Synergies of Targetry Experiment with Other Programs

H. Haseroth, CERN

with thanks to A. Fabich, Y. Kadi, J. Lettry, M. Lindroos, etc.

Proposal to Isolde and nToF Committee

CERN-INTC-2003-033
INTC-I-049
26 April 2004

A Proposal to
the ISOLDE and Neutron Time-of-Flight Experiments
Committee

Studies of a Target System for a 4-MW, 24-GeV Proton Beam

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Spokespersons: H.G. Kirk, K.T. McDonald
Local Contact: H. Haseroth

Participating Institutions

1) RAL
2) CERN
3) KEK
4) BNL
5) ORNL
6) Princeton University

Proposal submitted April 26, 2004

MINUTES (not yet approved 7/Feb./05) OF THE 170th MEETING OF THE RESEARCH BOARD HELD ON THURSDAY, 2 DECEMBER 2004

1.4

Approval of the proposal **P186** to the INTC, concerning studies of a target system for a 4-MW, 24-GeV proton beam, had been deferred from the last meeting so that further information could be provided on the support for the proposed test from the relevant scientific community, on the safety issues, and on the resources required from CERN. Along with memoranda concerning the resources [3] and safety [4], letters of support had been received, and the response was considered satisfactory. However, concerning resources, while it is stated that those requested from CERN are confined to providing the proton beam, the details of what this will involve in terms of associated costs for cooling and manpower have not been fully explored. In addition, it was considered that a contact person should be available at CERN for the duration of the experiment. **The proposal was approved by the Research Board, subject to further clarification of the resources required from CERN and the CERN contact person, to be followed up by S. Myers. The experiment will have reference number nTOF11.**

A Basic Concept for a Neutrino Factory

⇒Proton driver

⇒High-power proton beam onto a target

⇒System for collection of the produced pions and their decay products, the muons.

You may stop here for a Superbeam

⇒Energy spread and transverse emittance may have to be reduced: "phase rotation" and ionisation cooling

⇒(Fast) acceleration of the muon beam with a linac and "RLAs" (Recirculating Linear Accelerators) or FFAGs (?)

⇒Muons are injected into a storage ring (decay ring), where they decay in long straight sections in order to deliver the desired neutrino beams.

but other people are interested in high power targets too…

Synergies
Activities within CERN AB-ATB

ISOLDE molten metal target (Pb, La, Sn).

Carlo Rubbia's energy amplifier consisting of a spallation source cooled via convection of molten lead.

The three targetry work packages of the EURISOL-DS EU-project are financed by 2.6 M€, two of them convened by AB-ATB-staff.

The multi MW spallation n-source dedicated to the fission of 238U is based on a mercury loop of similar technology.

In addition, future targets for the production of secondaries using the SPL could benefit from such expertise.

SNS

The Hg loop specialists of the SNS are involved in the design of the experimental setup and are expected to contribute to the multi MW n-converter task of the EURISOL DS lead by Y. Kadi (CERN/AB) with contributions from PSI and IPUL Latvia.

GSI

One of the preliminary options mentioned for GSI's FAIR target that has to intercept at 1Hz 50 ns long bunches of 10^{12} fully stripped ^{238}U. Liquid jet targets are under investigation.

Let me concentrate on:

EURISOL / Isotope production

and

ADS (Energy amplifier etc.)

EUROPEAN COMMISSION CONTRACT No. HPRI-CT-1999-50001

THE EURISOL REPORT

A FEASIBILITY STUDY FOR A EUROPEAN ISOTOPE-SEPARATION-ON-LINE RADIOACTIVE ION BEAM FACILITY

December 2003

A FEASIBILITY STUDY FOR A
EUROPEAN ISOTOPE-SEPARATION-
ON-LINE
RADIOACTIVE ION BEAM FACILITY

7.3.2 Research facilities offering possibilities for synergy with EURISOL

From the beginning of the EURISOL project, it was obvious that the driver accelerator was the principal component presenting potential links to other research facilities. Indeed, the design of high-intensity proton accelerators with energies in the GeV region is of great current interest for the following projects:

• **Neutrino (and muon) factories.** The CERN community is studying such a facility based on a pulsed linac of 4-MW average power, called SPL.

- **Accelerator-driven hybrid reactor systems (ADS)**

This concept is proposed in Europe, in the USA and in Japan for nuclear waste incineration. The 'European Roadmap' prepared by the Technical Working Group (TWG) quotes the 10-MW level for the demonstration facility, and the 50-MW level for the industrial extrapolation for the accelerator running in CW mode. A preliminary design study for a demonstration facility, funded by the European Commission is presently under way.

- **Spallation neutron sources**

for material science, presently under construction in the USA (SNS) and in Japan, or planned in Europe (ESS). These projects use multi-MW linac accelerators in pulsed mode.

- **Technological irradiation tools**

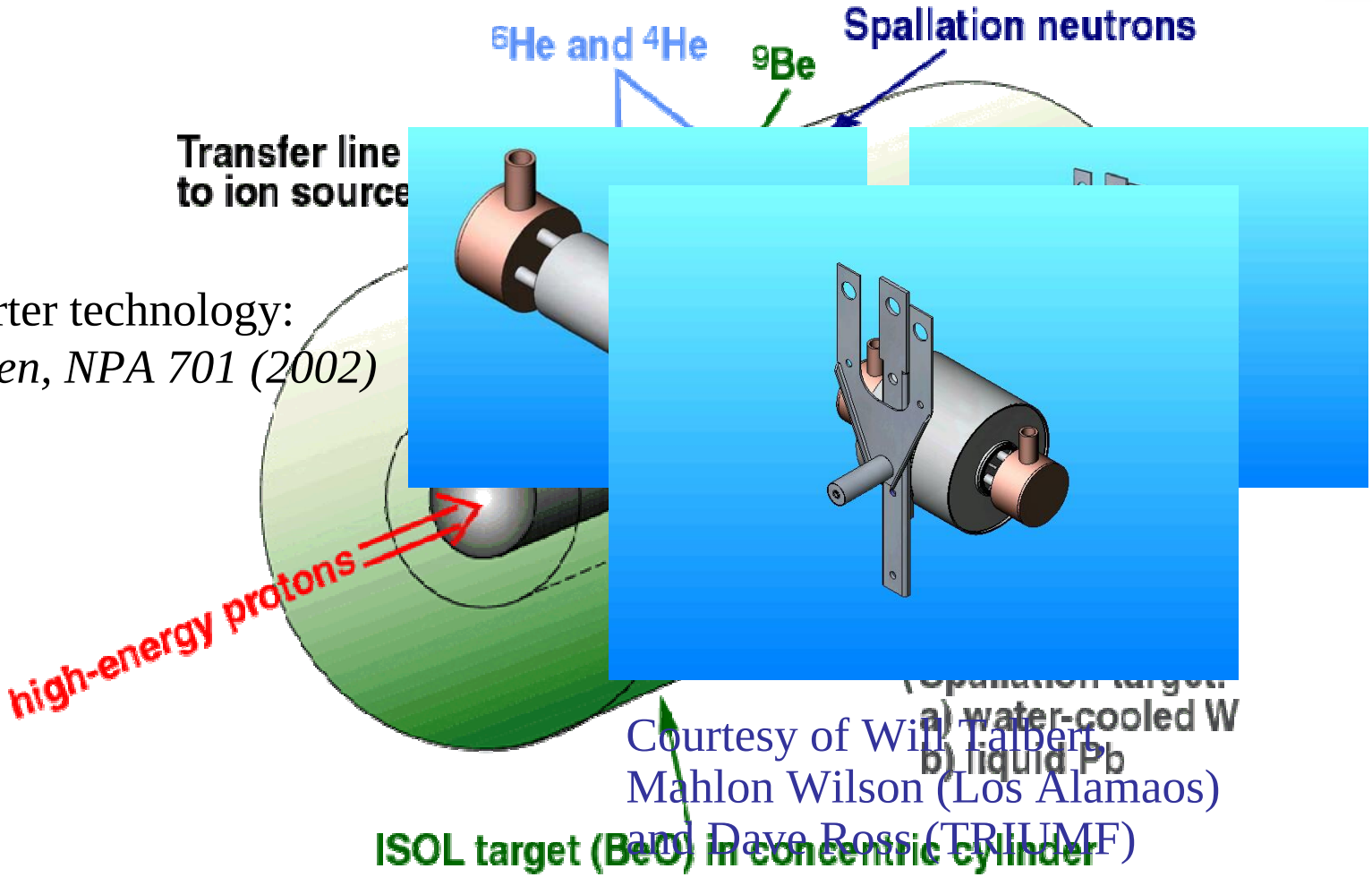
for the development of new radiation-resistant materials. These need neutron sources able to provide fluxes of some 10^{15} n/cm^2 s, corresponding to proton beam powers of the order of 10 MW.

