# 6He and 18Ne production for beta-beams

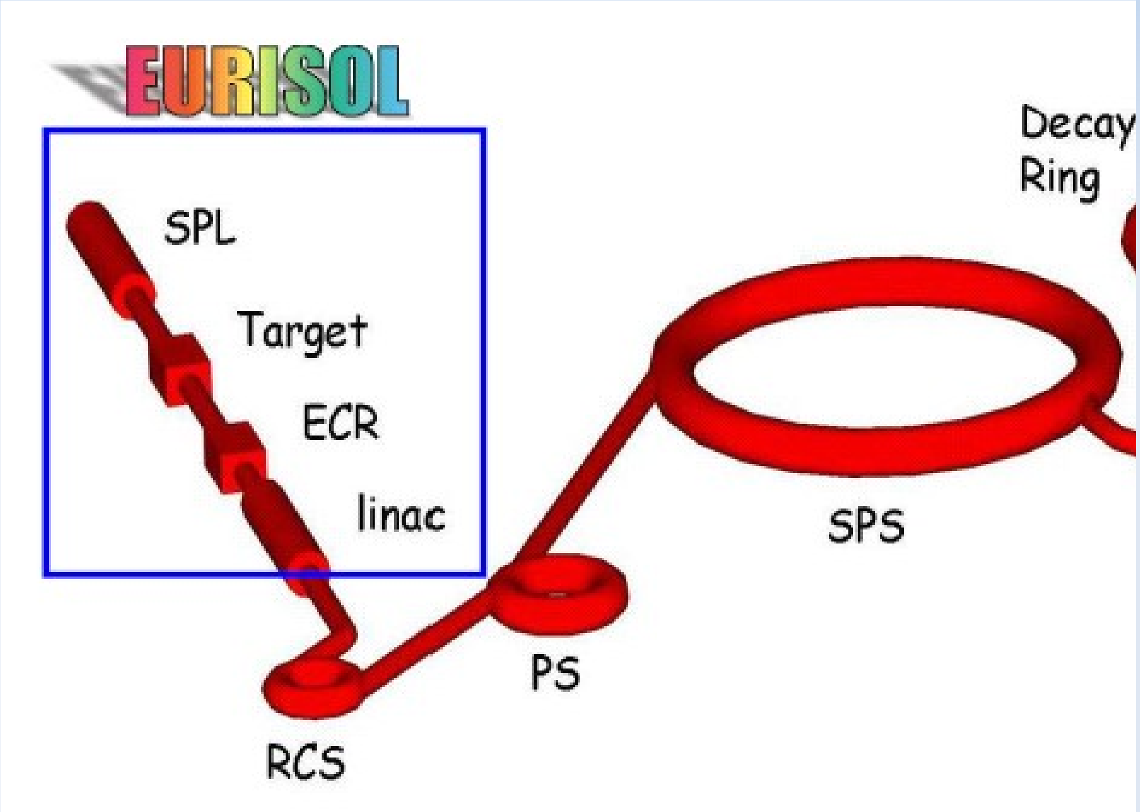
**Peter Valko**

**Thierry Stora**

Target and Ion Source Development
EN-STI(ISOLDE)

For optimal sensitivity we need to deliver
$1.1\ 10^{19}\ \nu$
and
$2.9\ 10^{19}$ anti-$\nu$
over 10 years

Production of $\nu_e$ & anti-$\nu_e$:
$3(.3)\ 10^{13}\ {}^{6}He/s$
$2(.1)\ 10^{13}\ {}^{18}Ne/s$
**out of the primary target**
(Final report, FP6 EURISOL-DS

