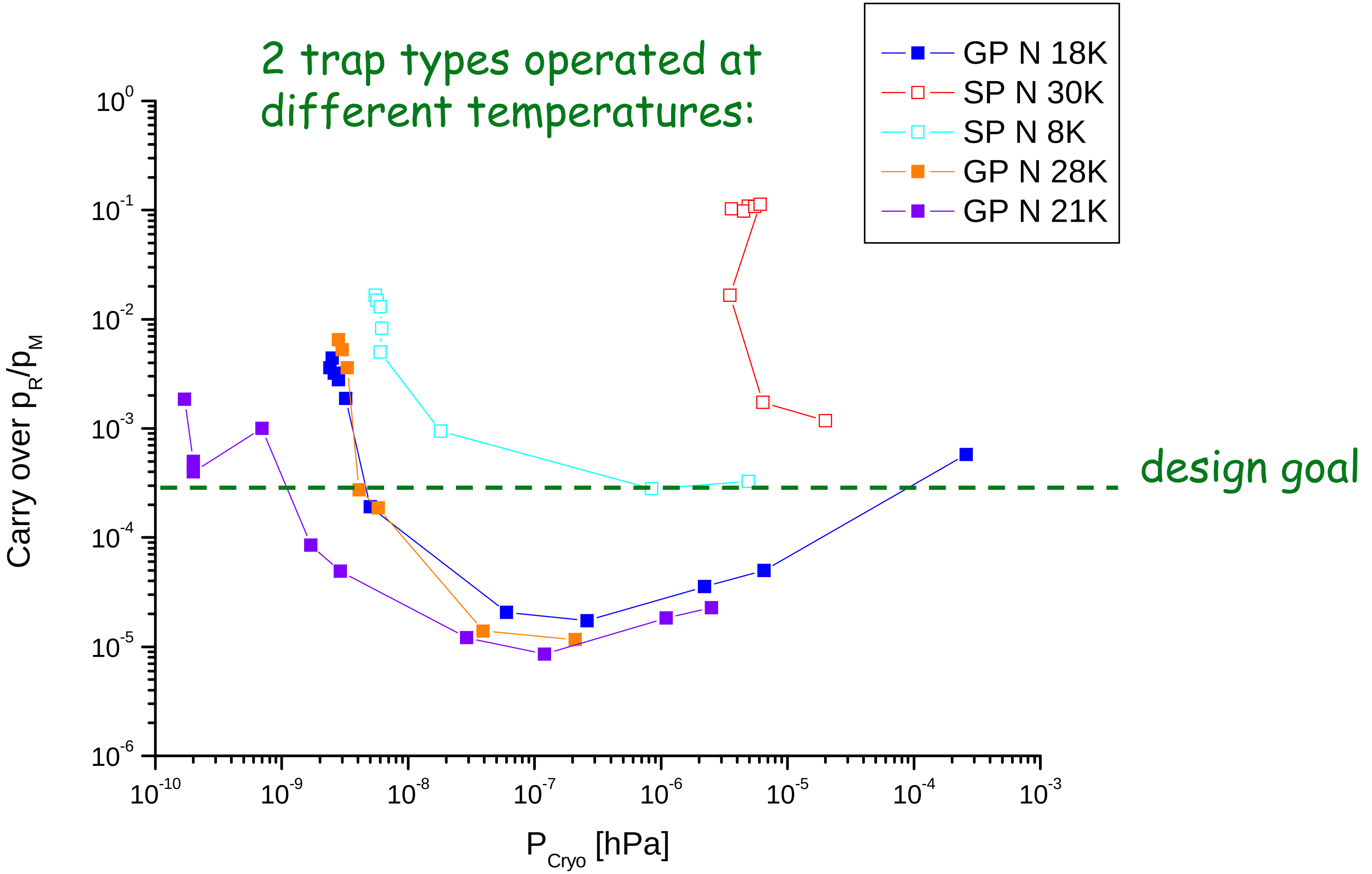
cryotrap prototype equipped with 6 thermal sensors (Si diodes)

Thirolf et al. (LMU)

Localization capability of Cryotrap

'carry over': fraction of leaking gas load transported across cryotrap

↳ retention capability (vs. pressure behind cryotrap)


2 trap types operated at different temperatures:

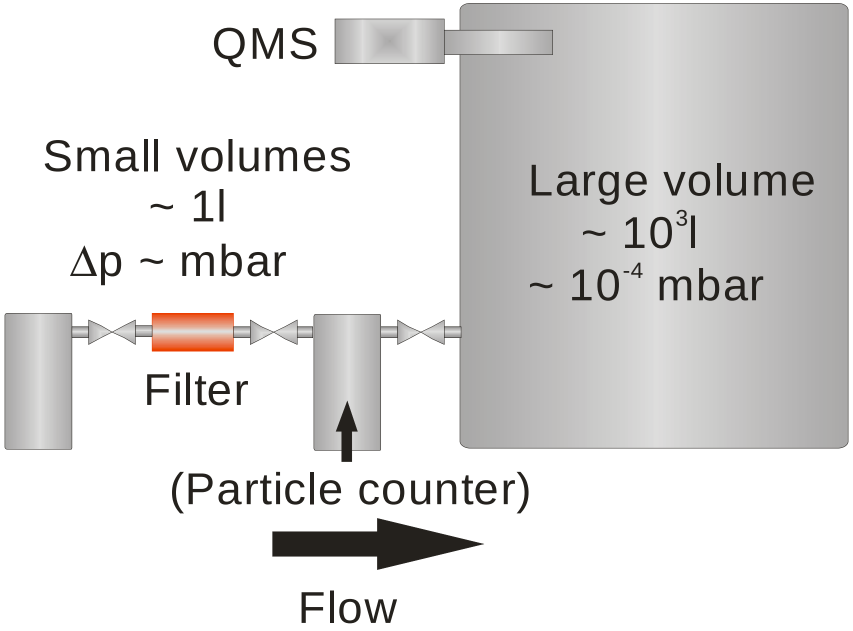
design goal

→ cryotrap works within (simulated) expectations!

