



EN Engineering Department
STI - RBS

High power targets For radioactive ion beams

Thierry.stora@cern.ch

Target and Ion Source Development Team Leader, ISOLDE (EN-STI-RBS)

Since EURISOL-DS, what's new?

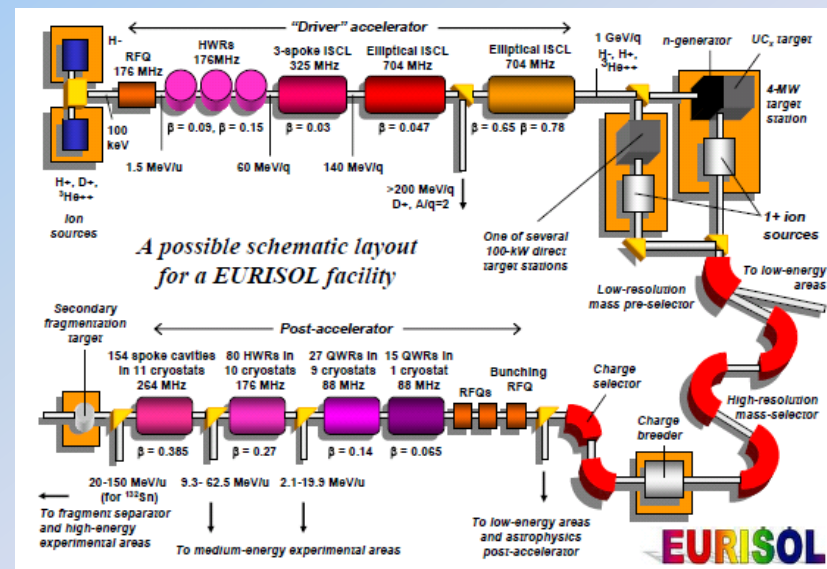
High power targetry workshop, Malmö, May 2011

Preparation for tests of a molten Pb/Bi loop target at ISOLDE



1st conceptual design of a molten salt target to produce $1\text{p.}\mu\text{A } ^{18}\text{Ne}$

Towards a 50kW n-converter



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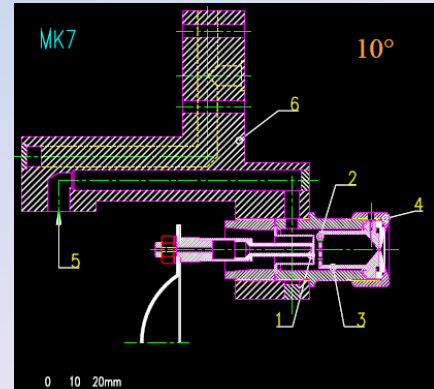
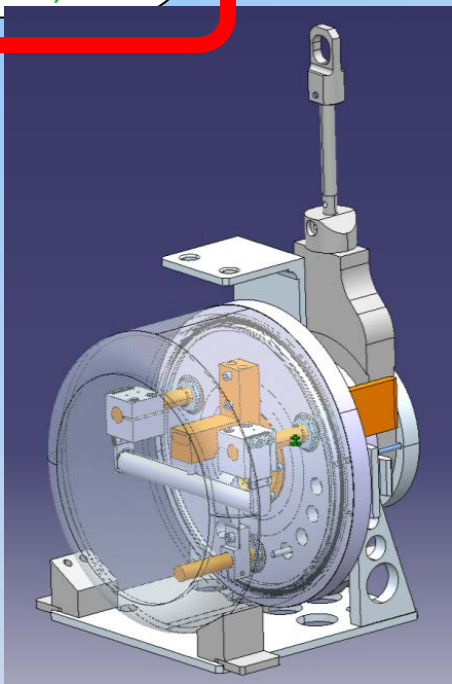
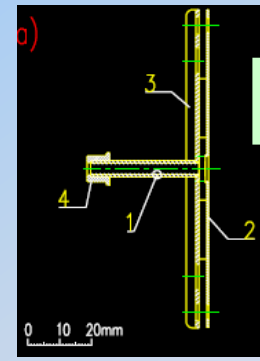
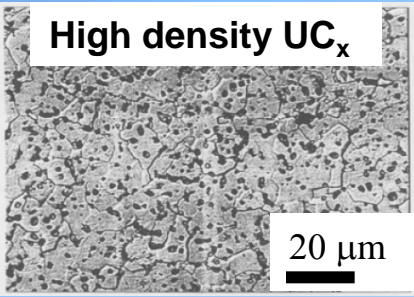
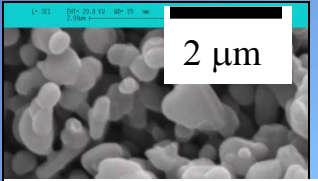
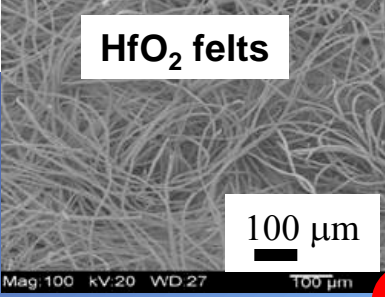
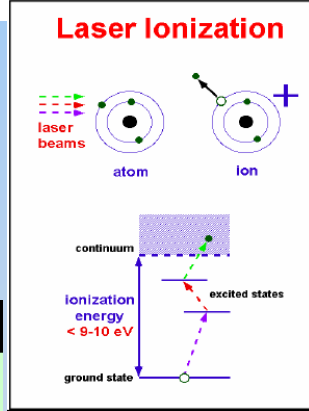
ISOLDE targets and ion sources

Target materials (30):

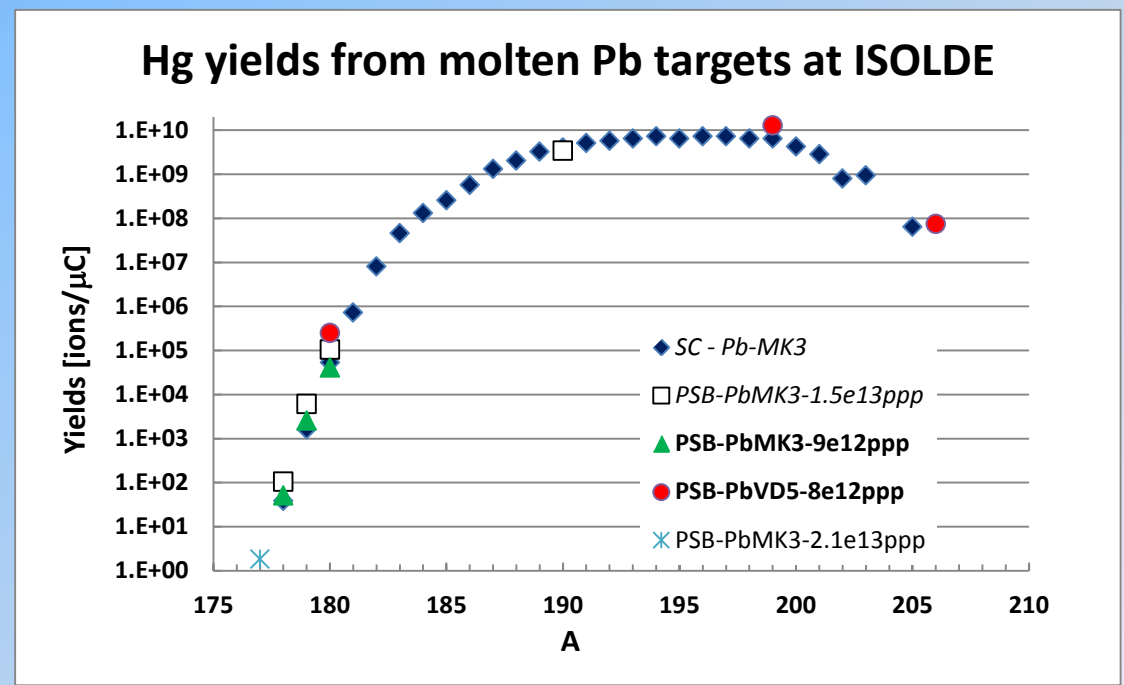
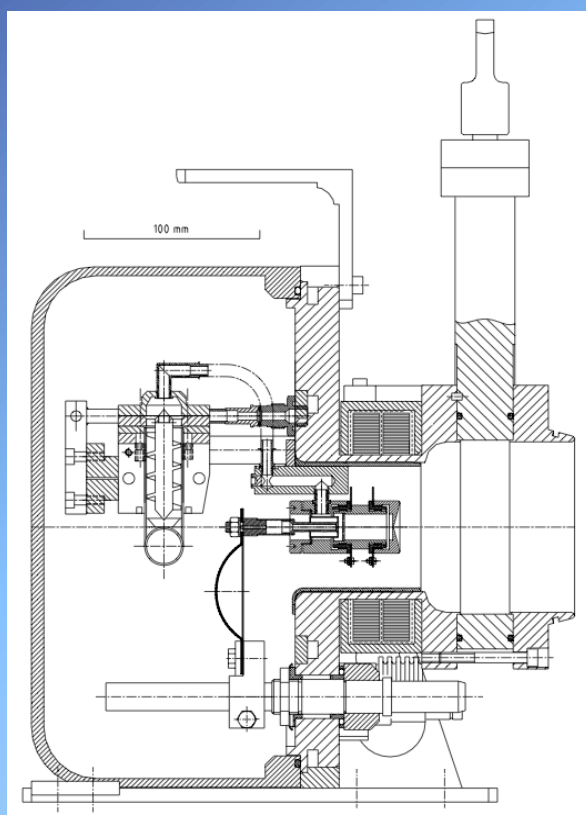
- Refractory oxides carbides (Al_2O_3 , SiC, nano Y_2O_3)
- Solid metals (Ta, Nb, Mo)
- Molten metals (Pb, La, Sn)
- Molten salt (NaF-LiF)