General Synergies

- Eurisol Hg loop
- Shocks are relevant issue for all pulsed targets (Isolde, GSI, Hydrodynamics codes…)
- codes to simulate secondary particle flux: FLUKA, MARS
- Rubbia's team on accelerator driven systems

^{6}He production by ^{9}Be(n,α)

Converter technology:
(*J. Nolen, NPA 701 (2002) 312c)*

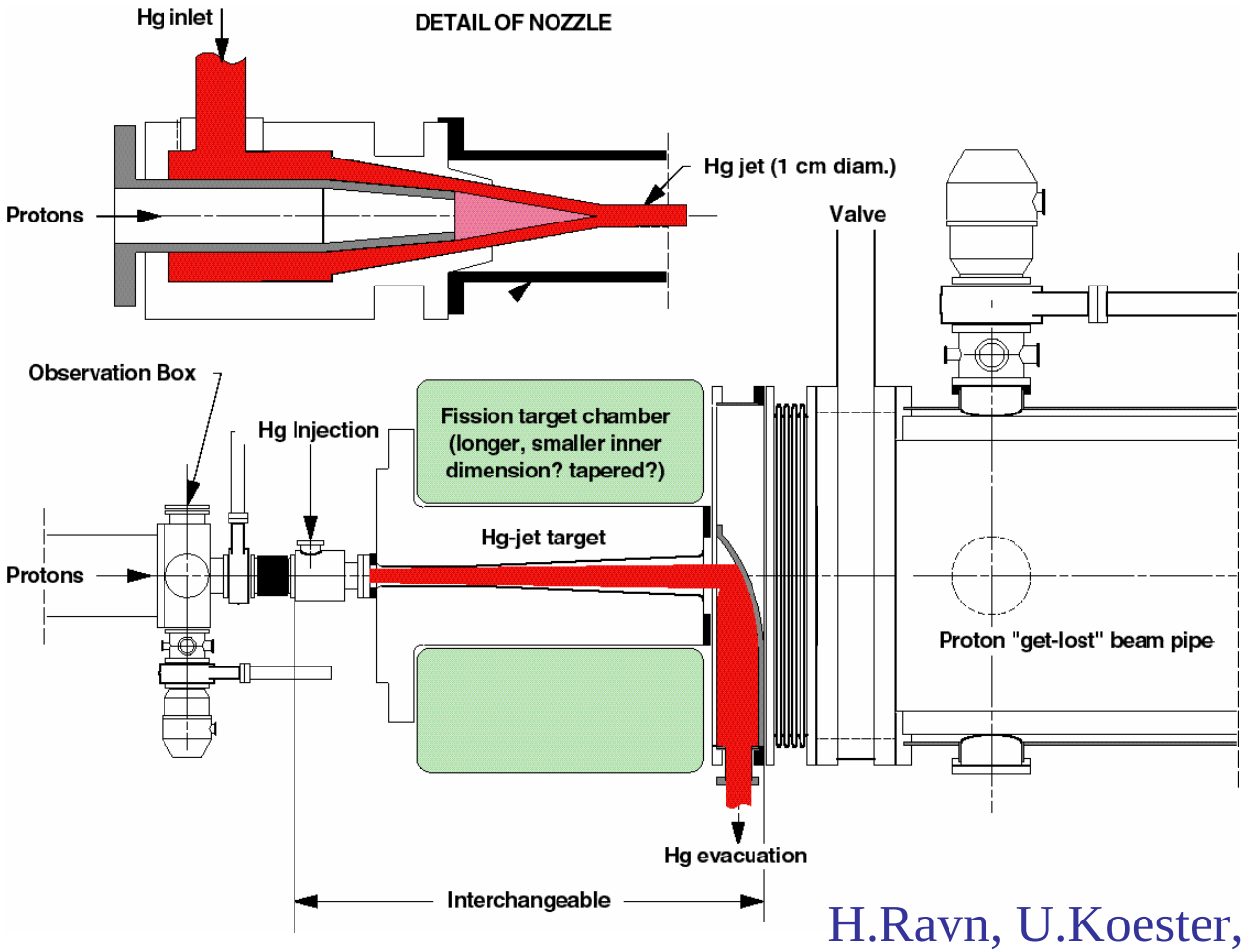


Courtesy of Will Talbert,
Mahlon Wilson (Los Alamaos)
and Dave Ross (TRIUMF)

Layout very similar to planned EURISOL converter target aiming for 10^{15} fissions per s.

Mats Lindroos

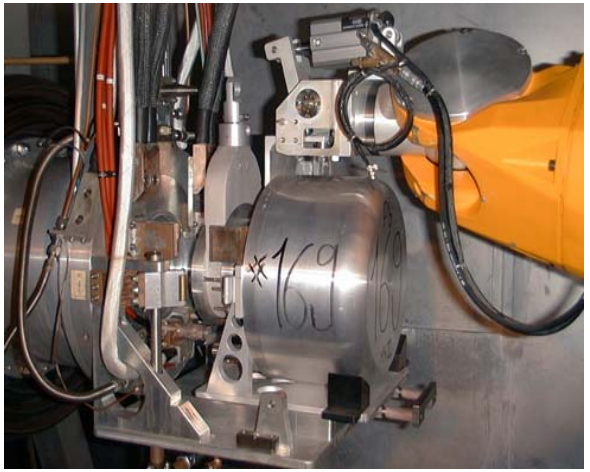
Mercury jet converter



Mats Lindroos

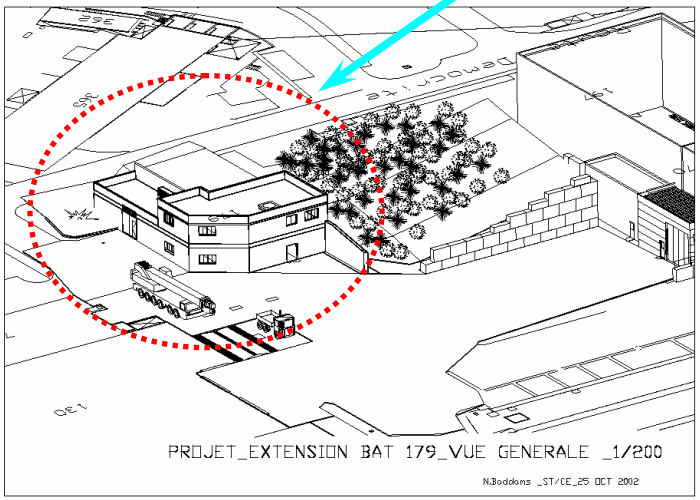
H.Ravn, U.Koester, J.Lettry, S.Gardoni, A.Fabich