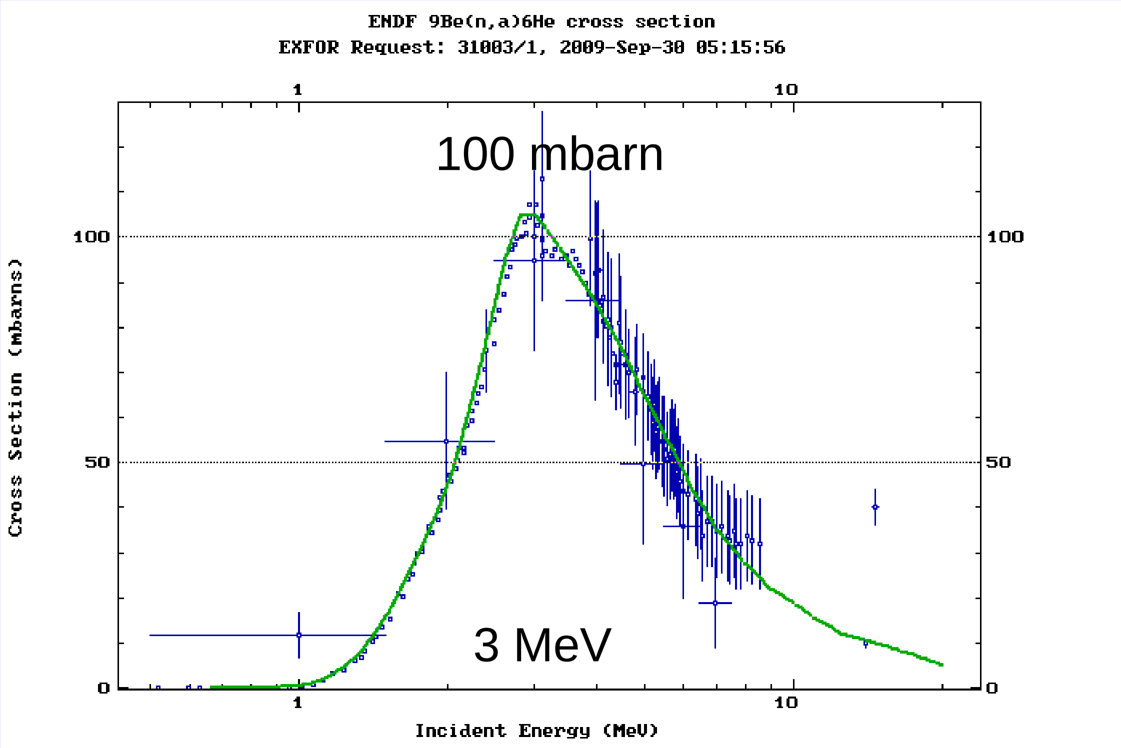


# Production of $^{6}He$ ions for beta beams

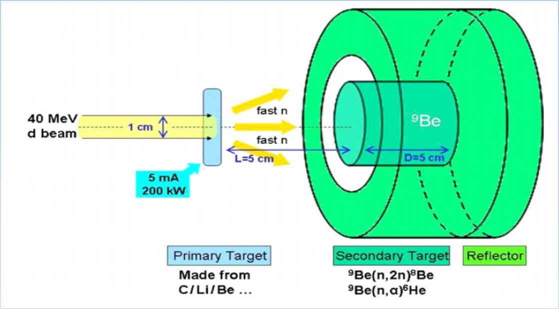
Elements driving the technical choices for isotopes and targets:

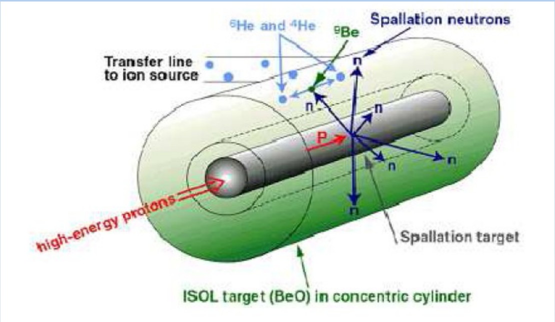
- Efficient production channels (high production cross-section σ)
- Isotopes "faciles" ($t_{1/2}$, release properties)
- Side effects (primary beam penetration range, heating, chemistry, …)

Production of $\nu_e$
Out of the target
$3 \cdot 10^{13}$ $^{6}He/s$



# Production of $^6$He ions for beta beams

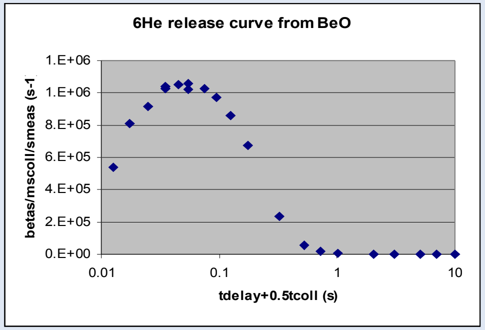



**M. Hass et al**

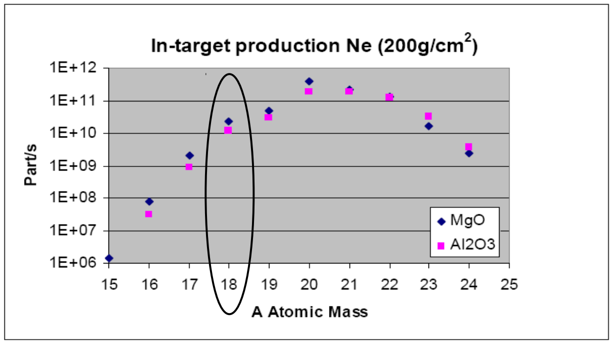
$10^{14}$ $^6$He/s 200 kW, 2 GeV proton beam in-target production. 50 – 90% extraction efficiency from realistic big targets
(reduced scale experiment doe at CERN-ISOLDE to confirm these numbers; Weizmann, GANIL and CERN collaboration).