Ion sources (>5):

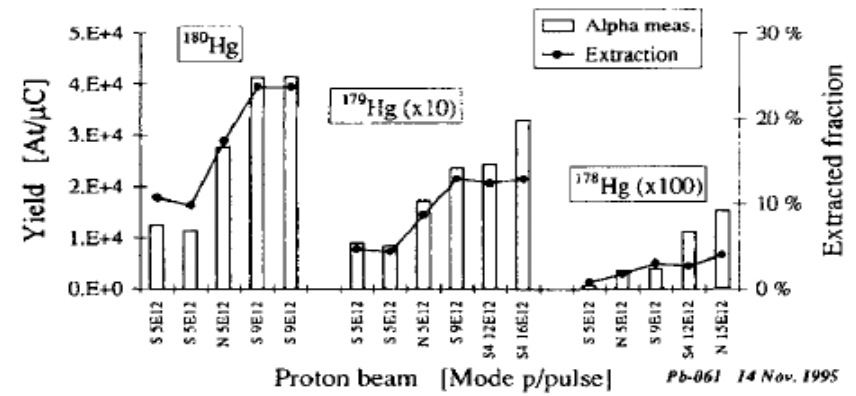
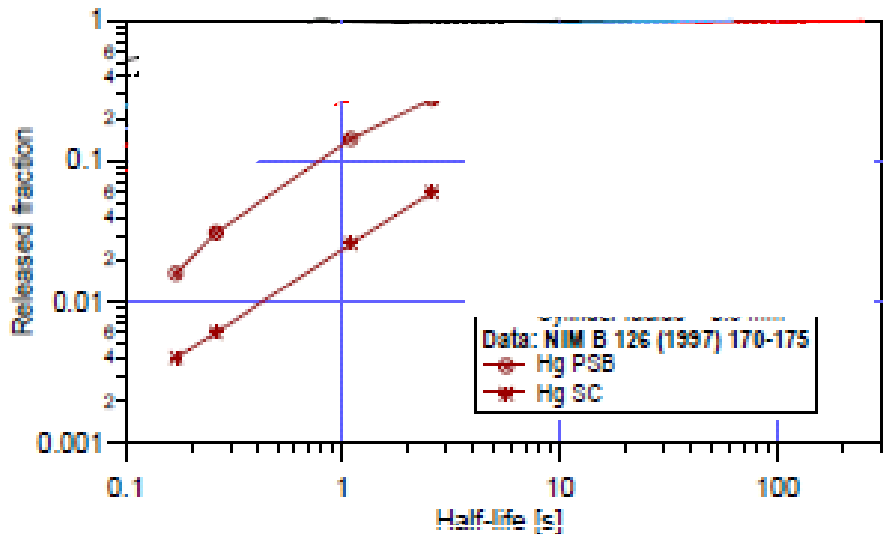
- Surface (W, Re, GdB6)
- FEBIAD, RF Plasma
- LIST



Molten metal targets



Molten metal target release properties



NIM B 126 (1997), 170

RIB intensity
 $[s^{-1} \mu A^{-1}]$

Prim. Part. beam
 Intensity
 $[s^{-1} \mu A^{-1}]$

Avogadro
 #

Diffus.+Effus.
 Efficiency

Beam transport
 Efficiency

$$I = \int \sigma(E) \Phi(E, x) \rho(x) N/A dx \epsilon_{diff+eff} \epsilon_{ion} \epsilon_{optics}$$

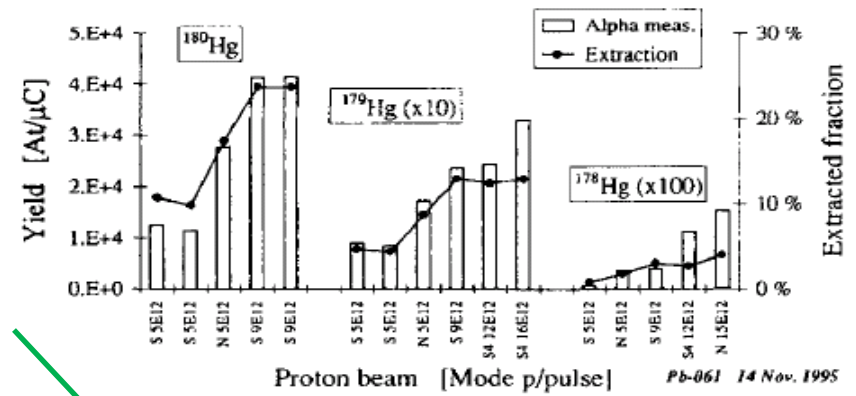
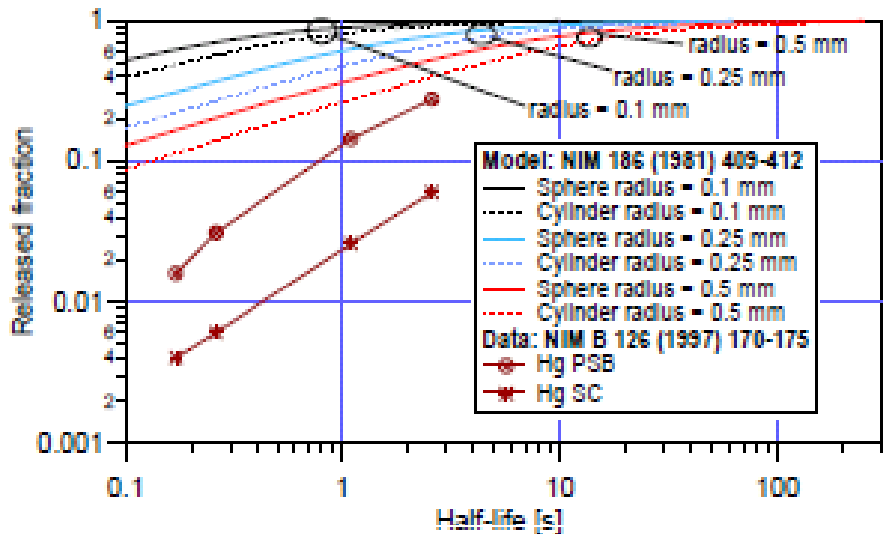
Cross section
 $[cm^2]$