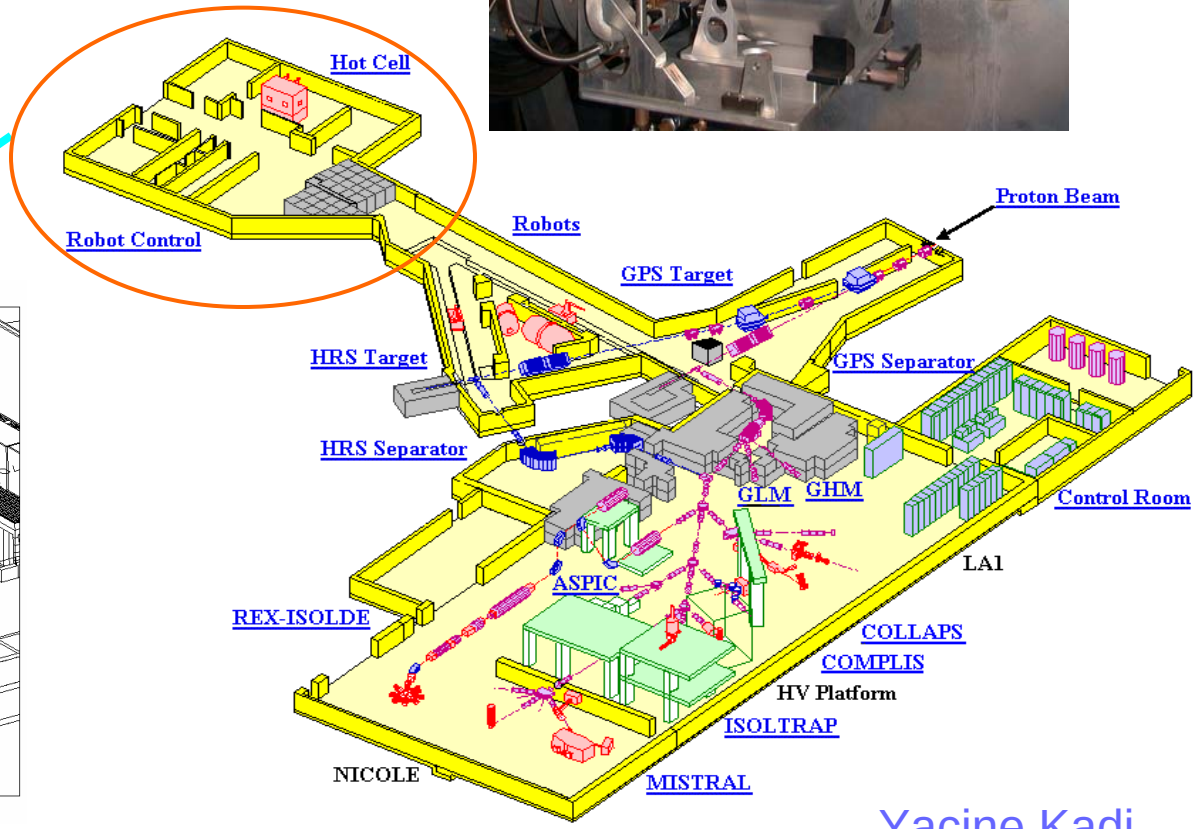
ISOLDE target handling



Class A laboratory (2004)

$\Sigma_{Isotopes}$ (*Activity/LA*) > 10’000





Yacine Kadi

EUROPEAN COMMISSION CONTRACT No. HPRI-CT-1999-50001

APPENDIX C

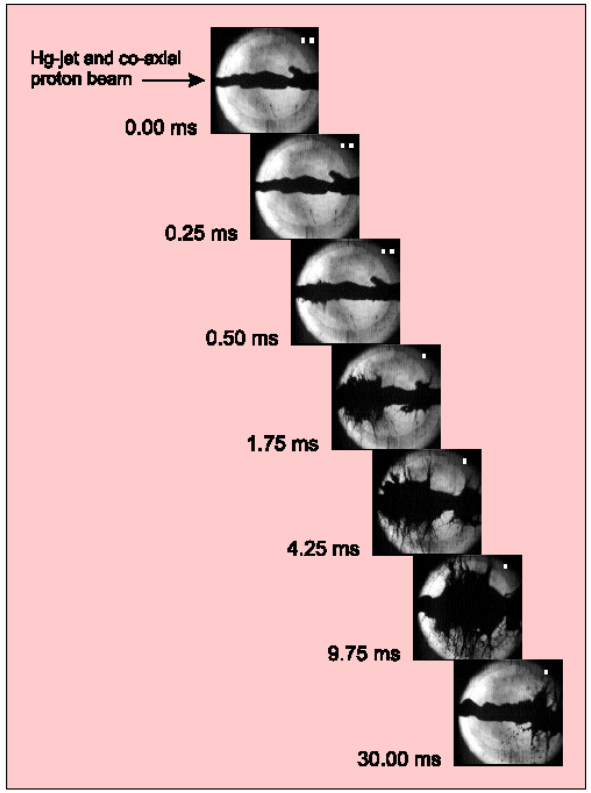
Targets and Ion Sources for EURISOL

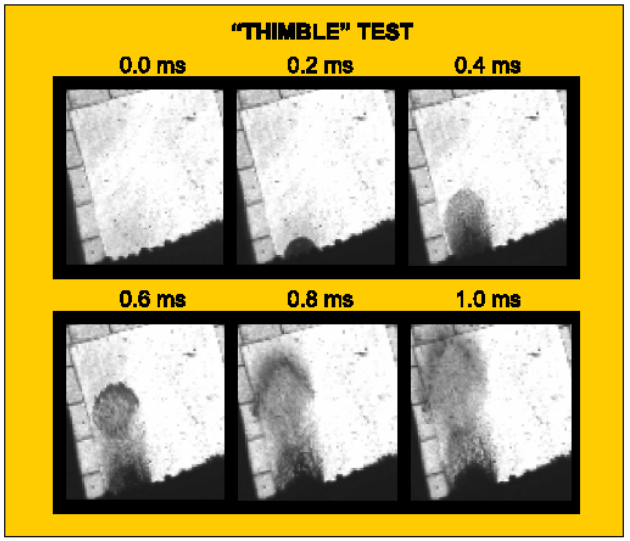
REPORT OF THE

TARGET & ION SOURCE TASK GROUP

December 2003

3.3.2 Recent R&D work on the Hg-jet





In conclusion the BNL-CERN thimble and jet test at 1/100 of the ultimate power density and 1/10 of the needed jet speed revealed no 'show-stopper' for the Hg-target concept.