Numbers have now been carefully checked. 1 kW of 1-2 GeV protons produces more $^6$He than 1 kW of 40 MeV deuterons.



# Production of $^{18}$Ne ions for beta beams

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

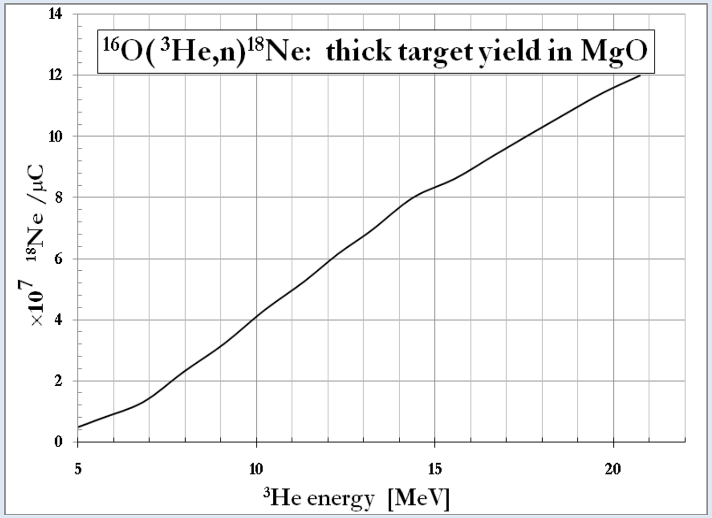



Silberberg-Tsao,
Thin target approx.

Nominal parameters:

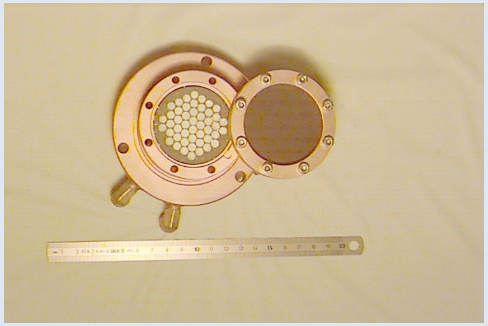
3 $10^{10}$ part/s (Fluka)

Production of $\nu_e$
Out of the target
2 . $10^{13}$ $^{18}$Ne/s




Validated at 9kW at LLN.
Needs ~ 200mA, $^3$He 21MeV, Ø86cm target

S. Mitrofanov,
M. Loiselet et al.



# Production of $^{18}$Ne ions for beta beams

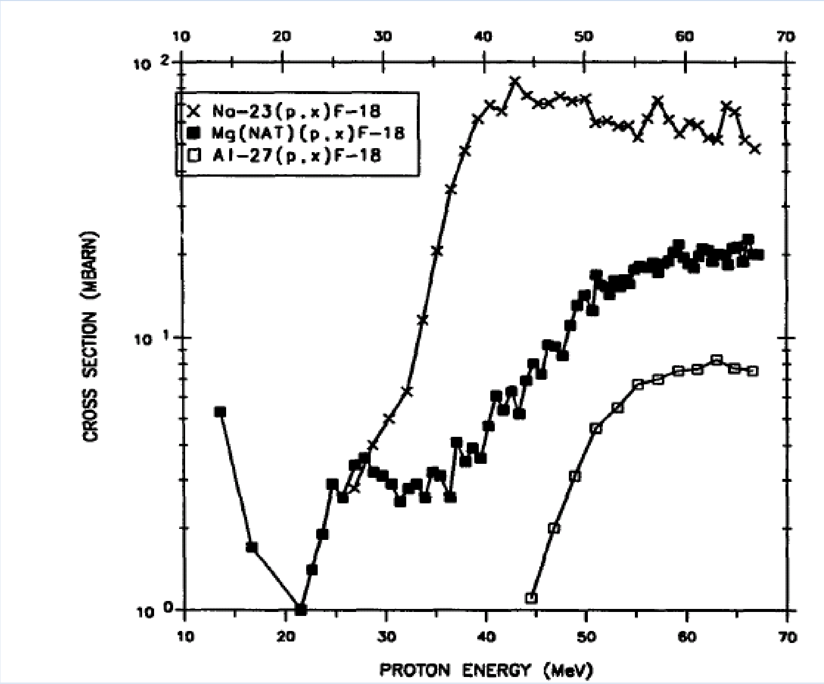
Other reactions (mainly coming from 18F production for PET imaging):