Target density
 $[g cm^{-3}]$

Target Atomic
 Mass [g]

Ionization
 Efficiency

Molten metal target release properties



NIM B 126 (1997), 170

RIB intensity [s⁻¹ μA⁻¹]

Prim. Part. beam Intensity [s⁻¹ μA⁻¹]

Avogadro #

Diffus.+Effus. Efficiency

Beam transport Efficiency

$$I = \int \sigma(E) \Phi(E, x) \rho(x) N/A dx \epsilon_{\text{diff+eff}} \epsilon_{\text{ion}} \epsilon_{\text{optics}}$$

Cross section [cm²]

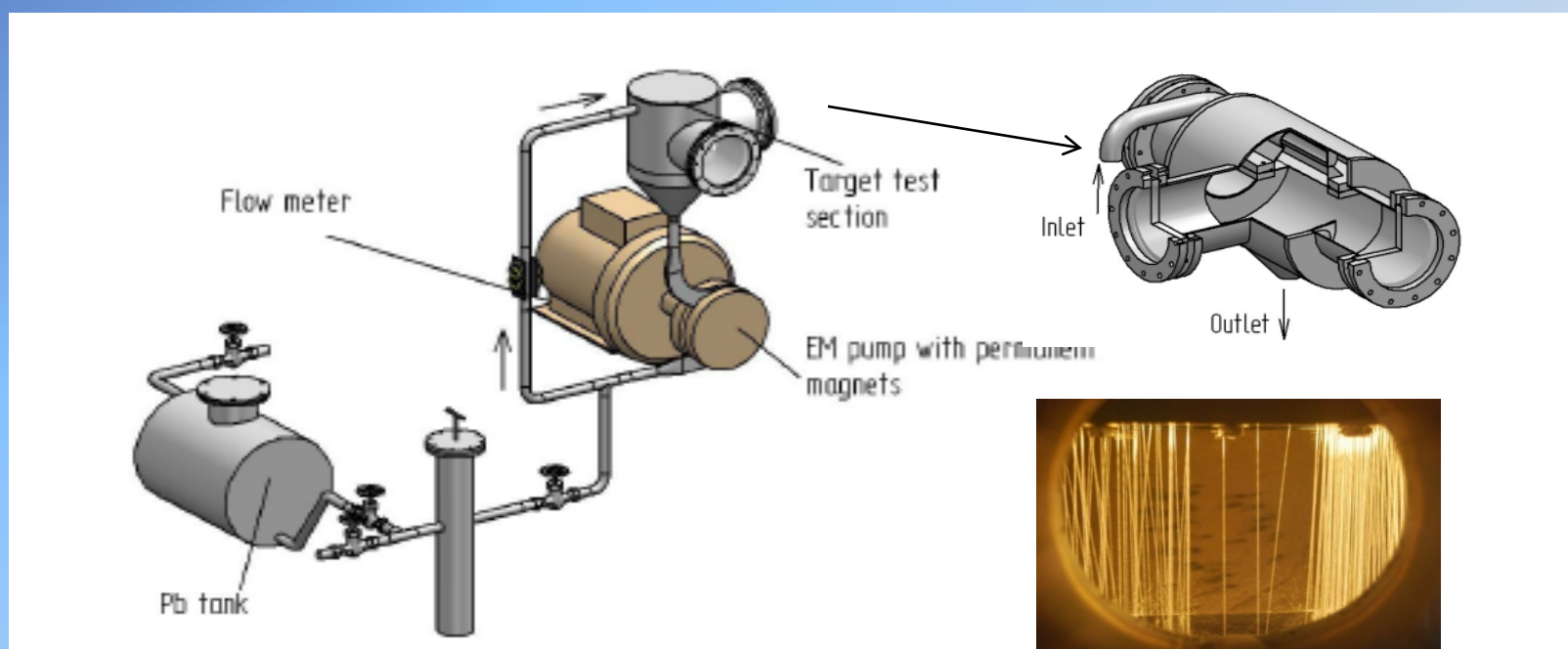
Target density [g cm⁻³]

Target Atomic Mass [g]

Ionization Efficiency

100kW molten target EURISOL DS

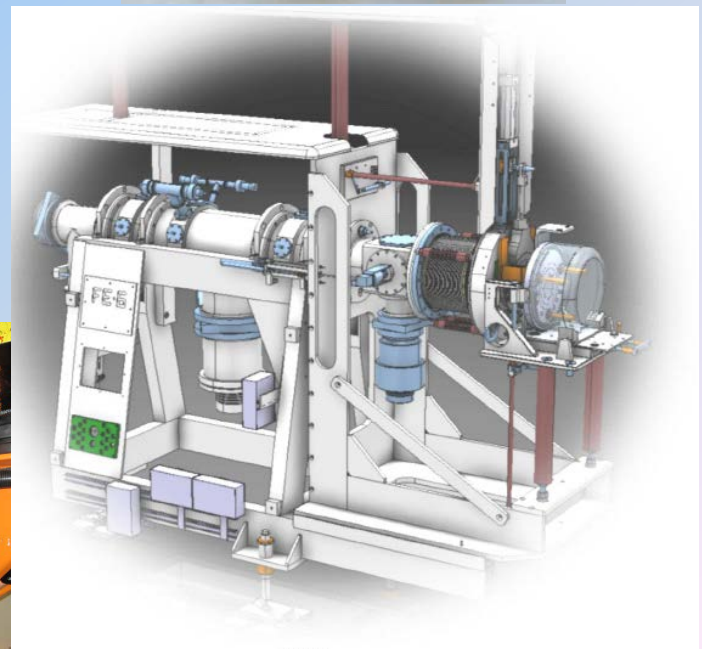
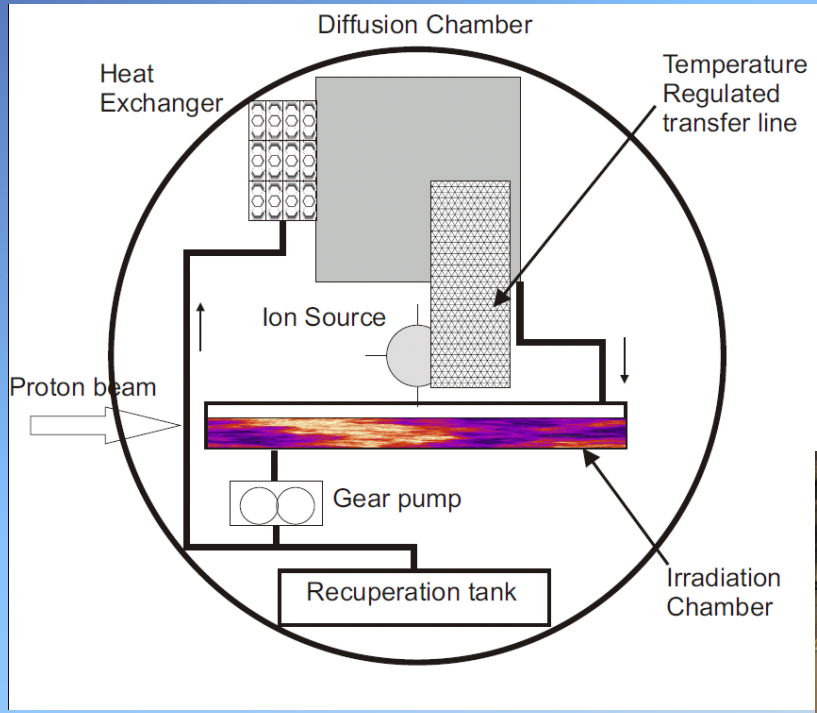
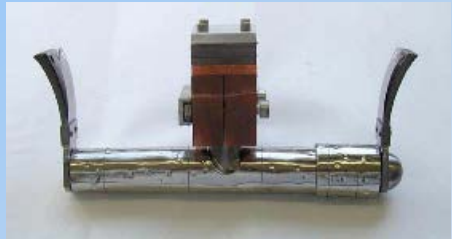
Experimental program at IPUL/Latvia showed feasibility of a molten Pb/Bi shower to accomodate 100 kW, 1GeV incoming proton beam



Liquid-metal loop setup at IPUL: final Report EURISOL DS, 2009 (E. Noah et al.)