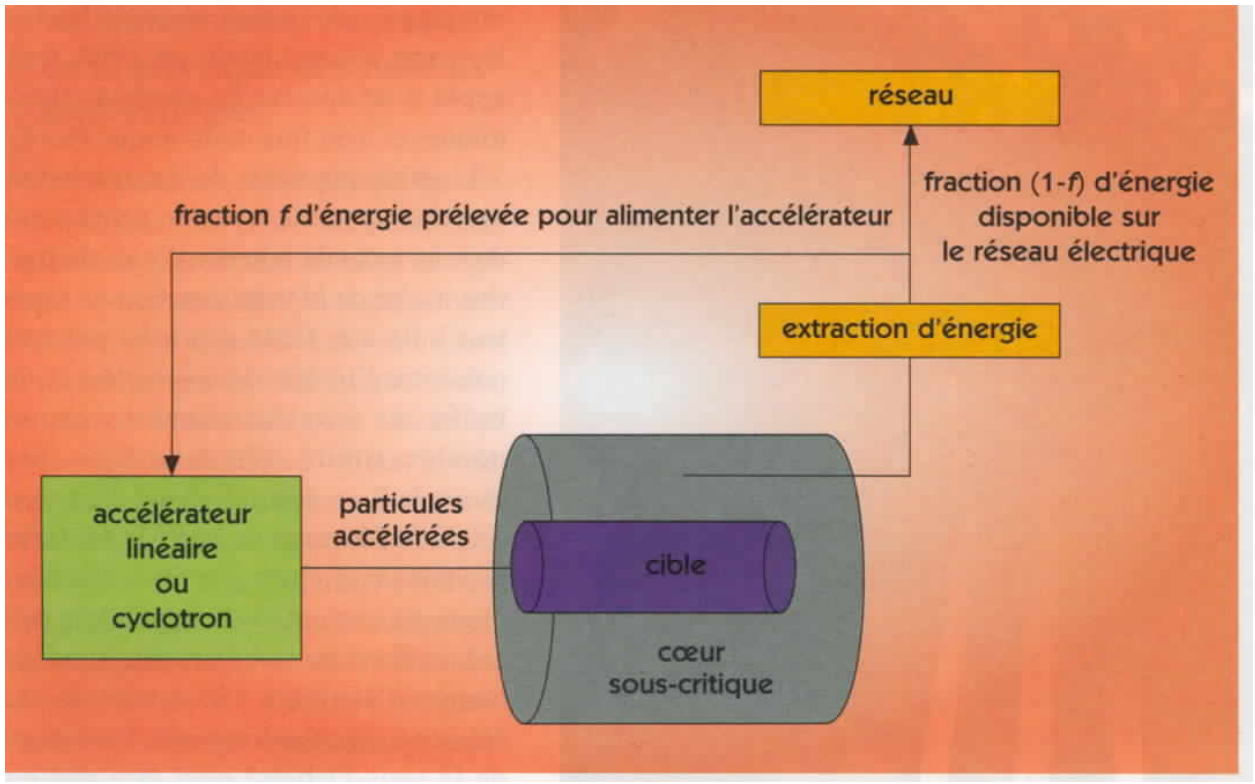
Table 8.1: Estimated production rates at EURISOL for a number of interesting nuclides which could be retrieved from the Hg-target.

Radio-isotope	Half-life $T_{1/2}$	X-section σ (mb)‡	Production rate§ (per s)	Alternative production processes		Applications
192-Ir	74 d	2.58E+00	**1.0E+14**	(n,γ)	reactor	Sealed sources for industry and cancer therapy
188-W/Re	69 d	6.90E-02	**2.7E+12**	(2n,γ)	HFR**	Radio-immuno-therapy with 188-Re
178-W/Ta	22 d	8.08E+00	**3.1E+14**	(p,4n)	accelerator	Generator with potential in PET†
177-Lu	6.7 d	6.31E-02	**2.4E+12**	(n,γ)	reactor	Therapy with labelled antibodies and peptides
166-Ho	25.8 h	5.30E-03	**2.0E+11**	(n,γ)	reactor	Therapy with labelled antibodies and peptides
149-Tb	4.12 h	9.21E-01	**3.5E+13**			Targeted Alpha Therapy, single cancer cell targeting
148-Gd	74.6a	5.31E-01	**2.1E+13**	spallation	accelerator	Low-energy alpha sources
153-Sm	46.75 h	1.41E-03	**0.6E+11**	(n,γ)	reactor	Therapy of bone metastases
127-Xe	76.4 d	9.22E-02	**3.5E+12**	(p,x...)	accelerator	SPECT*, lung ventilation and brain perfusion
117m-Sn	13.6 d	1.78E-01	**0.7E+13**	(n,γ)	HFR	Systemic radionuclide therapy
99-Mo/99m-Tc	66 h	2.78E-01	**0.6E+13**	(n,f)	reactor	Most important radionuclide for nuclear medical imaging
89-Sr	50.5 d	5.39E-01	**2.1E+13**	(n,γ), (n,p)	reactor	Palliative therapy of bone metastases
82-Sr/Rb	25.5 d	1.36E-01	**0.5E+13**	(p,4n)	accelerator	Generator, PET, myocardial perfusion
68-Ge/Ga	288 d	9.38E-02	**3.6E+12**	(p,2n), spall.	accelerator	Different PET imaging procedures, calibration of PET
67-Cu	61.9 h	3.83E-01	**1.5E+13**	(p,α)	accelerator	Therapy with labelled antibodies and peptides
44-Ti/Sc	47.3 y	1.77E-03	**0.7E+11**	spallation	accelerator	Generator, great potential for PET
32-Si	101 y	3.03E-02	**1.2E+12**			Important isotope for R&D and technical application
26-Al	7.16e5 y	6.05E-03	**2.3E+11**	(p,n)	cyclotron	Important isotope for R&D and technical application
28-Mg	20.9 h	1.45E-02	**0.6E+12**			Important isotope for R&D

ADS (Energy amplifier etc.)

Sub-Critical Systems (1)

- In Accelerator-Driven Systems a *Sub-Critical blanket* surrounding the spallation target is *used to multiply the spallation neutrons*.