$^{19}$F(p,2n)$^{18}$Ne : threshold 16MeV, peak at 1.6mbarn @ 30MeV (M. Loiselet, S. Mitrofanof)

$^{24}$Mg(p,αp2n)$^{18}$Ne : threshold 39 MeV, cross-sections ?

$^{27}$Al(p,X)$^{18}$Ne : ~ 4 mbarn @ 50-70 MeV (Lanulas-Solar, 1988&1992)

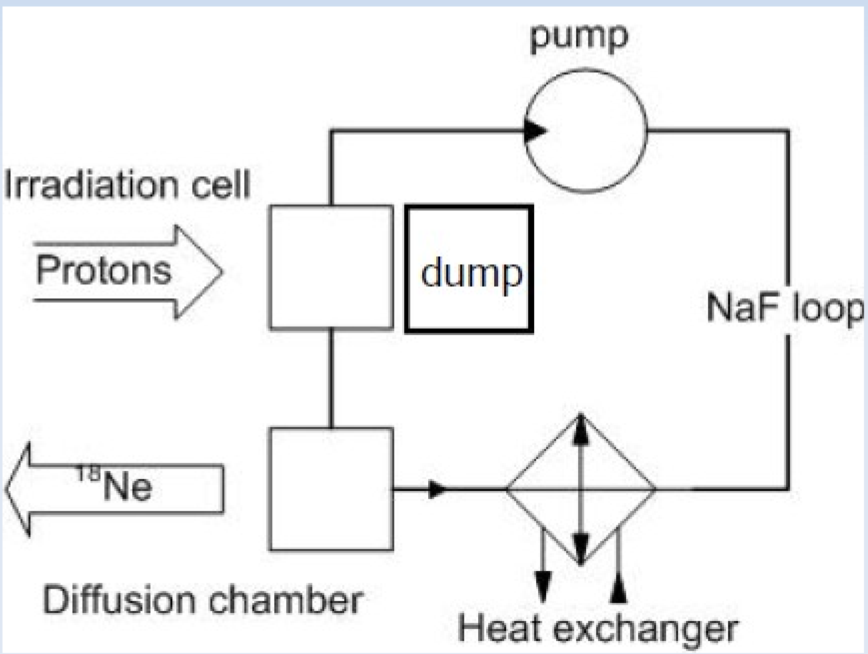
We need ~ 30mA, 70MeV p, and target R&D (~ 600kW to be dissipated) for 2 . $10^{13}$ $^{18}$Ne/s




**From worshop at CERN last year**

# Production of $^{18}$Ne ions for beta beams

## Conceptual target loop for 18Ne production:




More than 300 reports on molten salt reactors avaible from ORNL
Courtesy of O. Beneš, 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
Graphite 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 (848K 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

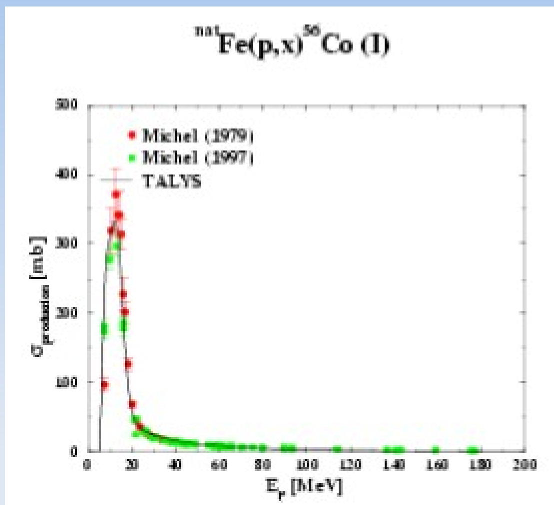
ORNL-5132: 1976-08 (37.9M PDF)
Molten-Salt Reactor Program: Semiannual Progress Report for Period Ending February 29, 1976