LIEBE - Liquid Eutectic Pb/Bi loop for EURISOL

The ISOLDE facility offers a possibility to test a Molten Pb/Bi target
 Static Pb/Bi target PbBi264 tested at ISOLDE in 2004



LIEBE - Work packages

Collaboration between CEA, CERN, IPUL, PSI, SCK-CEN, SINP

WP definition	WP holder	Coordinator
WP1 : Coordination	CERN	T. Stora
WP2 : Conceptual Design and simulations	SCK-CEN	P. Schurrmans
WP3 : Construction, assembly	CERN	M. Delonca
WP4 : Instrumentation	PSI	<i>K. Tomsen</i>
WP5 : Safety and Licensing	CEA	<i>H. Goutte</i>
WP6 : Target characterization and analysis	PSI	D. Schumann
WP7 : Radiochemistry	SINP	S. Lahiri
WP8 : Offline commissioning	IPUL	K. Kravalis/E. Platacis
WP9 : Online operation	CERN	<i>T. Stora</i>



T. Stora - EURISOL Town Meeting - Oct 2012

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Planning

WP	Q3-12	Q4-12	Q1-13	Q2-13	Q3-13	Q4-13	Q1-14	Q2-14	Q3-14	Q4-14	Q1-15	Q2-15	2018	
				<i>CERN-wide Long Shutdown 1</i>										
2 Design			1 st design	CFD, FEM		Final design								
3 Assembl						Techn. drawings	components	Procurement	Construction	Adaptation				
4 Instr.			Definition		Tests@ipul/cern			software						
5 Safety		CERN authorities.	Safety constraints	Risk analysis + RP			Risk analysis + RP II			Safety file	Beam permit			
6 Target charact					Release (Po...)	Inventory							Waste PIE	
7 Chemist		Activation Pb/Bi			Compar MC code				Activation Pb/Bi-II					
8 Offline		Test pumps IPUL	Test IPUL CERN						commissioning	commissioning	Cold check-out			
9 Online		Operational parameters		Definition of online tests				Modif target area I			Modif target area II	1 week online – Report	Final report	

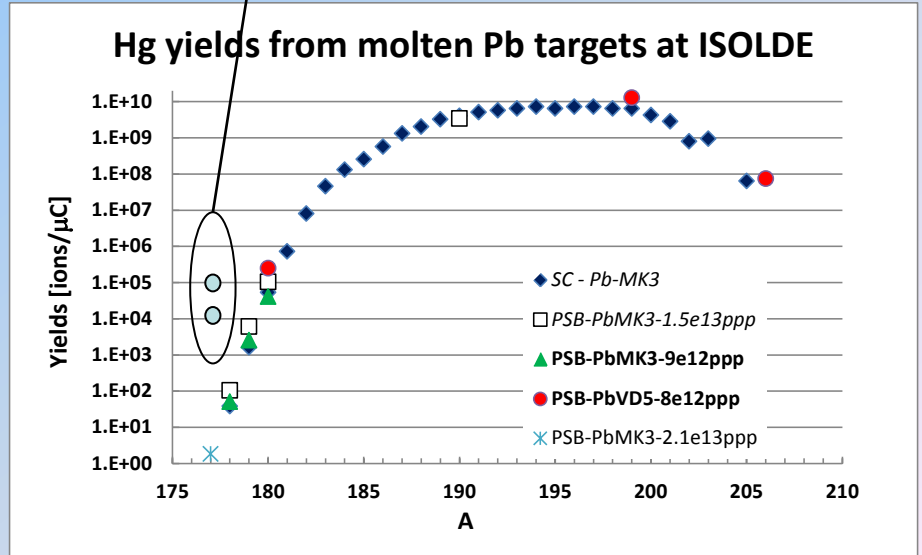
(TS, v2.0, Oct 2012)

Projected Hg beam intensities

177Hg Beam intensity at FRIB (400kW)
 (accessed Oct 2012)

Beam intensity at EURISOL in pps:
 X100 (100μA p beam)
 X10 VADIS ion source
 X20 release efficiency
 X2 σ if 2GeV p
 8% Post-acceleration
 (~1/15 would be available at HIE-ISOLDE)

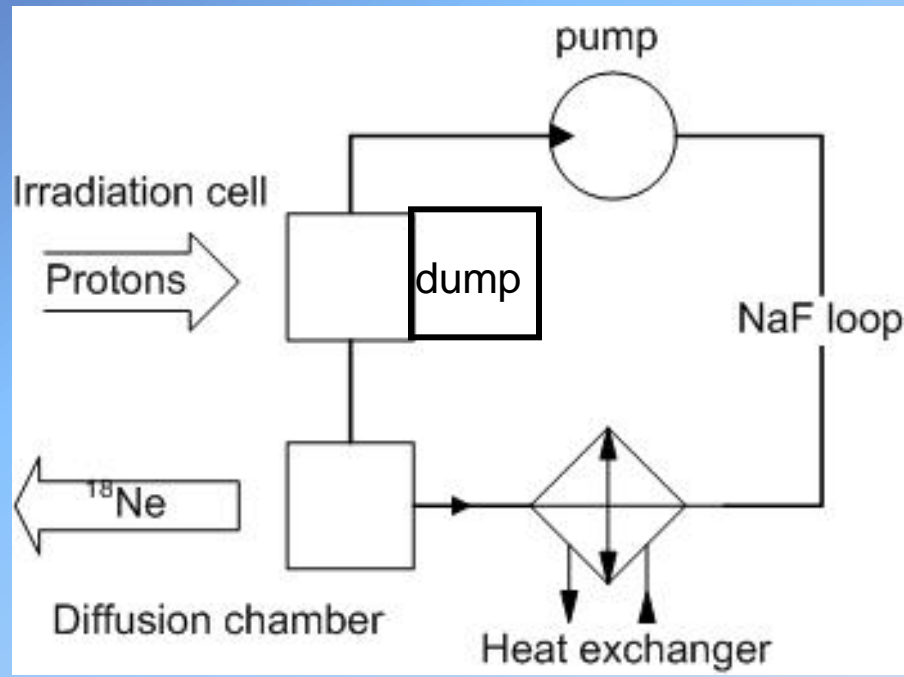
Beam		
AZ	209Bi	
Energy	210.2	MeV/u
Fragment		
Energy	160.4	MeV/u
B _γ (Q=Z)	4.204	Tm
Fast beam rate	3.37e+5	pps
Stopped beam rate	1.03e+5	pps
Reaccelerated beam rate	1.85e+4	pps



Conceptual target loop for ^{18}Ne production

Production of ν_e
For β -beams:
1. 10^{13} $^{18}\text{Ne}/\text{s}$ during 8 years

100's reports on molten salt reactors available from ORNL
Courtesy of A. Benes, ITU



[Preface: Molten Salt Reactors](#)
[Molten-Salt Reactors—History, Status, and Potential](#)
[Experience with the Molten-Salt Reactor Experiment](#)
[Molten-Salt Reactor Chemistry](#)
[New Developments in Materials for Molten-Salt Reactors](#)
[Engineering Development of the MSBR Fuel Recycle](#)
[Gaseous and Xenon Behavior and Their Influence on Molten-Salt Reactor Design](#)
[The Design and Performance Features of a Single-Fluid Molten-Salt Breeder Reactor](#)
[Reactor Physics and Fuel Cycle Analyses](#)

ORNL Reports Related to Liquid-Fluoride Reactors and Technology

ORNL-6952: 1999-09 ([84K PDF](#))
Uses For Uranium-233: What Should Be Kept for Future Needs?