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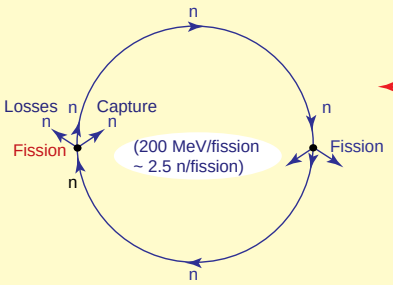
Sub-Critical Systems

Chain Reaction



Critical Reactor ← → **Energy Amplifier**

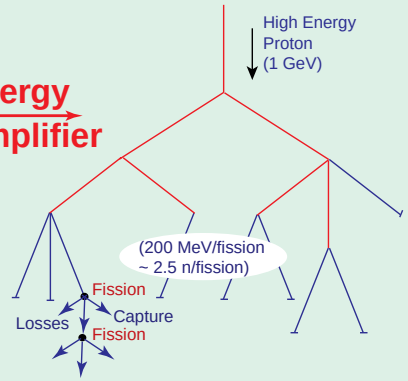
Effective neutron multiplication factor

$$k = \frac{\text{Production}}{\text{Absorption + Losses}}$$

Self-sustained process:
k = 1
(if k < 1 the Reactor stops
if k > 1 the Reactor is supercritical)

⇒ The time derivative of the power kept equal to zero by control

Nuclear Cascade



Externally driven process:
k < 1 (k = 0.98)

$$E_{tot} = G \times E_p$$

Energy Produced — Beam Energy

⇒ Constant Energy Gain

☆ ADS operates in a non self-sustained chain reaction mode
- ⇧ minimises criticality and power excursions

🕐 ADS is operated in a sub-critical mode
- ⇧ stays sub-critical whether accelerator is on or off
- ⇧ extra level of safety against criticality accidents

🕑 The accelerator provides a control mechanism for sub-critical systems
- ⇧ more convenient than control rods in critical reactor
- ⇧ safety concerns, neutron economy

🕒 ADS provides a decoupling of the neutron source (spallation source) from the fissile fuel (fission neutrons)

🕓 ADS accepts fuels that would not be acceptable in critical reactors
- ⇧ Minor Actinides
- ⇧ High Pu content
- ⇧ LLFF...

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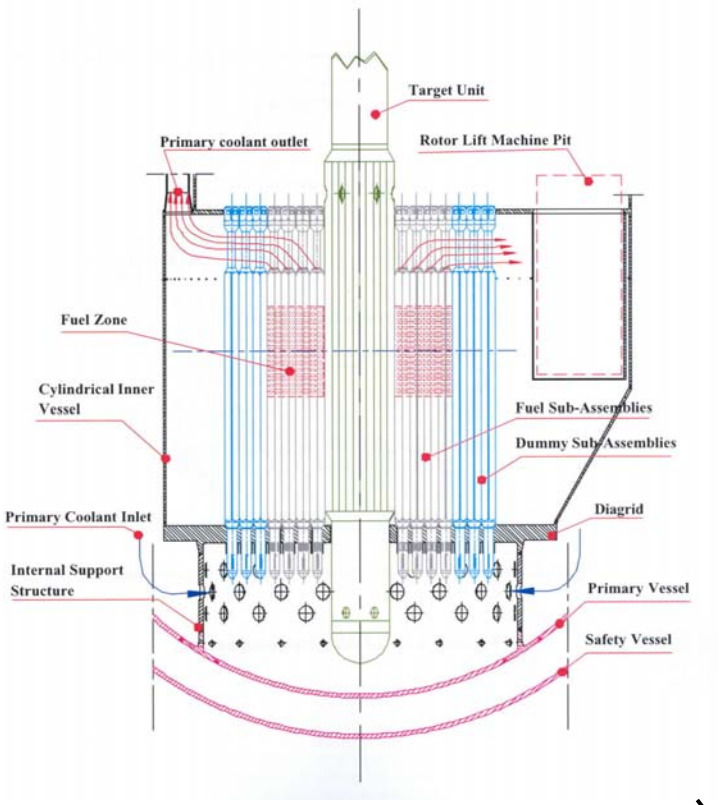
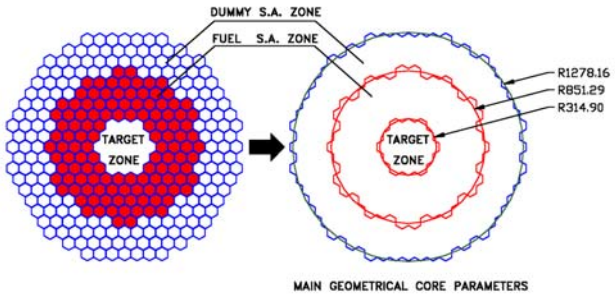
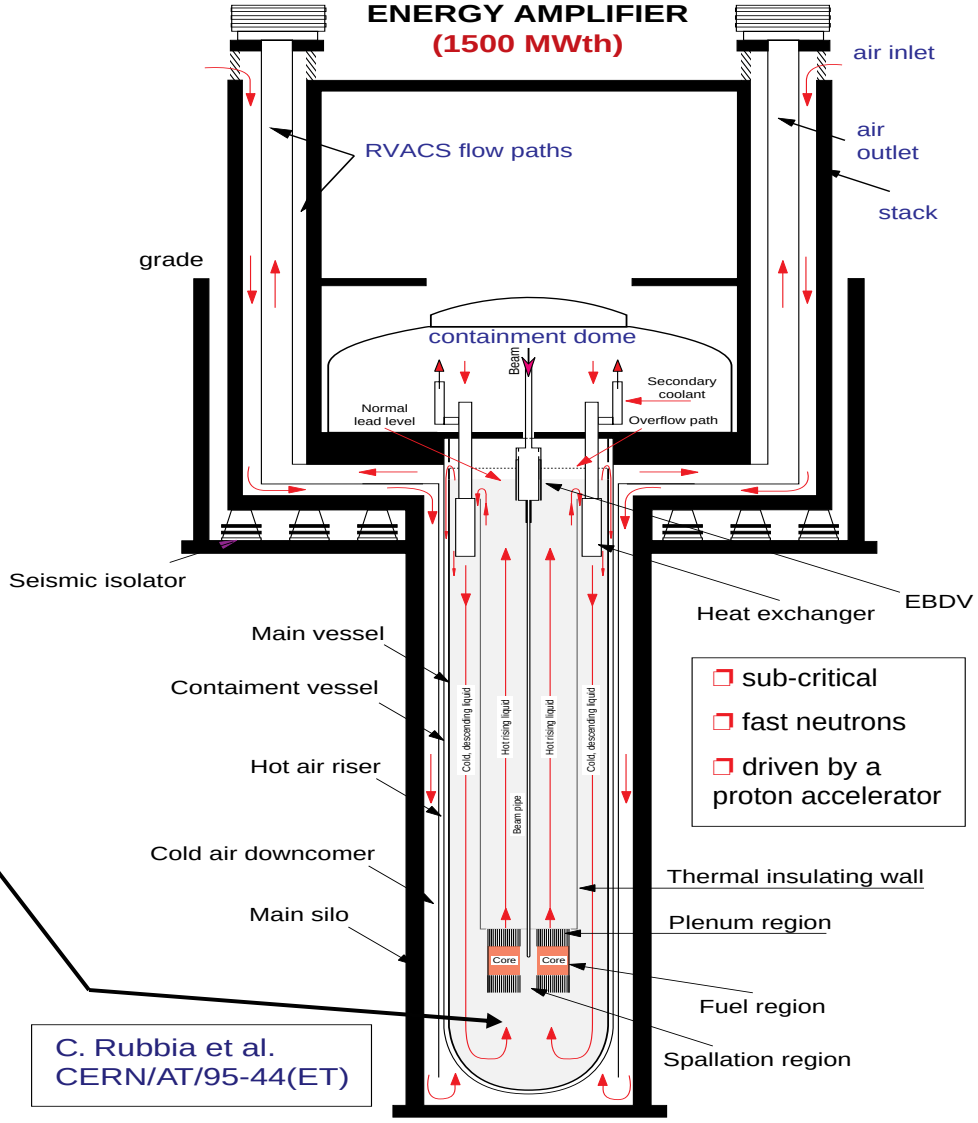
The Energy Amplifier Concept







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Transmutation of Nuclear Waste ?