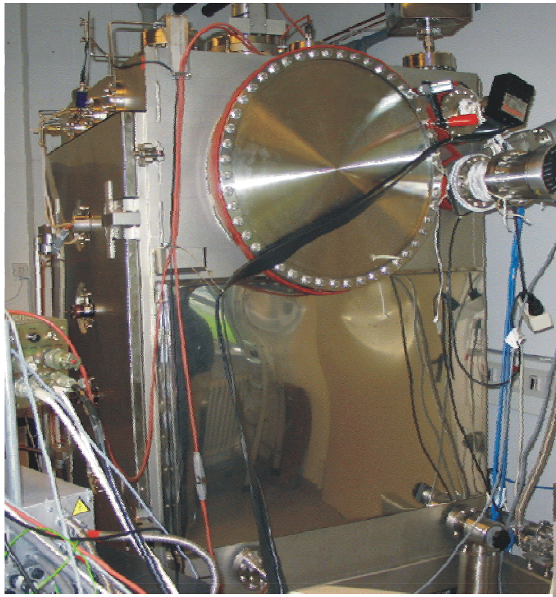
B) Gas purification system

test slow diffusion filter for aerosols (between decay tanks and release stack):

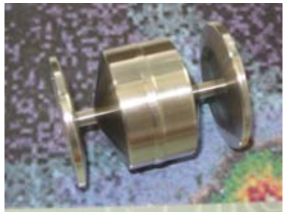
test setup:

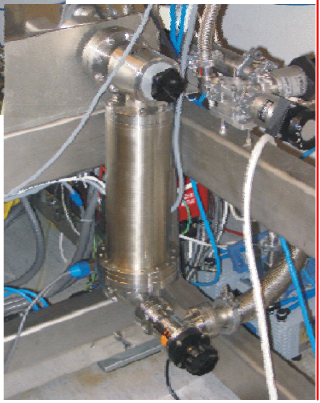


large-volume vacuum chamber (~ 2 m^3, bakeable) with QMS:



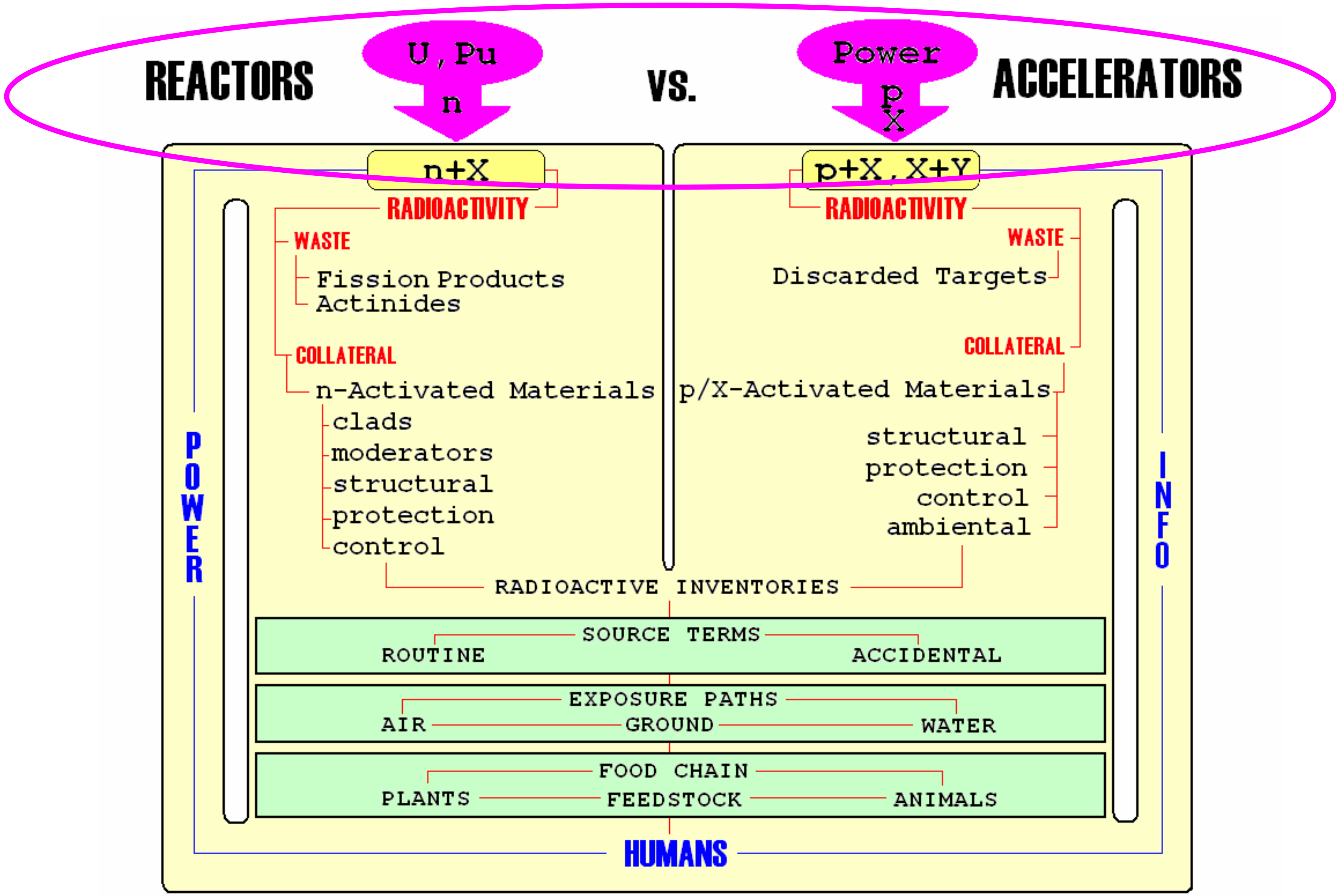
- cleanest, most efficient all-metal filter available
- sintered nickel membrane filter
- specification:
  particle retention: > 99.9999999%
  < 0.03 particles/liter larger than 0.01µm