ORNL-5388: 1978-12 ([18.8M PDF](#))
Interim Assessment of the Denatured 233U Fuel Cycle

ORNL-5176: 1977-02 ([4.2M PDF](#))
Engineering Tests of the Metal Transfer Process from MSBR Fuel Salt

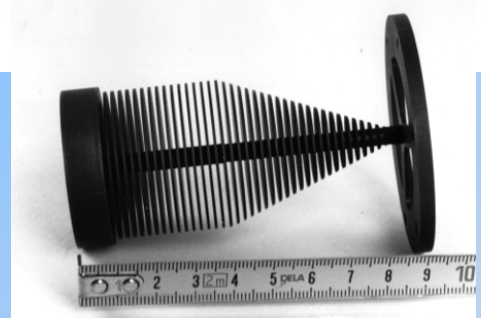
ORNL-5132: 1976-08 ([37.9M PDF](#))
Molten-Salt Reactor Program: Semiannual Progress Report for Period Ending February 29, 1975

ORNL-5078: 1976-02 ([30.4M PDF](#))
Molten-Salt Reactor Program: Semiannual Progress Report for Period Ending August 31, 1975

ORNL-5047: 1975-09 ([32.1M PDF](#))
Molten-Salt Reactor Program: Semiannual Progress Report for Period Ending February 28, 1975

ORNL-5018: 1974-12 ([46.6M PDF](#))
Program Plan for the Development of Molten-Salt Breeder Reactors

Projectile fragmentation



18Ne Beam intensity at FRIB (400kW)
(accessed Oct 2012)

Beam		
AZ	20Ne	
Energy	293.6	MeV/u
Fragment		
Energy	232.8	MeV/u
B ₂ (Q=Z)	4.194	Tm
Fast beam rate	8.04e+10	pps

Final yields

σ.I.R.ξ

200kW

Conservative version:


		On target	In C.B.	
²⁰ Ne 100A MeV	¹⁸ Ne	1 10 ¹¹	5 10 ¹⁰	↑ × 1.6
⁷ Li 100A MeV	⁶ He	5 10 ¹²	2.5 10 ¹²	↑ × 1.5

This is supposing a 300MV HI driver


Gains: Li "converter", Energy (× 10 for 450A MeV) and I...

Marion-2003 Antonio C.C. Villari - ISABEL

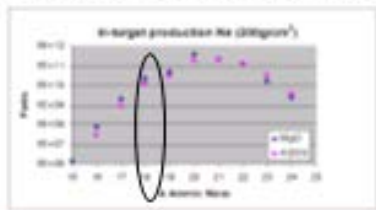
^{18}Ne production after EURISOL-DS



Production of ^{18}Ne ions for ν_e



- Direct spallation of 1 GeV protons onto thick oxide targets Al (p,X) ^{18}Ne

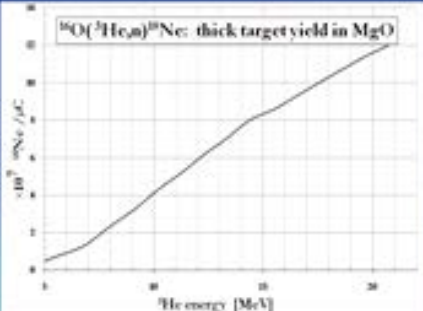


In-target production ^{18}Ne (atoms/cm²)
 Al energy [MeV]

Blanking time: 100 ns (target radius)

Beam parameters: 2.10¹⁷ p/shot (RBS)


Production of ν_e
 $2 \cdot 10^{13}$ $^{18}\text{Ne}/\text{s}$



$^{18}\text{O}(^3\text{He},\alpha)^{18}\text{Ne}$: thick target yield in MgO
 10^{17} ^{18}Ne / μC
 ^3He energy [MeV]

Validated at 9kW at LLN.
Needs ~200mA, ^3He 21MeV, \varnothing 86cm target

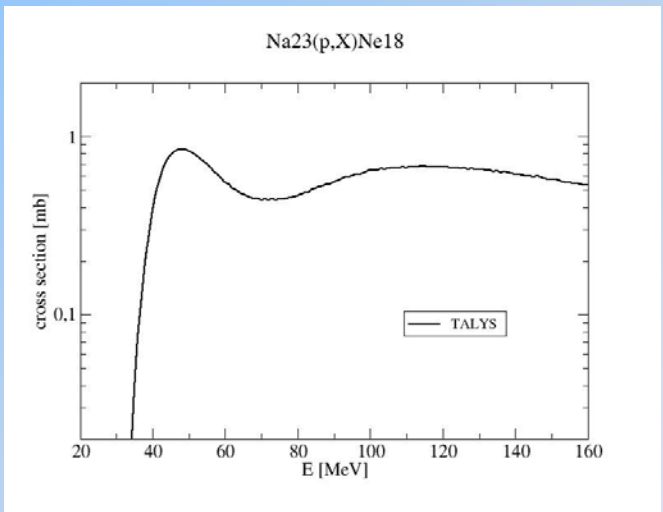
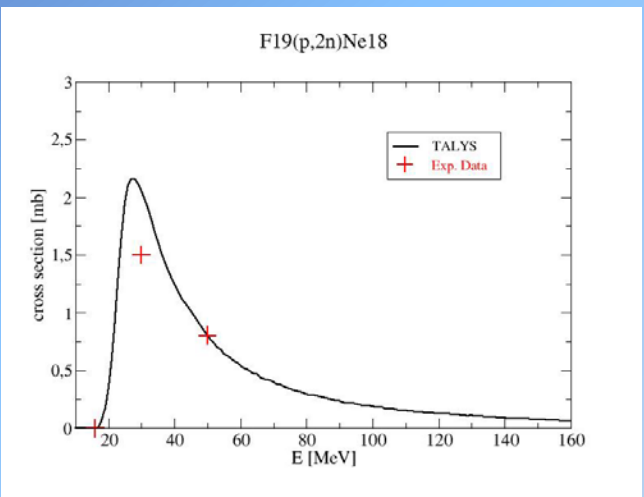
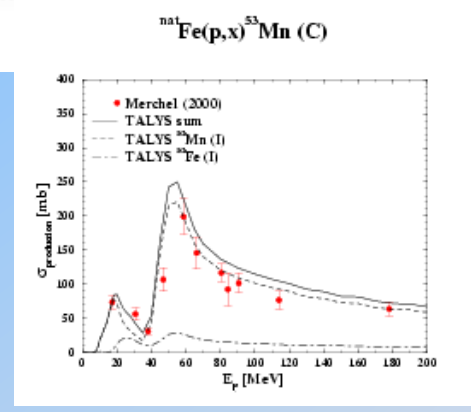
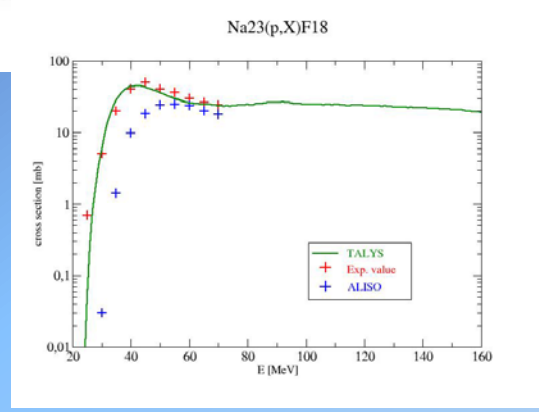
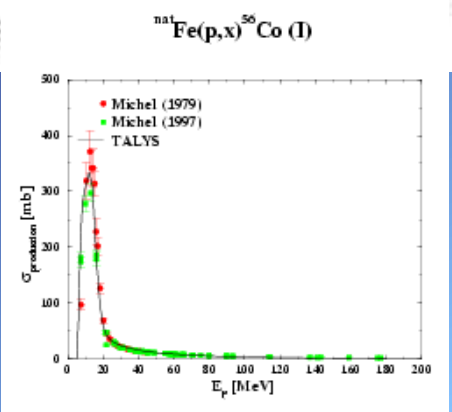
S. Mitrofanov,
M. Loiselet et al.