- Europe : 35% of electricity from nuclear energy
- produces about 2500 t/y of used fuel: 25 t (Pu), 3.5 t (MAs: Np, Am, Cm) and 3 t (LLFPs).
- social and environmental satisfactory solution is needed for the waste problem
- The P&T in association with the ADS can lead to this acceptable solution.

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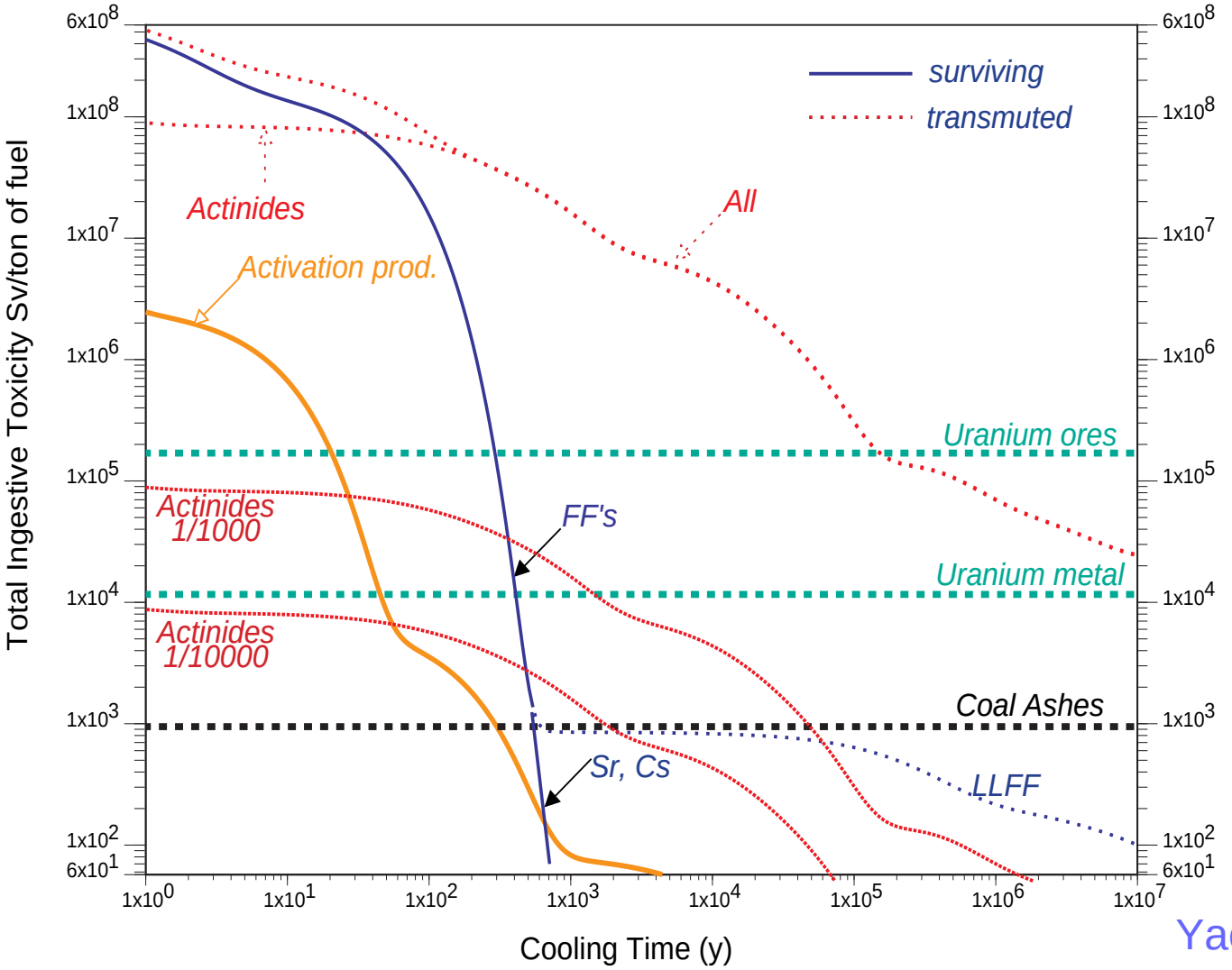
Transmutation of Nuclear Waste ?

Surviving Ingestive radio-toxicity of 1 ton of LWR Waste



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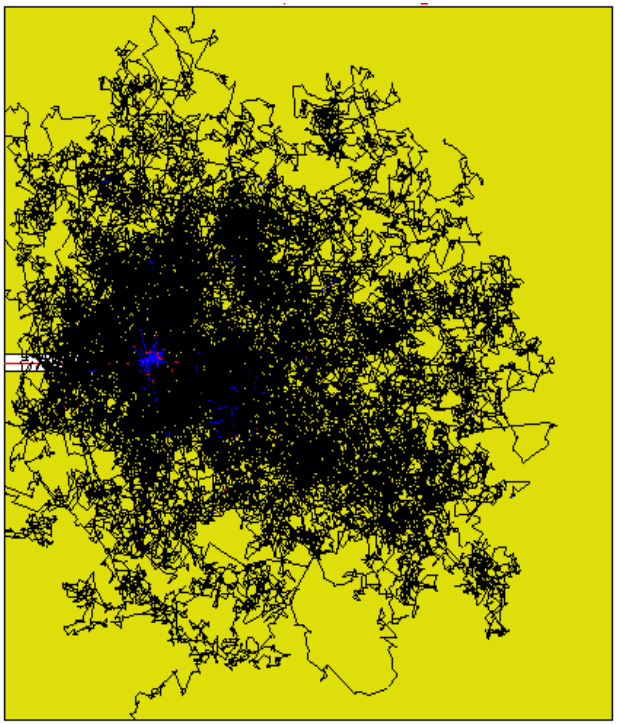
ADS VALIDATION: *The TARC Experiment*

Simulation of neutrons produced by a single 3.5 GeV/c proton

(147 neutrons produced, 55035 scattering)

Very flat and homogenous n-spectrum!