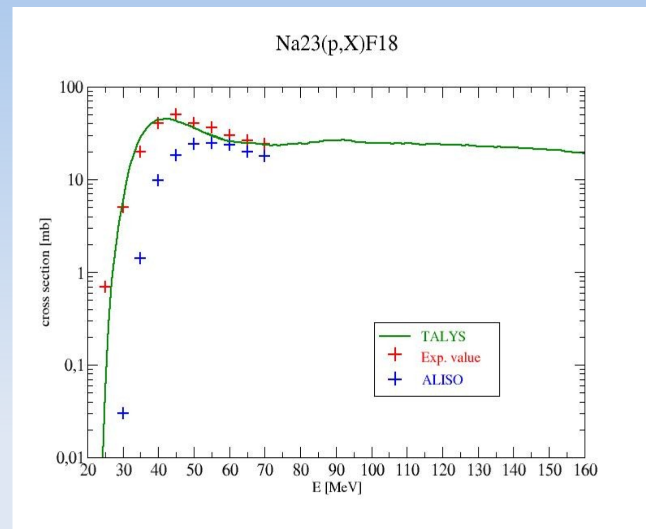
ORNL-5078: 1976-02 (30.4M PDF)
Molten-Salt Reactor Program: Semiannual Progress Report for Period Ending August 31, 1975

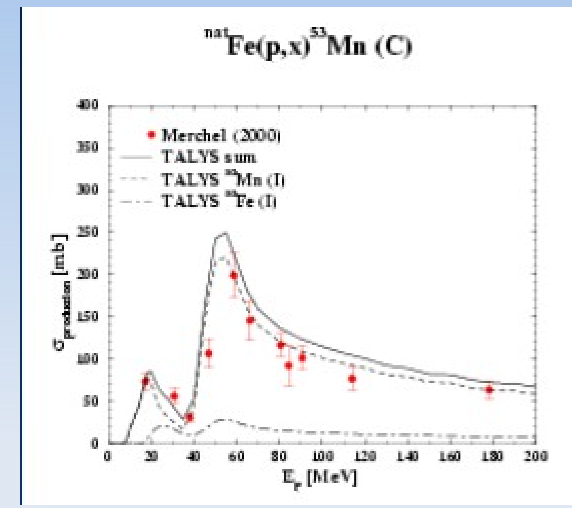
ORNL-5047: 1975-09 (32.1M PDF)
Molten-Salt Reactor Program: Semiannual Progress Report for Period Ending February 28, 1975

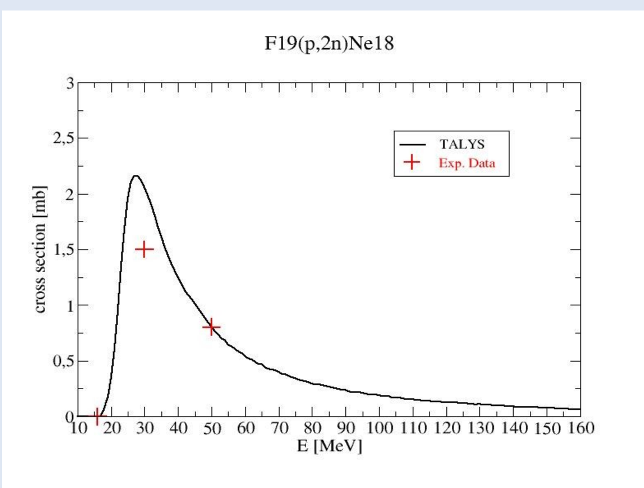
ORNL-5018: 1974-12 (40.6M PDF)
Program Plan for the Development of Molten-Salt Breeder Reactors

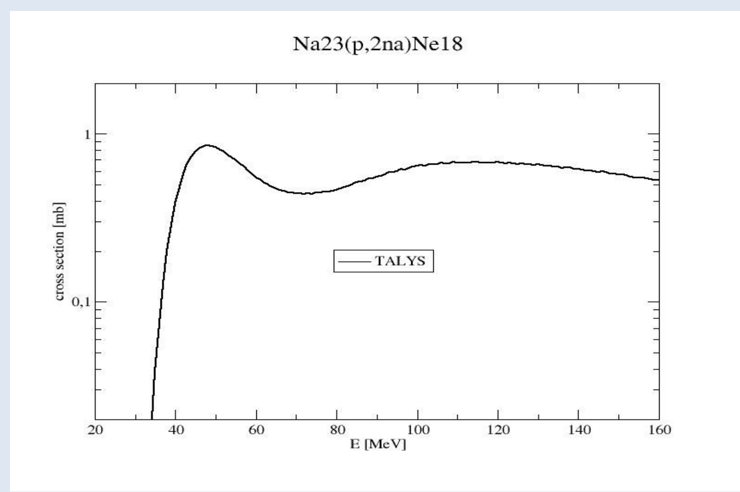
# TALYS code benchmarking




A.J. Koning, S. Hilaire, 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, S. Leray, EDP Sciences, 2008, p. 211-214