B) Exposure evaluations

Vamanu et al. (NIPNE)



REACTORS vs. ACCELERATORS

U, Pu → n → n+X

Power → p, X → p+X, X+Y

RADIOACTIVITY

WASTE

Fission Products
Actinides

Discarded Targets

COLLATERAL

n-Activated Materials
- clads
- moderators
- structural
- protection
- control

p/X-Activated Materials
- structural
- protection
- control
- ambiental

RADIOACTIVE INVENTORIES

SOURCE TERMS: ROUTINE, ACCIDENTAL

EXPOSURE PATHS: AIR, GROUND, WATER

FOOD CHAIN: PLANTS, FEEDSTOCK, ANIMALS

HUMANS

POWER

INFO

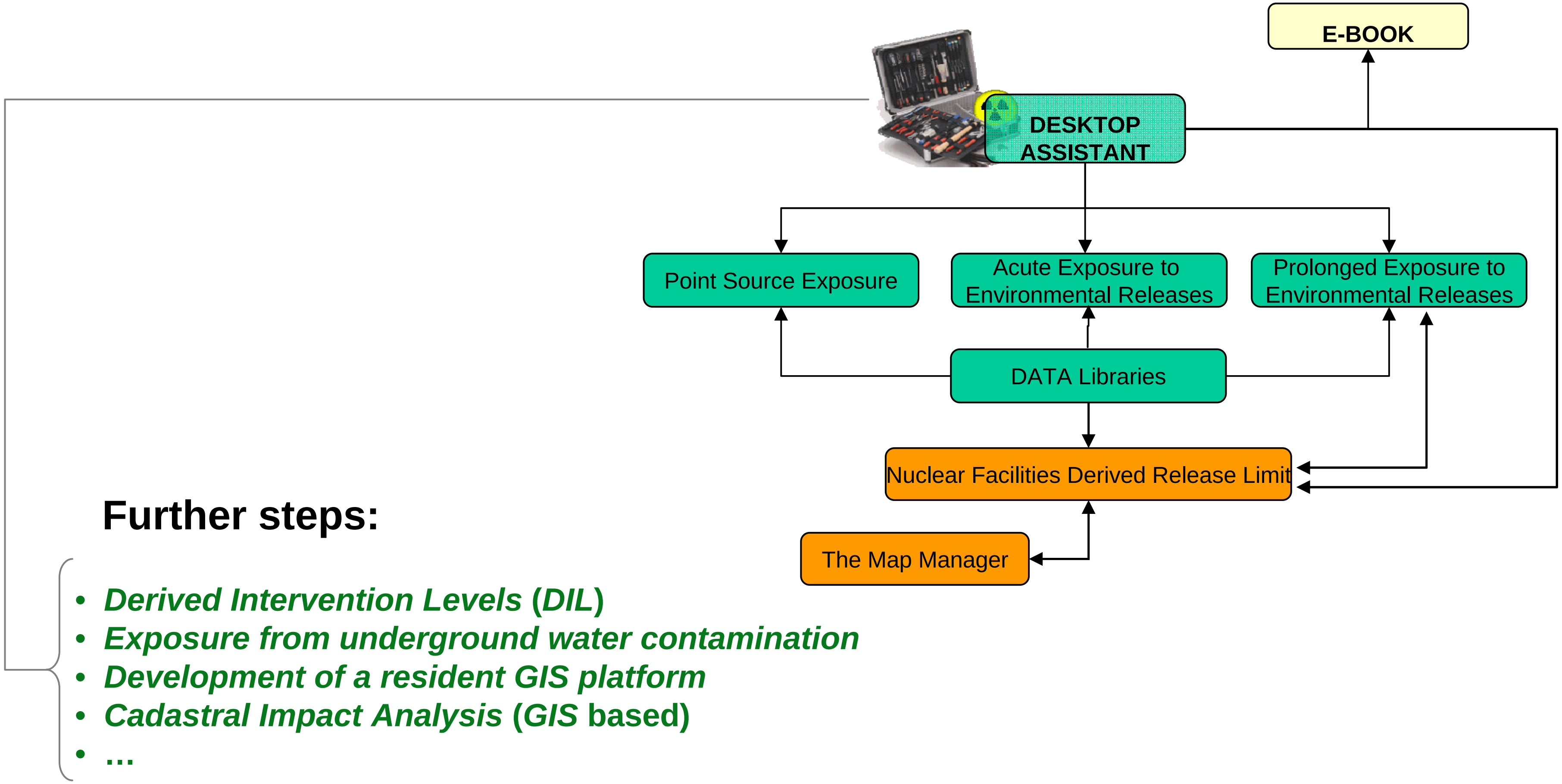
Combination of knowledge on accelerator & research reactor based nuclear installations → creation of dedicated toolkit →ADS!