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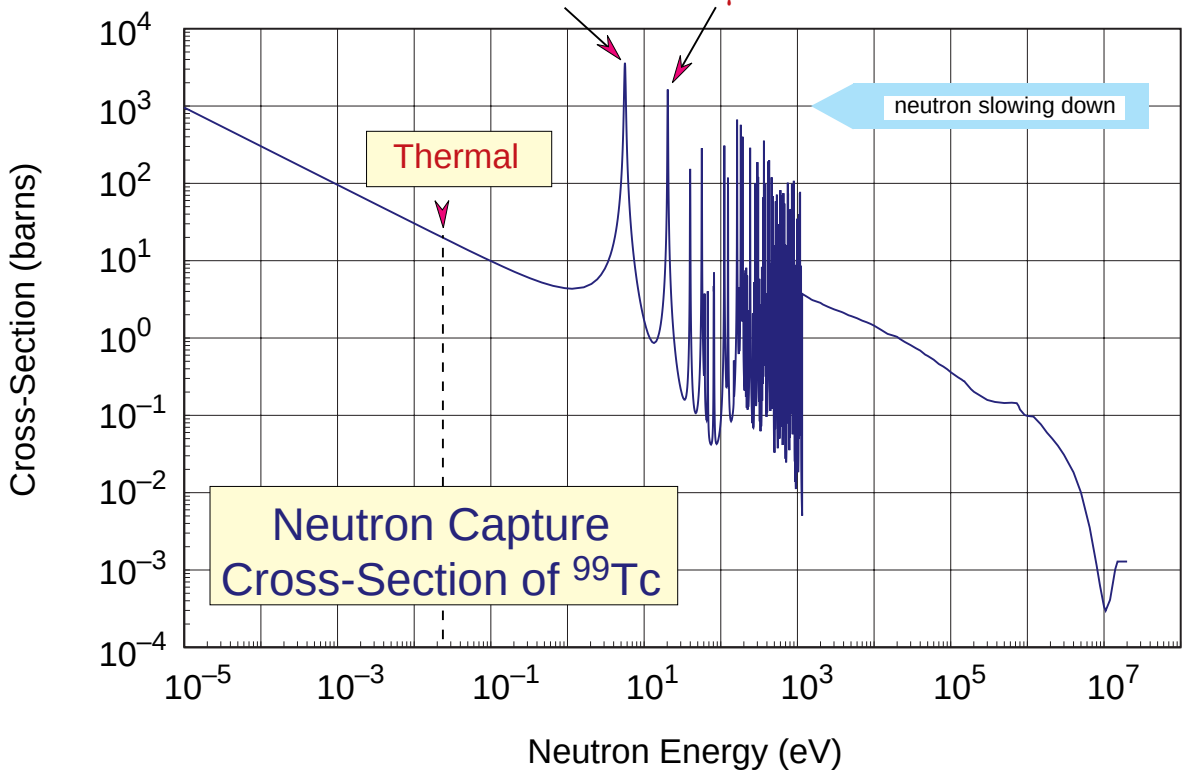
TARC Experiment

^{99}Tc ($t_{1/2} = 2.1\times10^{5}$ ans) + n → ^{100}Tc ($t_{1/2}$ = 15.8 s) + γ prompts (1)

$^{100}Ru^{*} \rightarrow {}^{100}Ru$ (stable) + γ's (2)

ARC maximizes Neutron Capture Rate



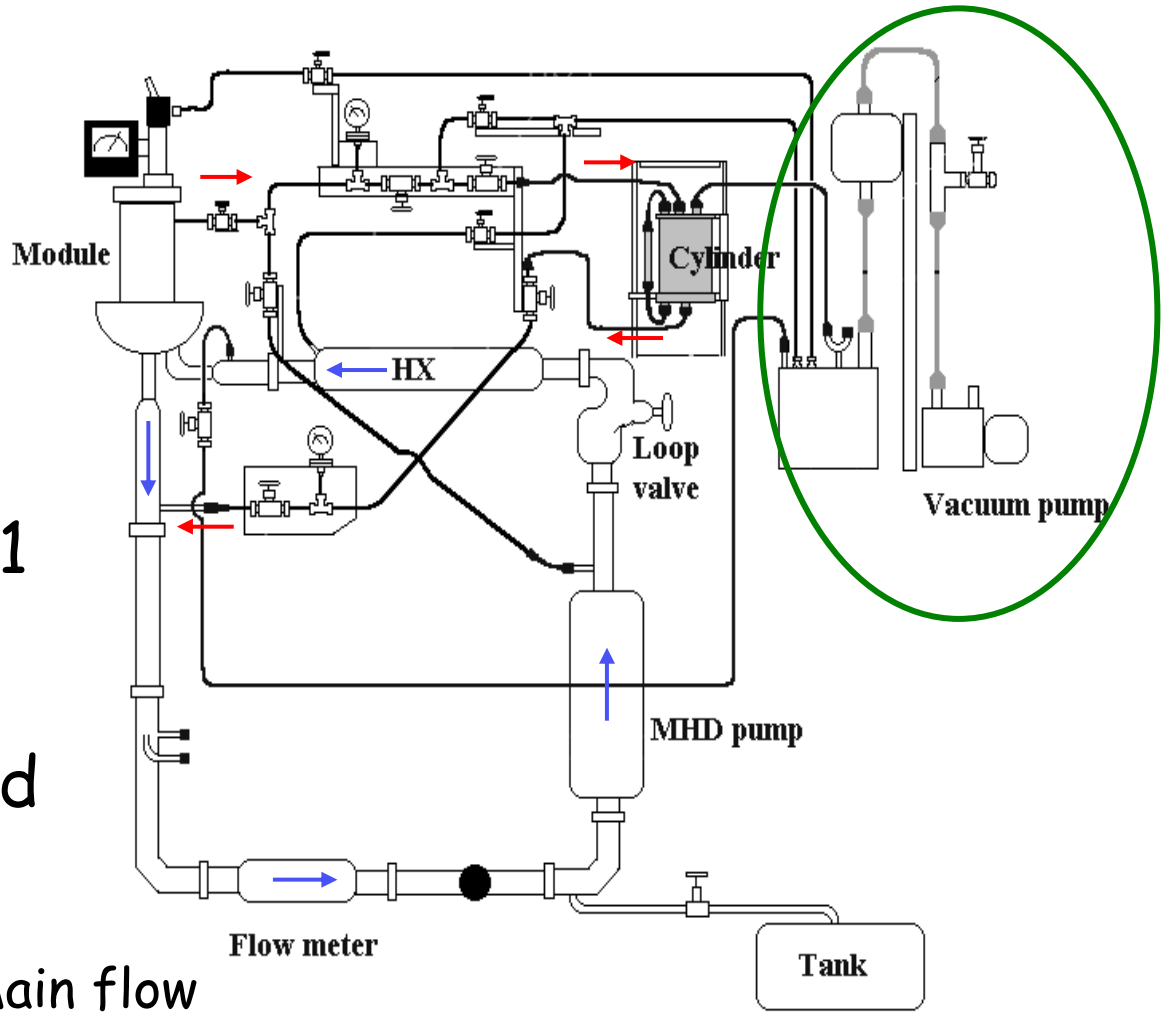
Note that even at low energies ^{208}Pb does not capture many neutrons. They are captured mainly by $^{205\text{-}207}Pb$

Quite some activity throughout Europe. The main facilities or experiments of relevance are:

- IPHI (High Intensity Proton Injector) in France and TRASCO (TRAsmutazione SCOrie) in Italy, on the design of a high current and reliable proton linear accelerator.
- MEGAPIE (MEGAwatt PIlot Experiment), a robust and efficient spallation target, integrated in the SINQ facility at the Paul Scherrer Institute in Switzerland. The SINQ facility is a spallation neutron source fed by a 590 MeV proton cyclotron.
- MUSE-4 (At the MASURCA installation in CEA-Cadarache, using the GENEPI Accelerator), as a first image of a sub-critical fast core fed by external neutrons.
- JRC-ITU The Minor Actinide (fuel fabrication) and advanced aqueous and pyro-processing Laboratories at JRC-ITU in Karlsruhe.
- JRC-IRMM Neutron data activity at Gelina TOF Facility in Geel.
- N_TOF (Neutron Time of Flight) experiment at CERN, Geneva, for nuclear cross-section measurements.
- KALLA (KArlsruhe Lead LAboratory) and
- CIRCE (CIRCuito Eutettico) facilities for Pb and Pb-Bi Eutectic technology development in Brasimone, Italy.