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

# Production of $^{18}Ne$ ions for beta beams

Selection of a suitable eutectic comprising Na and F nuclei:

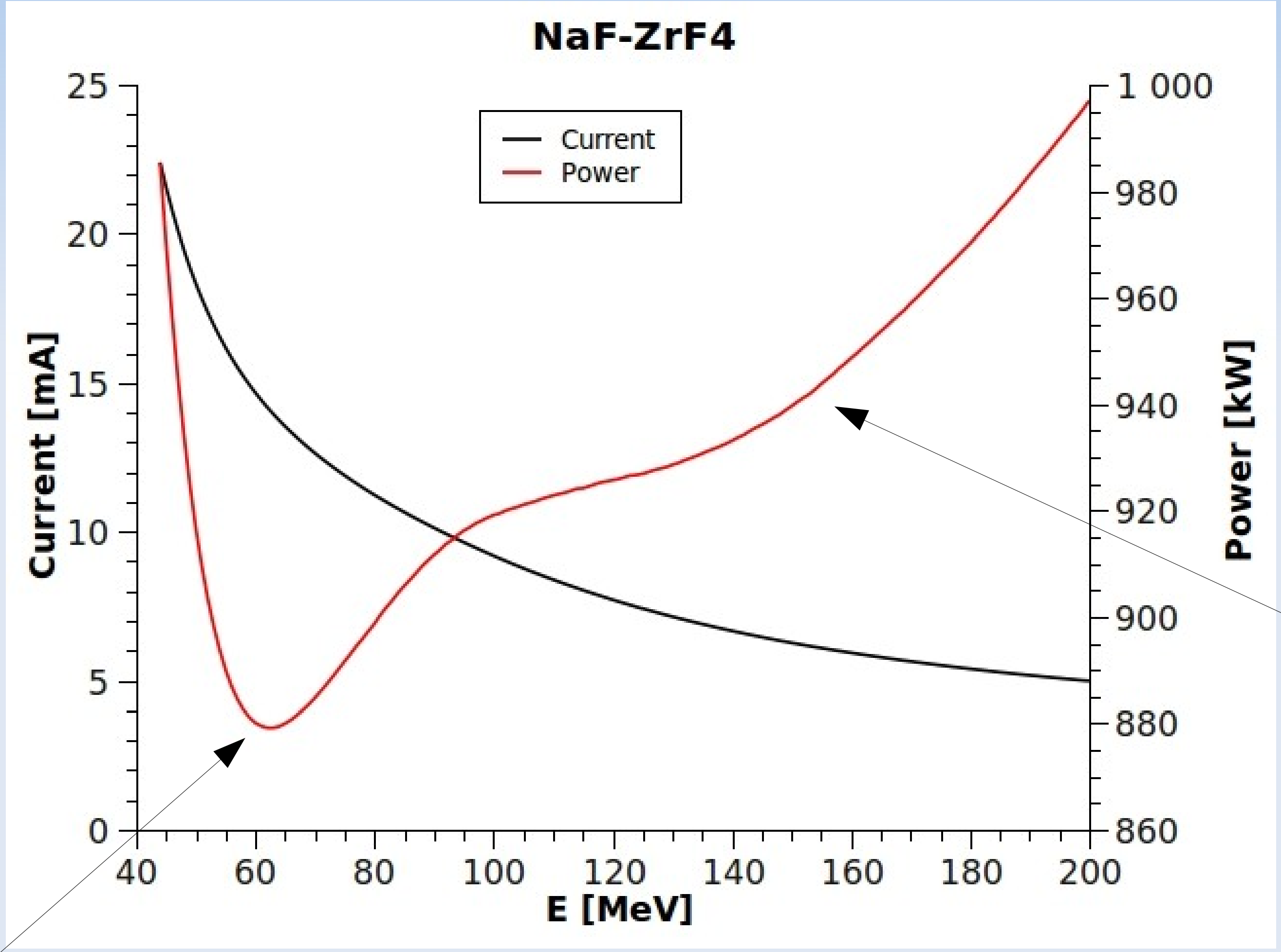
Melting point of NaF is ca 1000 ºC

| Salt | Composition [mol %] | Melting point [ºC] | Density [g/cm3] (700 ºC) | Viscosity [cP] (700ºC) | Vapor pressure [mmHg] (900ºC) | Yield protons 6mA 160MeV | Yield helium3 6mA 160MeV |
|---|---|---|---|---|---|---|---|
| NaF-BeF2 | 57 - 43 | 340 | 2.01 | 7 | 1.4 | 8.8E+012 | 7.1E+012 |
| NaF-NaBF4 | 8 - 92 | 384 | 1.75 | 0.9 | 9500 | 8.4E+012 | 6.9E+012 |
| NaF-ZrF4 | 60 - 40 | 500 | 3.14 | 5.1 | 5 | 1.0E+013 | 8.2E+012 |