B) Toolkit Creation for EURISOL: Exposure Evaluations

Vamanu et al. (NIPNE)

→ Methodology **validated**, **recommended** & **accepted** by international regulatory bodies

→**Tools**, **data** & **knowledge** to be used in *environmental and health impact*



Further steps:

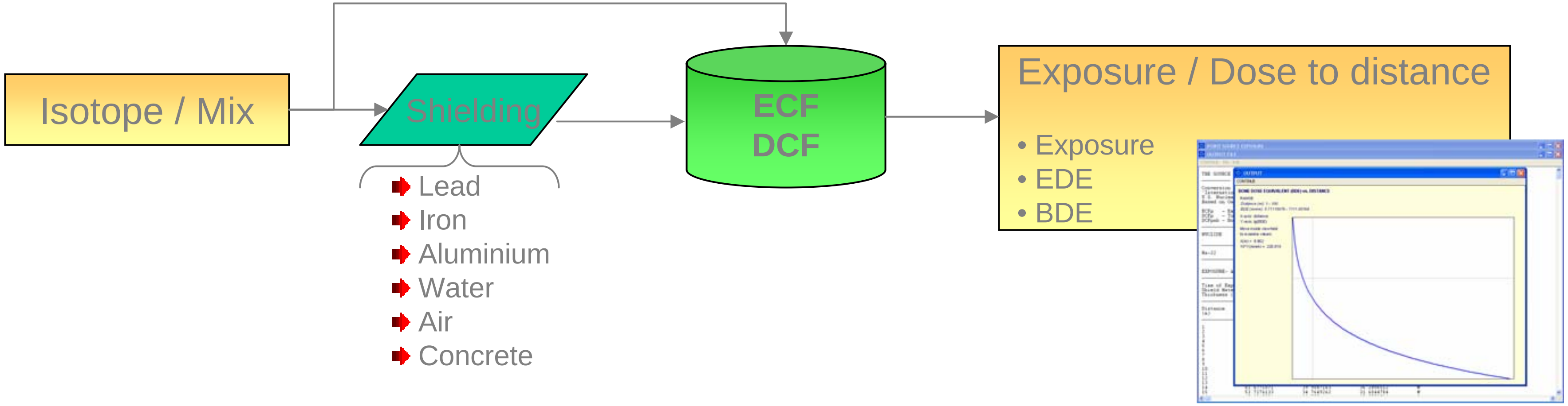
- ***Derived Intervention Levels (DIL)***
- ***Exposure from underground water contamination***
- ***Development of a resident GIS platform***
- ***Cadastral Impact Analysis (GIS based)***
- ***…***

B) Toolkit Creation for EURISOL

T5: Safety & Radioprotection

Vamanu et al. (NIPNE)