Hg Experiments at IPUL

- 8 ton **Hg**
- Q up to **11 l/s**
- **Vacuum** above free surface < 0.1 mbar
- Minimal pump load is necessary (to avoid pump cavitation)



- Main flow
- Adding/Removing Hg from cylinder
- Vacuum system

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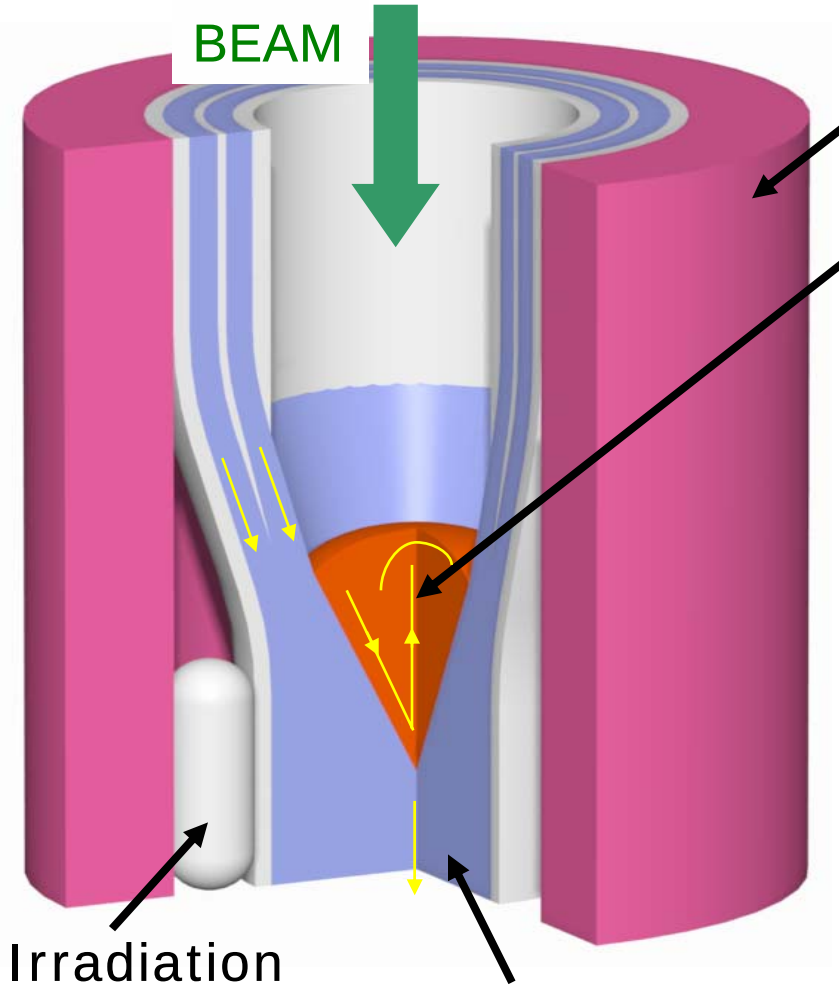
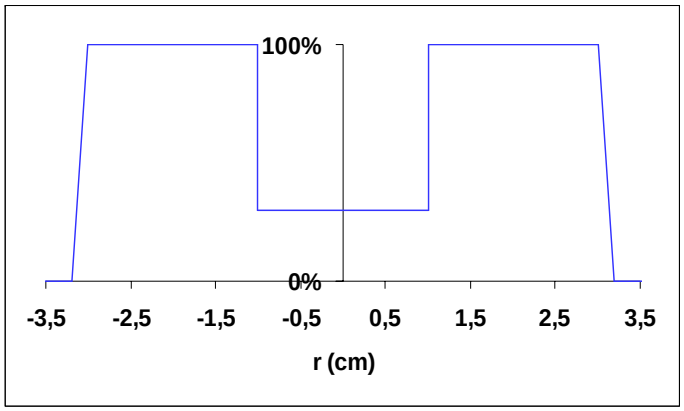
Spallation Target: Desired Target Configuration



Fast core

Volume-minimized **recirculation zone** gets lower 'tailored' heat input



Example of radial tailoring

High-speed flow (2.5 m/s) permits effective heat removal

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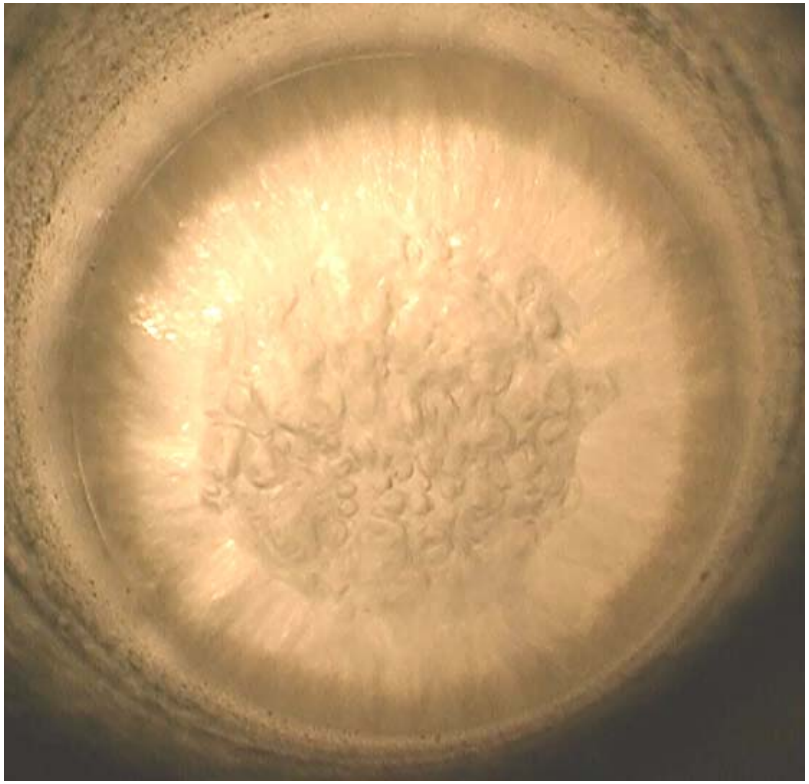
DG16.5 H_2O Experiments

➔ Similarity check: OK !

nominal volume flow 10 l/s

vacuum pressure 22 mbar



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Hg jet will not be used for the energy amplifier, but for demonstrations.

However, Hg jet is very interesting for isotope production.

Conclusions

There is a lot of interest AND activity in the targetry domain.

Our proposed High Power Pulsed Target Test with a powerful proton beam will be watched with great interest by other communities and the outcome will encourage the other activities and is likely to increase their support.

A next generation target experiment might well be a common effort with those communities in a really dedicated test facility!


Thank you