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)

# Production of $^{18}$Ne ions for beta beams

The beam current and power for a constant yield $10^{13}$ $^{18}$Ne/s




Upgraded LINAC 4

Lowest power

# Production of $^{18}$Ne ions for beta beams

## Candidate materials for molten salt loop

| Candidate material | Salt corrosion resistance | Air corrosion resistance | Long-term strength at 1000 °C | Highest usage temperature [°C] |
|---|---|---|---|---|
| Hatelloy N | Excellent | Good | Very good | 730 |
| Haynes 242 | Very good | Good | Very good | 540 |
| Alloy 800H or HT | Poor-fair | Good | Very good | 980 |
| Haynes 214 | Very good | Good | Good | 1000 |
| MA 956 | Very good | Good | Good | ? |
| MA 754 | Very good | Good | Good | ? |
| Cast Ni superalloys | Very good | Good | Good | ? |

O. Benes, el. al., ALISA, Review Report on Liquid Salts for Various Application, version V4

# Production of $^{18}$Ne ions for beta beams

## Candidate materials for molten salt loop

Hastelloy N is the most promising candidate for application up to 750 ºC

Hastelloy N composition:

| | Cr | Mo | W | Al | Ti | Fe | C | Co | Ni |
|---|---|---|---|---|---|---|---|---|---|
| Hastelloy N | 6.31 | 16.1 | 0.06 | 0.01 | 4.03 | 0.03 | 0.03 | 0.15 | 72.2 |

O. Benes, el. al., ALISA, Review Report on Liquid Salts for Various Application, version V4

# Production of $^{18}$Ne ions for beta beams

## Candidate materials for molten salt loop

| Loop # | Alloy | Salt | Duration [h] | $T_{max}$ [°C] | Corrosion depth [mil] | ORNL report # or [reference] |
|---|---|---|---|---|---|---|
| 15A | INOR-8 | $73LiF\text{-}2BeF_2\text{-}25ThF_4$ | 39476 | 677 | 0.05 | *TM-4286* |
| 1208 | INOR-8 | FLiNaK | 8760 | 677 | 1 | *2799* |
| 1190 | INOR-8 | $58NaF\text{-}35BeF_2\text{-}7ThF_4$ | 8760 | 677 | 1 | *2799* |
| 1233 | INOR-8 | $71LiF\text{-}16BeF_2\text{-}13ThF_4$ | 8760 | 677 | 0 | *2973* |
| 1213 | INOR-8 | $71LiF\text{-}29ThF_4$ | 3114 | 677 | 0 | *2626* |
| 15 | INOR-8 | $73LiF\text{-}2BeF_2\text{-}25ThF_4$ | 2003 | 677 | 0 | *TM-4286* |
| 1165 | INOR-8 | FLiNaK | 1340 | 677 | 0 | *2551* |
| 1164 | INOR-8 | $58NaF\text{-}35BeF_2\text{-}7ThF_4$ | 1000 | 677 | 0 | *2551* |
| 1221 | INOR-8 | $71LiF\text{-}29ThF_4$ | 1000 | 677 | 0 | *2626* |
| 1228 | INOR-8 | $71LiF\text{-}16BeF_2\text{-}13ThF_4$ | 1000 | 677 | 0 | *2723* |
| MSRE | INOR-8 | $67LiF\text{-}33BeF_2$ | 26000 | 649 | 0 | *TM-4174* |
| 9354-3 | INOR-8 | $35LiF\text{-}27NaF\text{-}38BeF_2$ | 19942 | 649 | 0 | *3215* |
| 1194 | INOR-8 | FLiNaK | 1000 | 607 | 0 | *2551* |
| 1195 | INOR-8 | $35LiF\text{-}27NaF\text{-}28BeF_2$ | 1000 | 607 | 0 | *2551* |

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)