Example: Point Source Exposure



Isotope / Mix

Shielding

- Lead
- Iron
- Aluminium
- Water
- Air
- Concrete

ECF
DCF

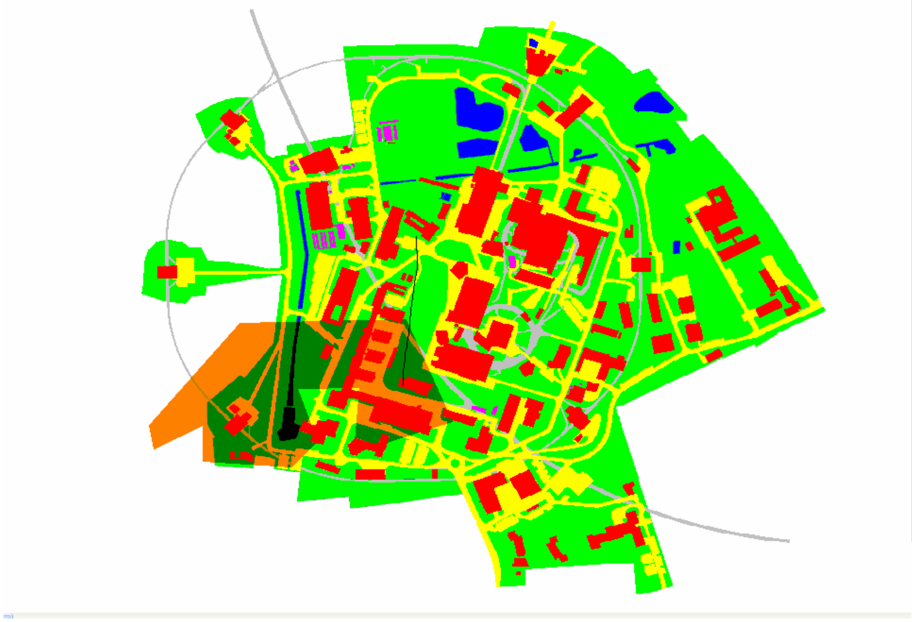
Exposure / Dose to distance

- Exposure
- EDE
- BDE

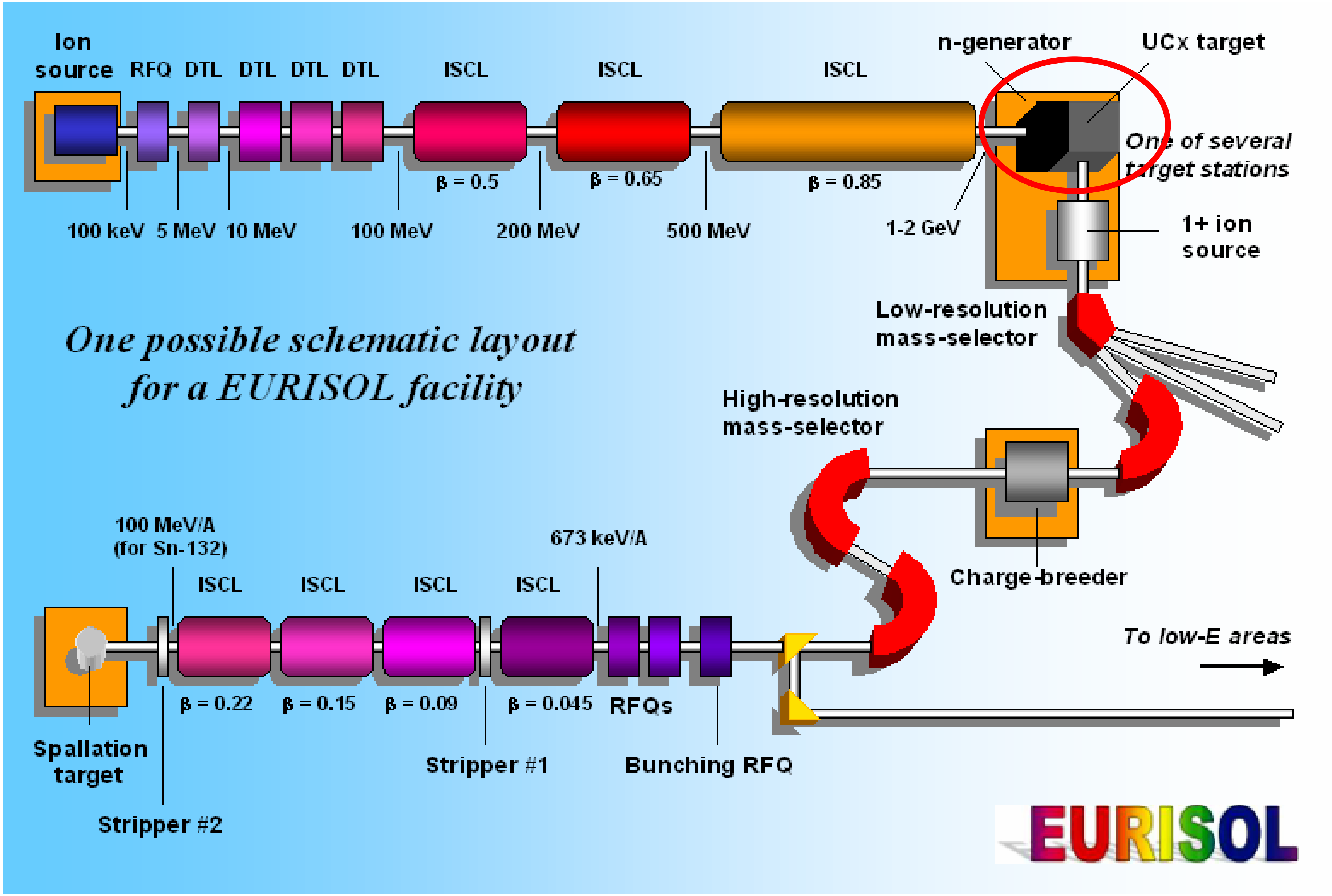
Example: Derived Release Limits

Definition of the Complex Nuclear Compound in terms of

- Emission Sources
- Receptors
- Weather conditions
- …



A) DNs in the liquid Hg loop



One possible schematic layout for a EURISOL facility

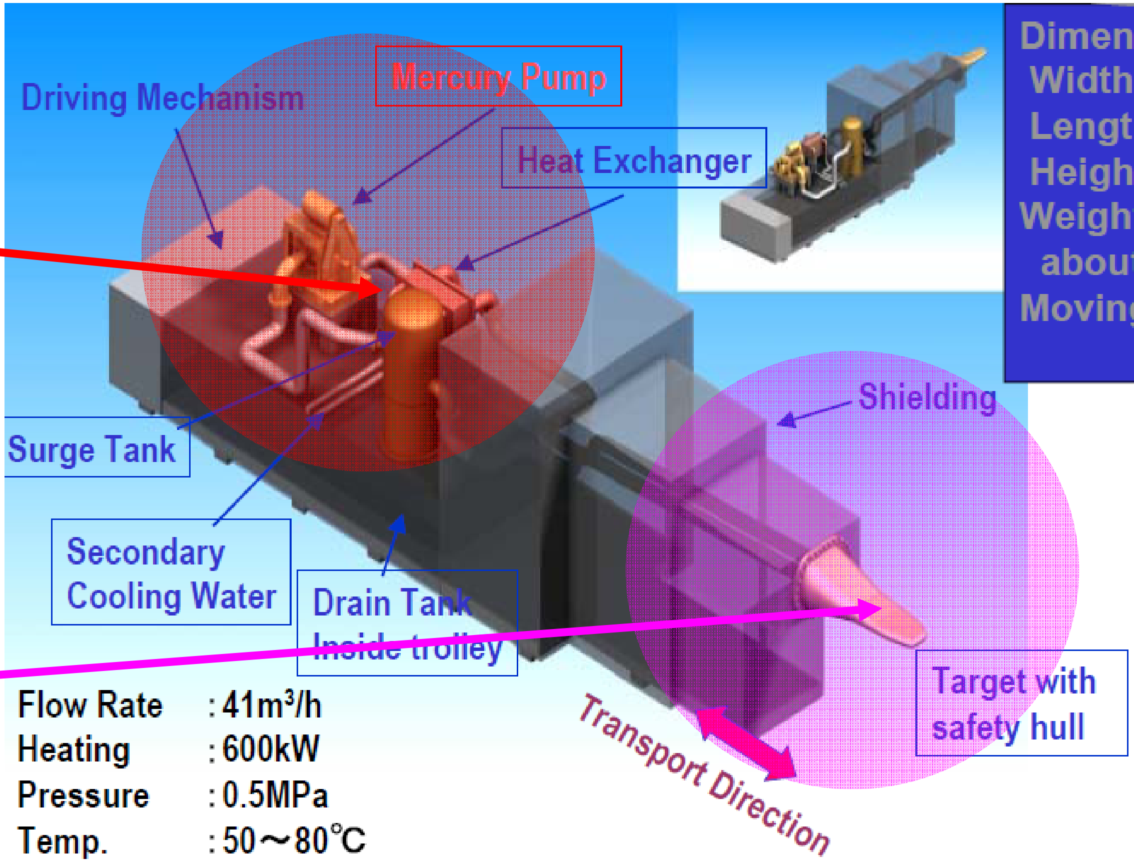
A) DNs in the liquid Hg loop

J-PARK

Dimension :
Width 2.6 m
Length 13.0 m
Height 4.0 m
Weight :
about 260 ton
Moving Distance
22 m