NeutrinoCafe - CERN

T. Stora 1st Mar 2010

EN Engineering Department STI - RBS **Production at intermediate energies**



A.J. Koning, S. Hilaire and M.C. Duijvestijn, „TALYS-1.0“, Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22-27, 2007, Nice, France, editors O.Bersillon, F.Gunsing, E.Bauge, R.Jacqmin, and S.Leray, EDP Sciences, 2008, p. 211-214.

M. C. Lagunas-Solar in Proc. Of the IAEA consultants' meeting in data requirements for Medical radioisotope production, INDC(NDS)-195/GZ, 1988, p.55

Molten salt selection

Suitable eutectic comprising Na and F nuclei :

Salt	Composition [mol %]	Melting point [°C]	Density [g/cm ³] (700 °C)	Vapor pressure [mmHg](900°C)	Yield protons 6mA 160MeV
NaF-BeF ₂	57 - 43	340	2.01	1.4	8.8E+012
NaF-NaBF ₄	8 - 92	385	1.75	9500	8.4E+012
NaF-ZrF₄	60 - 40	500	3.14	5.1	1.0E+013
NaF-LiF	61-39	649	2.59	1	0.9E+013

NaF : melting point at ca 1000° C

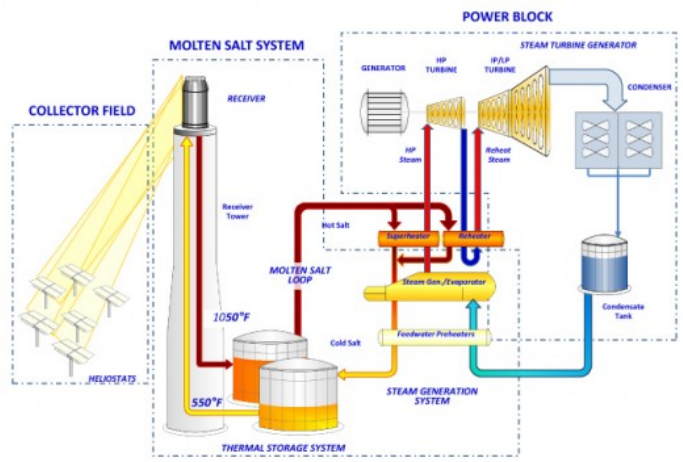
D. F. Williams, Assessment of Candidate Molten Salt Coolants for the NGNP/NHI Heat-Transfer loop, ORNL/TM-2006/69, Oak Ridge National Laboratory, Oak Ridge, TN (2006)

Molten salt “acceptance”

- Mixture of $\text{NaNO}_3:\text{KNO}_3$ (60:40 % mol.)
- Used in solar power tower systems (Spain, U.S.A, Australia, Italy)
- Efficient and low cost medium to store thermal energy
- Salt storage system lowers cost of solar plant operation



Gemasolar Array, Spain



<http://www.gizmag.com/california-first-molten-salt-solar-power-plant/17298/>

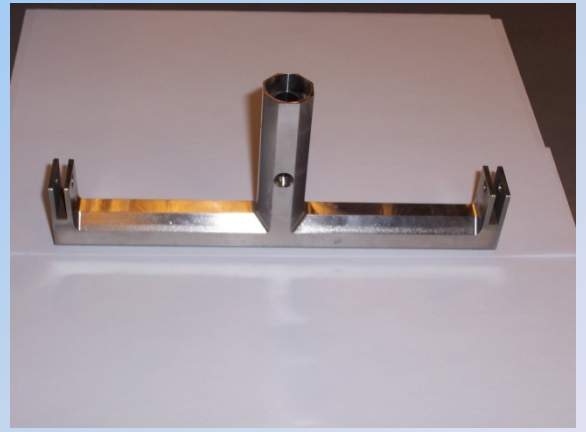
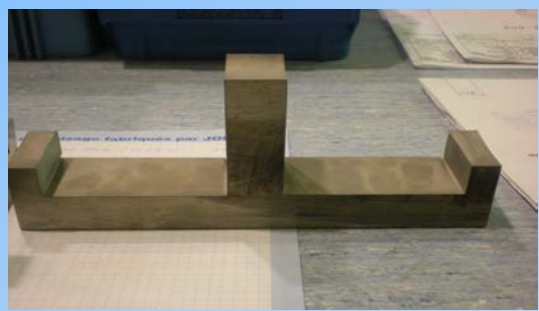
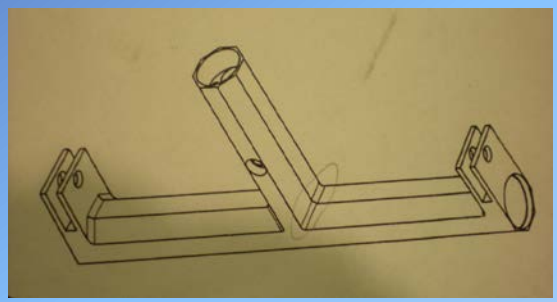


Molten alkali fluorides:

- High electric conductivity
- Heavy metal fluoride glass compositions for fabrication of mid-infrared, ultra low loss optical fibers


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Container in fluoride resistant alloy (Haynes 242) (Machined at Cern Main Workshop, EN-MME-MS)



Haynes 242 alloy chemical composition (%weight)

	Ni	Mo	Cr	Fe	Co	Mn	Si	Al	Cu
Haynes 242	65	25	8	2	2.5	0.8	0.8	0.5	0.5

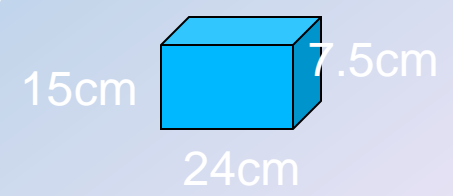
Scaling of the irradiation chamber

Position on axis [cm]	stopping power [Mev/cm]	Deposited beam power 6mA, 160MeV [kW]
1	12	74
2	13	78
3	14	83
4	15	90
5	16	99
6	19	111
7	22	133
7.5	15	89
total target	126	756
total dump	34	204
total window	*	20

For $\Delta T = 100^\circ \text{C}$, $C_p = 1.17 \text{ J/g K}$,
 We need 2.7 L/s

Window is 360 cm^2 , eg $15 \times 24 \text{ cm}$

Compatible material (Ni, Cr, Mo, Fe)
 up to 1000°C :
 Hastaloy N



Salt	Reynolds modulus	Prandtl modulus	Nusselt modulus	Fluid temperature [°C]	Heat transfer coefficient [$\text{W.m}^{-2}.\text{K}^{-1}$]
NaF-NaBF4	5100-45000	5,3-5,64	35-225	450-610	1380-10100

J. A. Lane, H. G. MacPherson, F. Maslan, Fluid Fuel Reactor, Chapter 13, Addison-Wesley, Reading, Mass. (1958)

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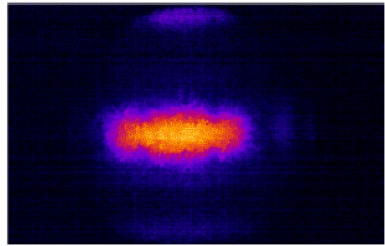
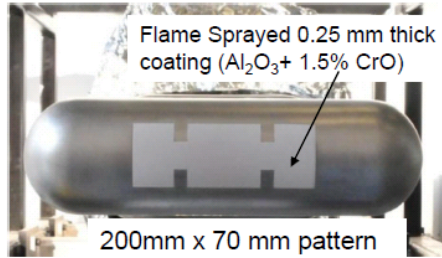
Operational Experience for High Power Spallation Targets

John Haines, Bernie Riemer (ORNL),
Masatoshi Futakawa (JAEA),
Werner Wagner and Michael Wohlmuther (PSI)