Delayed neutrons

Prompt neutrons

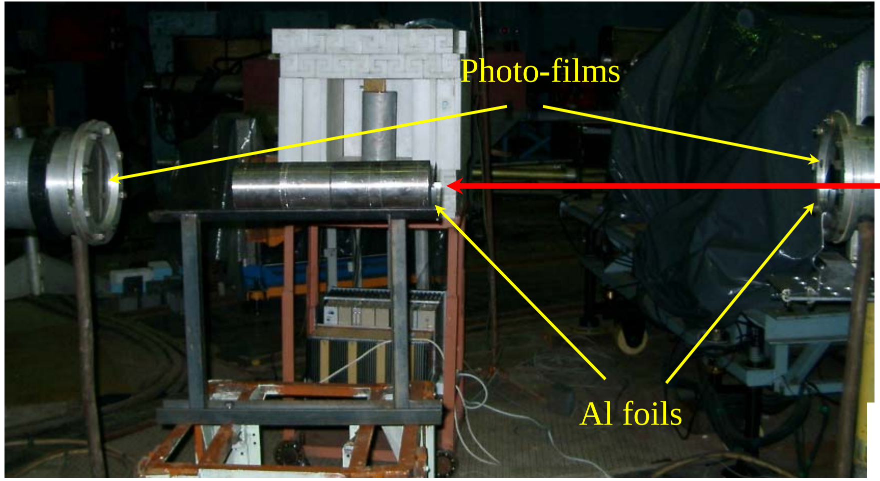


Flow Rate : $41 m^3/h$
Heating : 600kW
Pressure : 0.5MPa
Temp. : 50～80℃

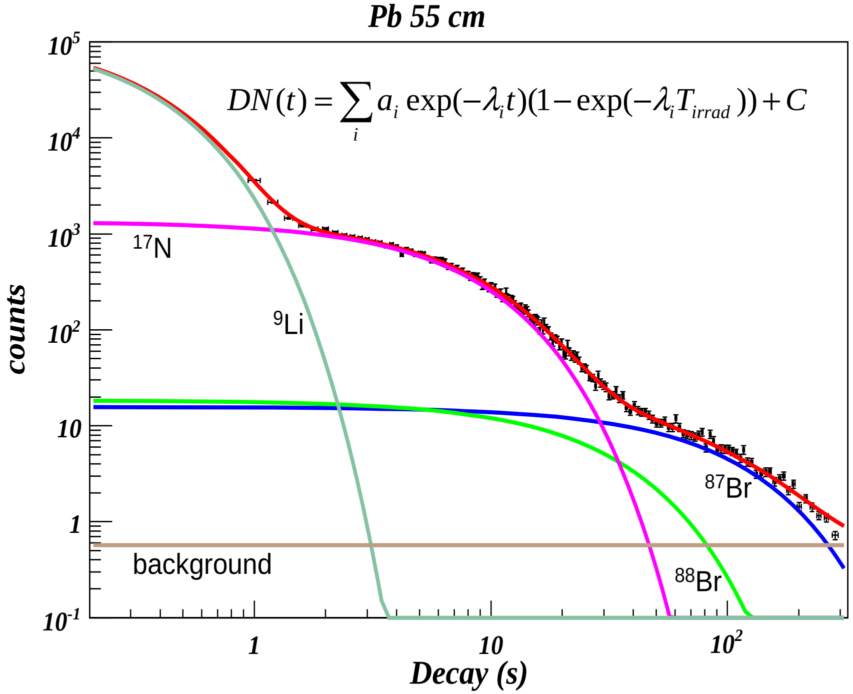
short Hg transit time →
“moving” beta, photon and delayed neutron (DN) radioactivity

A) DNs in the liquid targets

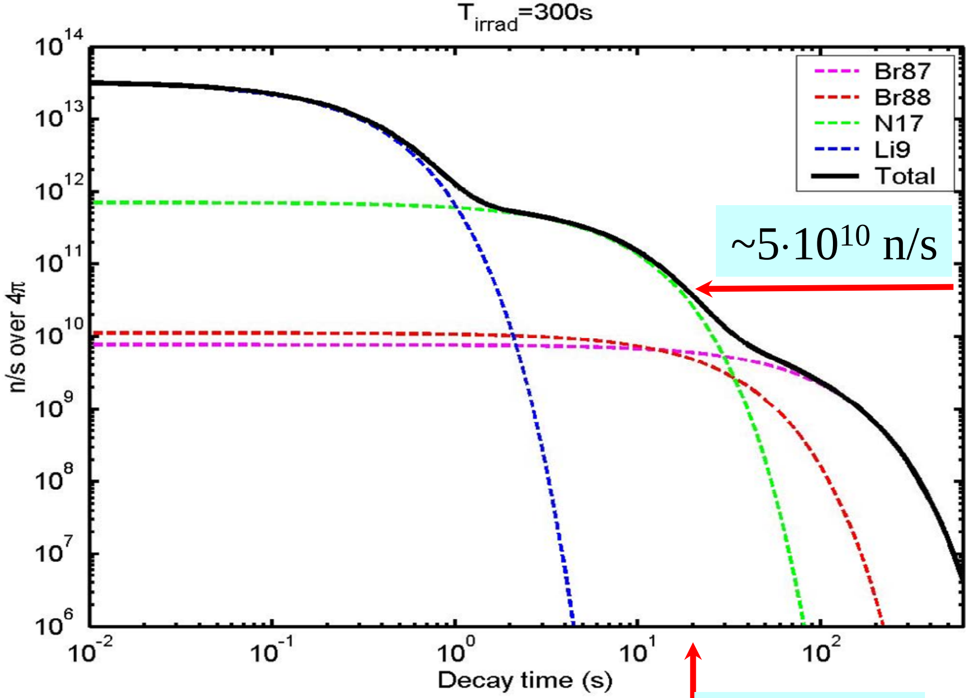
Experimental characterization of DNs from 1GeV p + Pb (55 cm); PNPI-



p(1GeV) + Pb (55 cm thick; 10 cm ∅) at 1mA (1 MW)



$$DN(t)=\sum_i a_i \exp(-\lambda_i t)(1-\exp(-\lambda_i T_{irrad}))+C$$

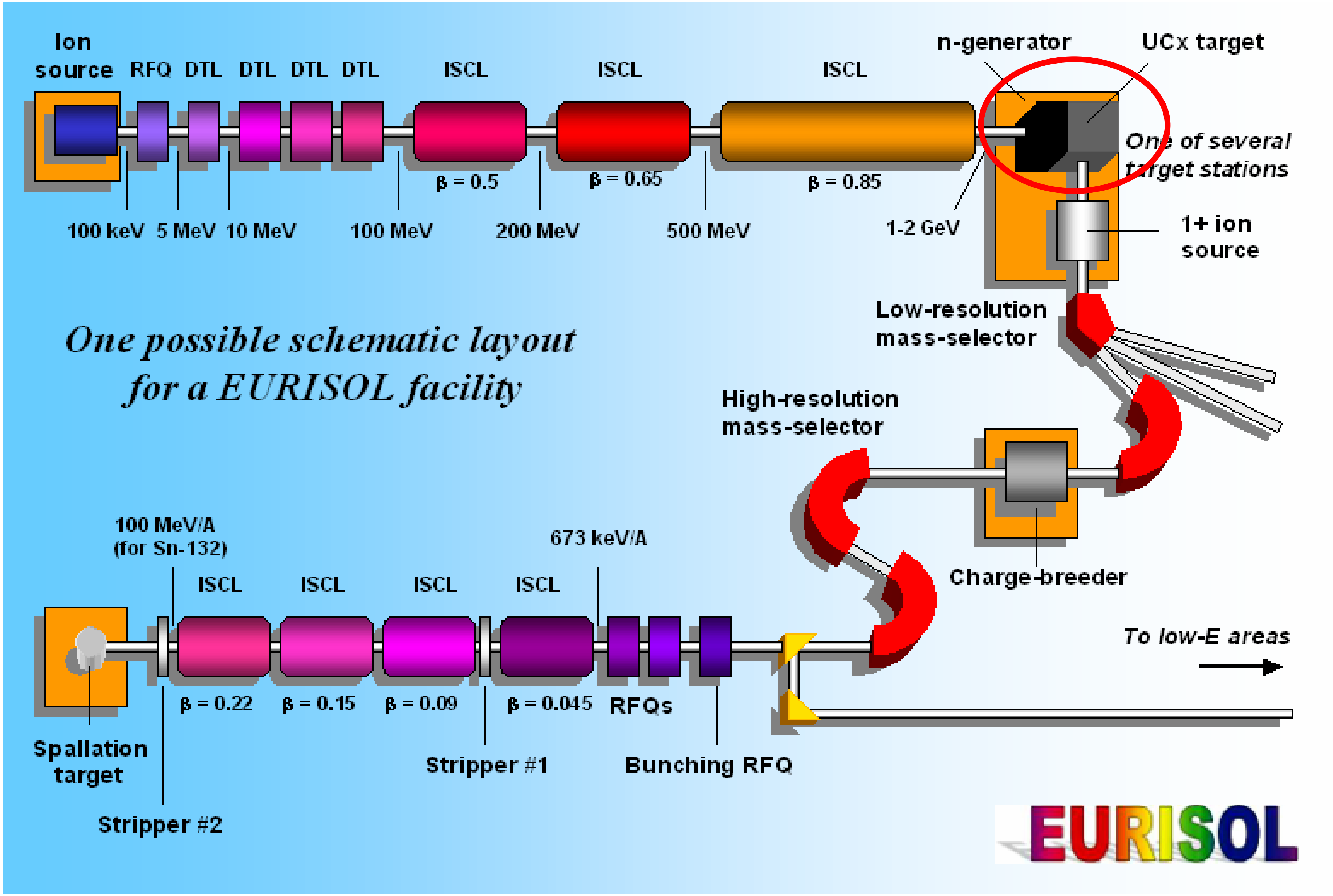


~$5 \cdot 10^{10}$ n/s

~20 s after

A. Prevost et al. (CEA)

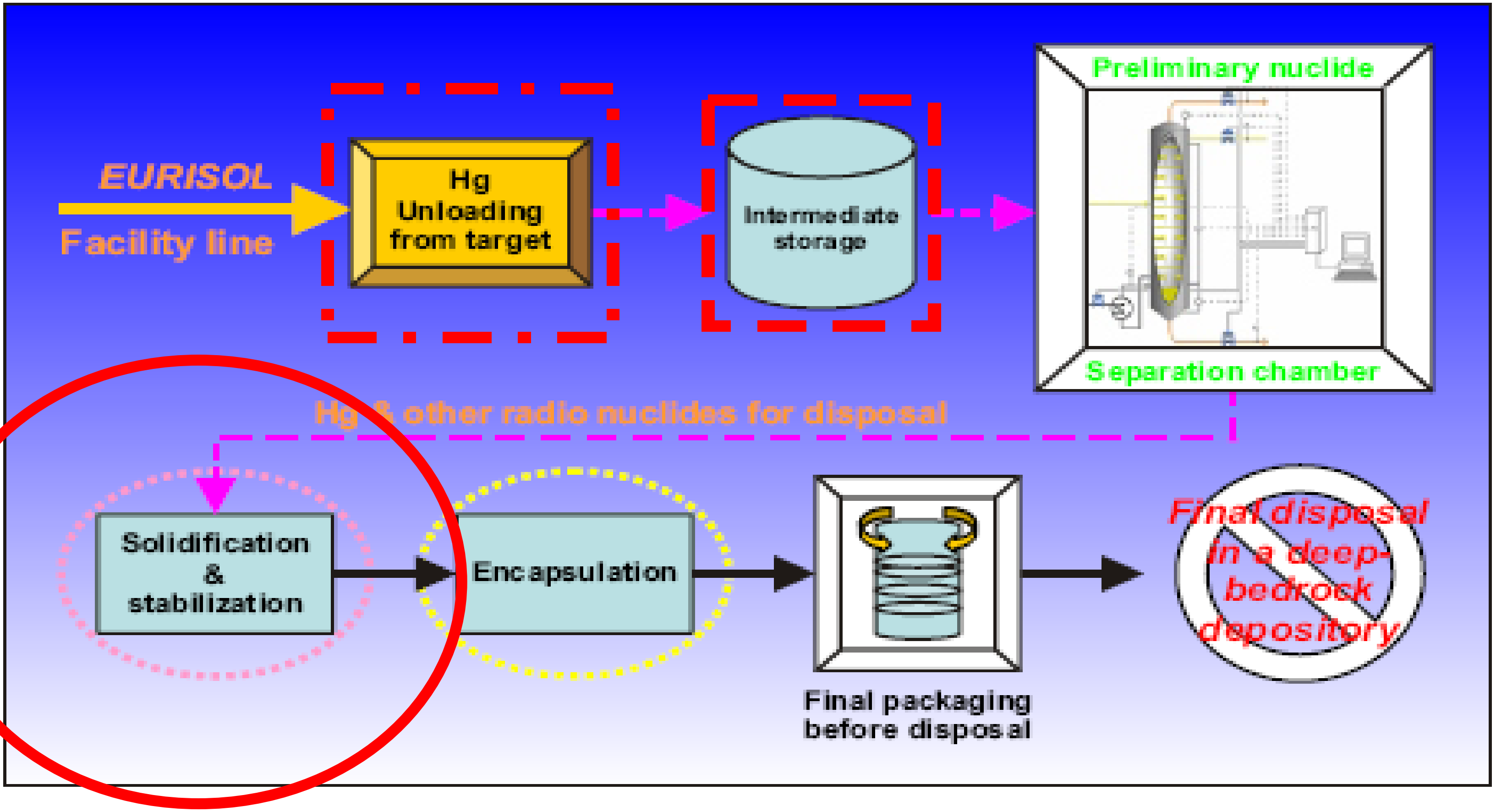
C) Disposal of liquid Hg



One possible schematic layout for a EURISOL facility

C) Disposal of liquid Hg

A schematic layout for Hg-target disposal strategy



Chiriki et al. (FZJ)

C) Disposal of liquid Hg → Solidification

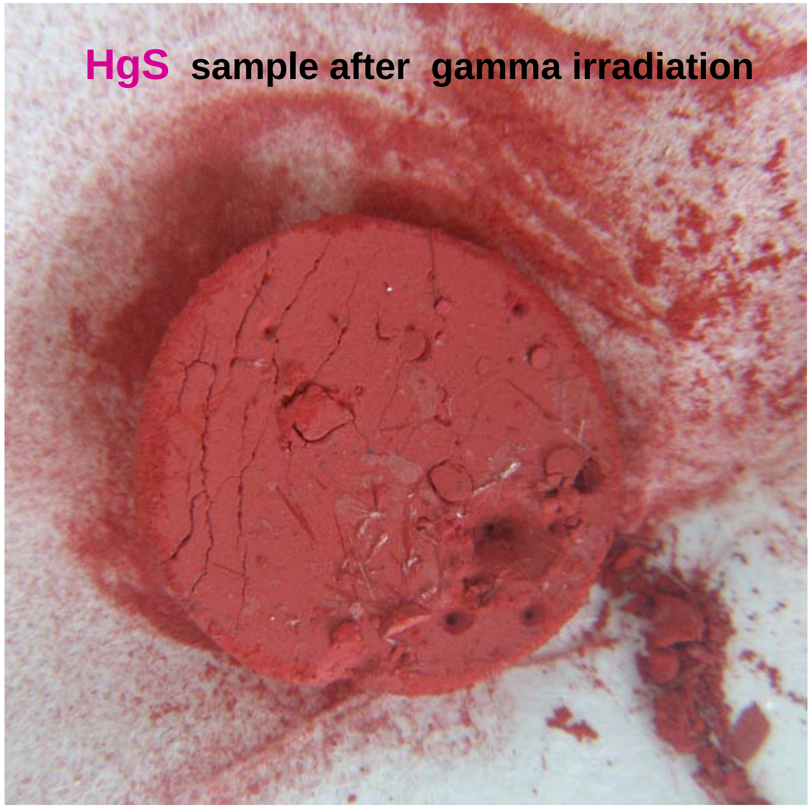
A) Chemical stabilization of Hg as an inorganic compound, e.g. HgS, HgSe, HgO, Hg_2Cl_2, $HgCl_2$

B) Stabilization by dissolution in metals called amalgamation, e.g. Cu, Zn, Sn, Ag, dental amalgam, Alloy powders

- ✓ **HgS is highly insoluble in water, stable solid, and dominating mercury mineral in nature**

- ✓ **HgS is a powder and instead of a paste as amalgams, thus making it is an easier process**
- ✓ **HgS has very high loading compared to transition metal amalgams (Zn amalgam was studied)**
- ✓ **Formation process is a single step reaction**

- ✓ **Elemental sulfur is relatively cheap, and enough process options are available with sulfur**


HgS sample after gamma irradiation

Chiriki et al. (FZJ)

Optimistic Summary

Work is in progress but
we are only at the end of the beginning!

Thanks to all participants!

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