4th High Power Targetry Workshop
Malmö, Sweden
May 2, 2011

Target Imaging System

- Implemented Target Imaging System on second target
 - System was functional for full life of 2nd target (3200 MW-h)
 - 3rd target installed with enlarged and improved coating pattern
 - Improved resolution system was installed with 3rd Proton Beam Window in December 2010



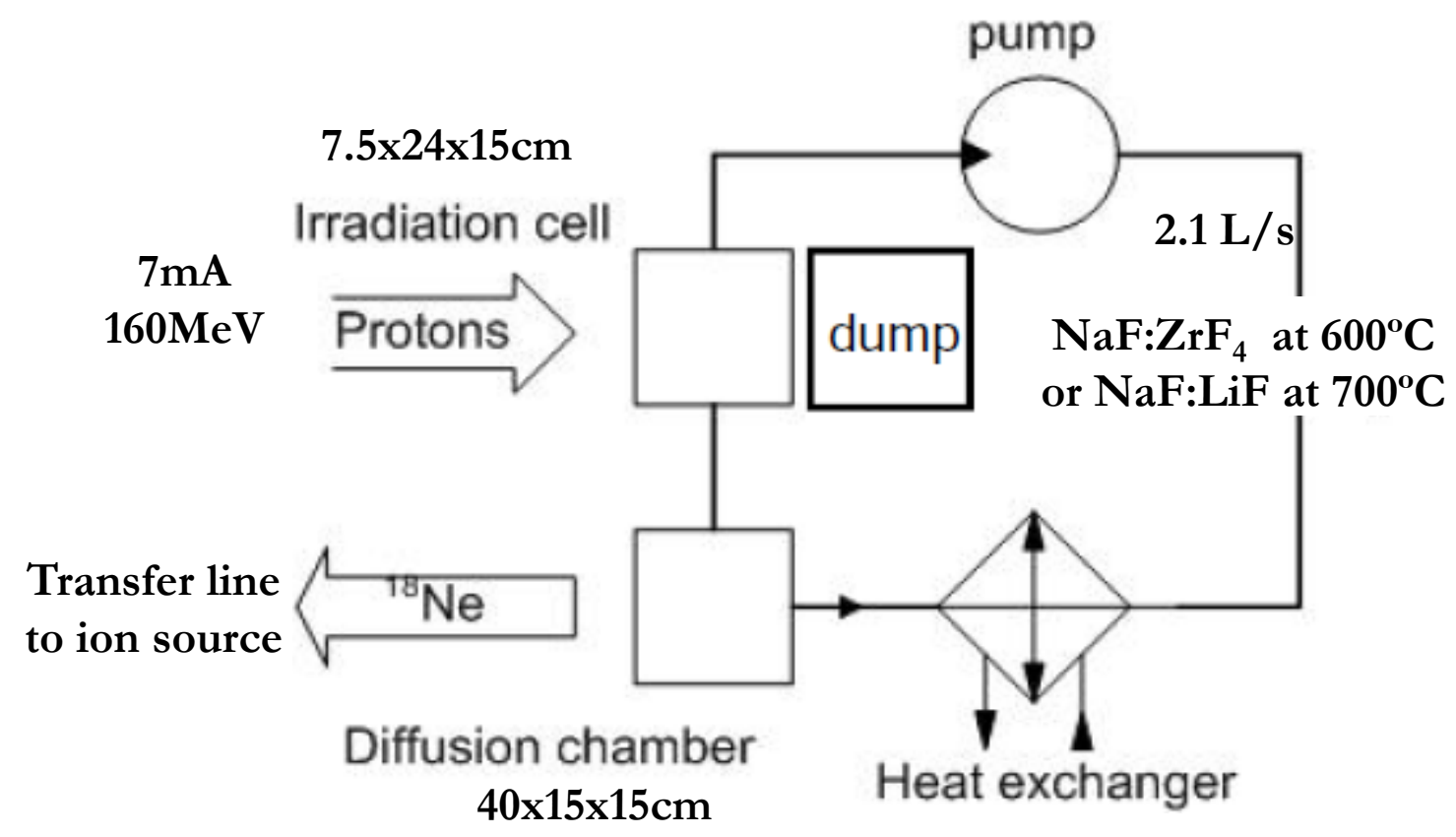
Target Imaging System

32 Managed by UT-Battelle for the U.S. Department of Energy

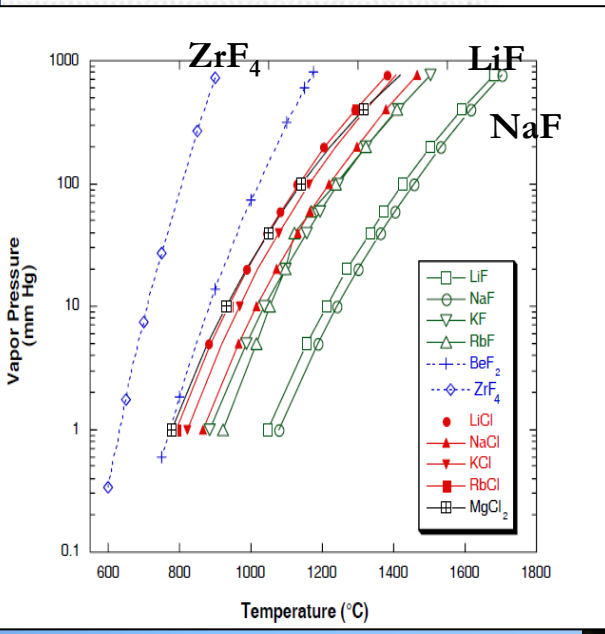
4th HPTW 2011



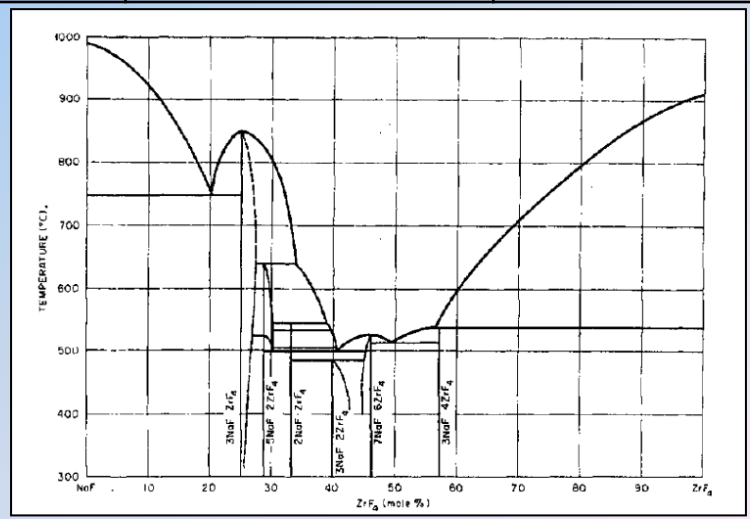
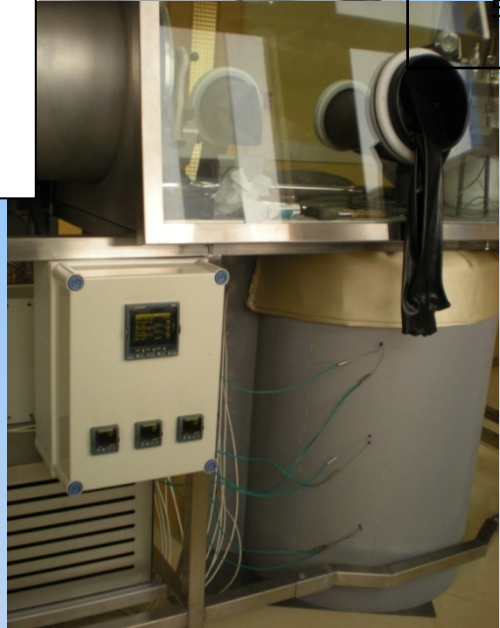
Conceptual design of NaF MW target loop for ^{18}Ne production



Chemical issues



Temperature	Phases below T	Phases above T
500C (start of fusion)	3NaF:2ZrF ₄ (solid)	γ2NaF:ZrF ₄ , 7NaF:6ZrF ₄ (ss)
506C	γ2NaF:ZrF ₄ , 7NaF:6ZrF ₄ (ss)	γ2NaF:ZrF ₄ (liquid)
525C	γ2NaF:ZrF ₄ , Liquid phase	Liquid phase



All handling and manipulation in gloveboxes under controlled argon atmosphere

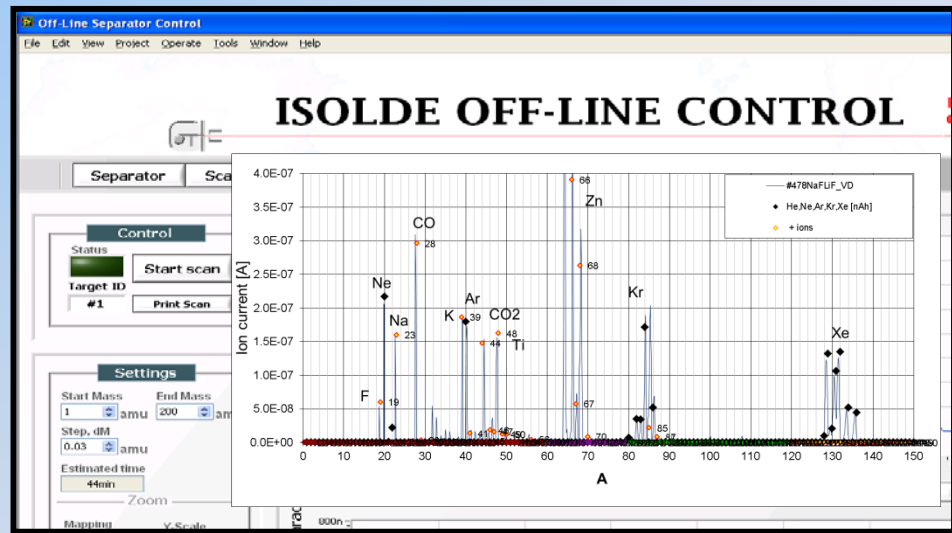
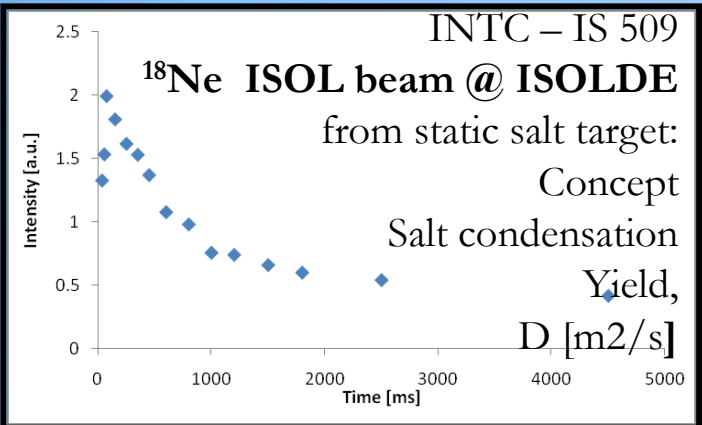
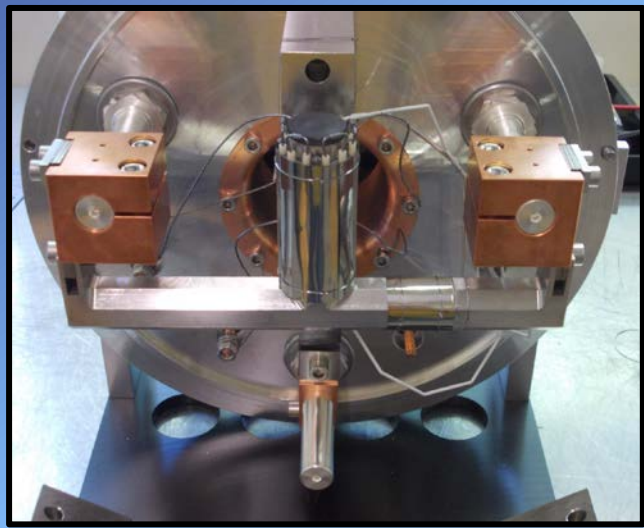


T. Stora - EURISOL Town Meeting - Oct 2012



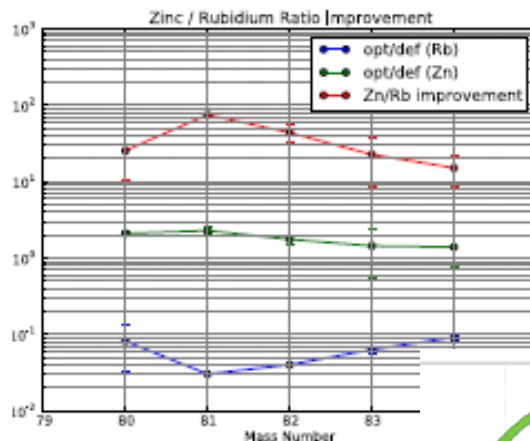
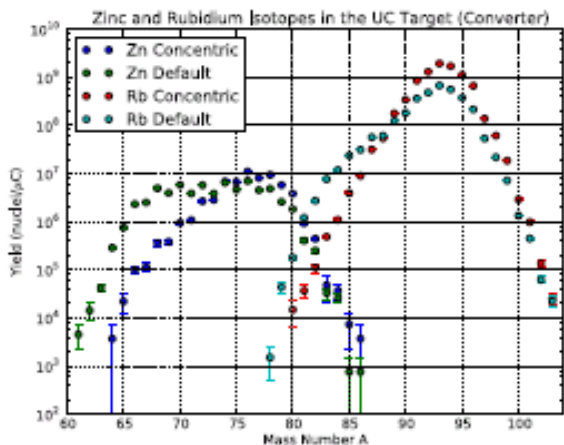
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Successful online tests of static target

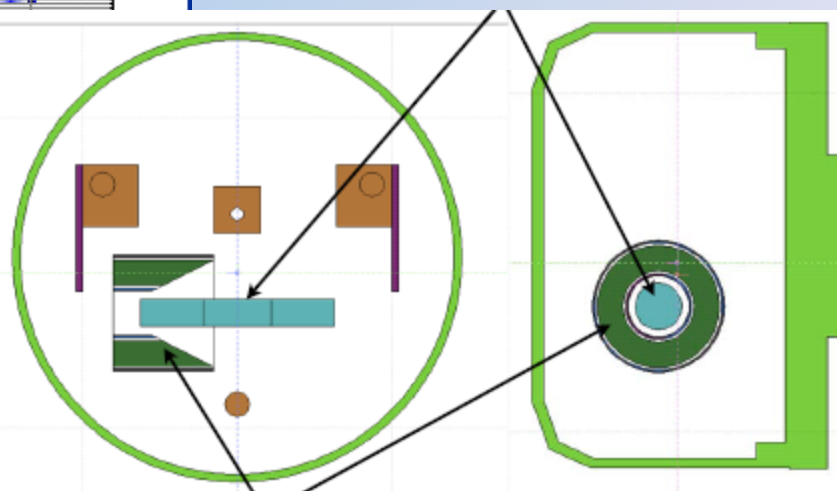


And last but not least : n converter

Concentric UCx Target – Zn and Rb Yields (preliminary results)



• $^{80}\text{Zn}/^{80}\text{Rb}$ ratio is improved ~25 times (slightly more than in previous optimization)



Online tests at ISOLDE – 1st phase
2nd phase in 2014, benefit for HIE-ISOLDE 2GeV
50kW project agreement



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Thank you !

Don't forget the posters:

M. Delonca

T. Mendonca

R. Luis

And many more