# Production of $^{18}$Ne ions for beta beams

## Scaling of the irradiation chambre:

For $\Delta T$ = 100 ºC, Cp = 1.17 J/g.K, we need **2.1 l/s**

Size of the window is 360 cm$^2$,
e.g. 15X24 cm$^2$
Projected range is 7.5 cm

Size of the chambre:
**15x24x7.5 cm$^3$**

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

**Calculated with SRIM**

| 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 |
| 8 | 30 | 178 |
| Total target | 126 MeV | 756 |
| Total dump | 31 MeV | 186 |
| Total window (1 mm thick) | 3 MeV | 18 |

# Production of $^{18}$Ne ions for beta beams

## Scaling of the irradiation chambre:

Cooling of the window (10 kW for 0.5 mm thickness) is done with the circulating molten salt.

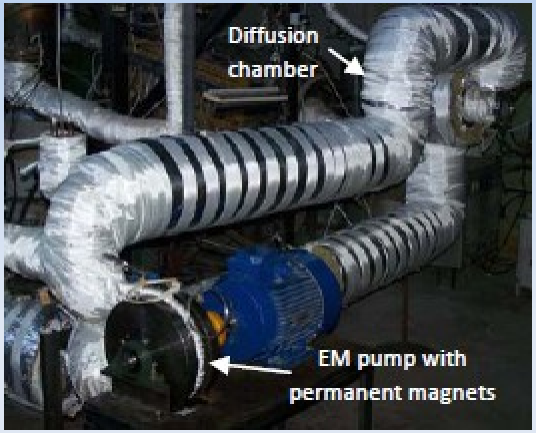
Heat transfer coefficient estimates are avaible on salt/Hastelloy N

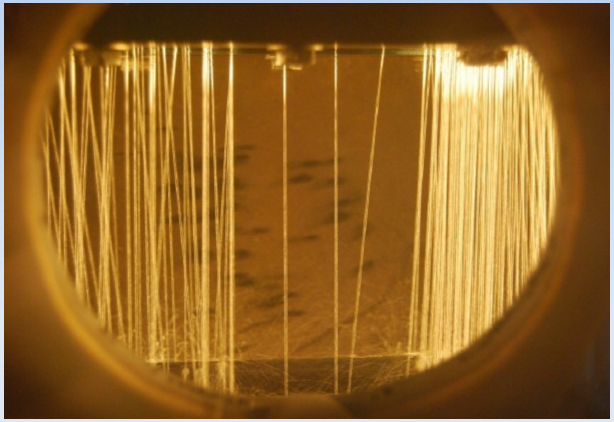
| Salt | Reynolds modulus | Prandtl modulus | Nusselt modulus | Fluid temperature [ºC] | Heat transfer coefficient [$W.m^{-2}.K^{-1}$] |
|---|---|---|---|---|---|
| NaF-NaBF4 | 5100-45000 | 5,3-5,64 | 35-225 | 450-610 | 1380-10100 |

M.D. Silverman, W.R. Huntley, H.E. Robertson, ORNL/TM-5335

# Production of $^{18}$Ne ions for beta beams

## Scaling of the diffusion chambre:



E. Noah @ IPUL Lab
Molten Pb/Bi
EURISOL DS

M. Fujioka, Y. Arai, Diffusion of Radioisotopes from Solids in the form of Foils, Fibers and Particles, Nucl. Instr. and Meth. 186 (1981) 409

Diffusion coeficients

D = 2-4 $10^{-5}$ $cm^2/s$ for Kr and Xe

D estimate at 4-8 $10^{-5}$ $cm^2/s$ for Ne

Mean diff. Time 0.13 s for 5 $10^{-5}$ $cm^2/s$

R.J. Kedl, A. Houtzeel, ORNL-4069: 1967-06

| Diffusion coefficient [mm2.s-1] | Hole radius [mm] | Released fraction Cylinder | Released fraction Sphere |
|---|---|---|---|
| 1.0E-003 | 0.25 | 0.35 | 0.47 |
| 2.5E-003 | 0.25 | 0.5 | 0.63 |
| 5.0E-003 | 0.25 | 0.64 | 0.76 |
| 1.0E-003 | 0.1 | 0.68 | 0.79 |
| 2.5E-003 | 0.1 | 0.83 | 0.9 |
| 5.0E-003 | 0.1 | 0.91 | 0.95 |

# Production of $^{18}Ne$ ions for beta beams

## Scaling of the diffusion chamber

Volume in diffusion chamber (droplets at 1 m/s)

Height: **40 cm** / tortuosity factor

Surface: **15x15 cm$^2$** / hole surface density (10 %)

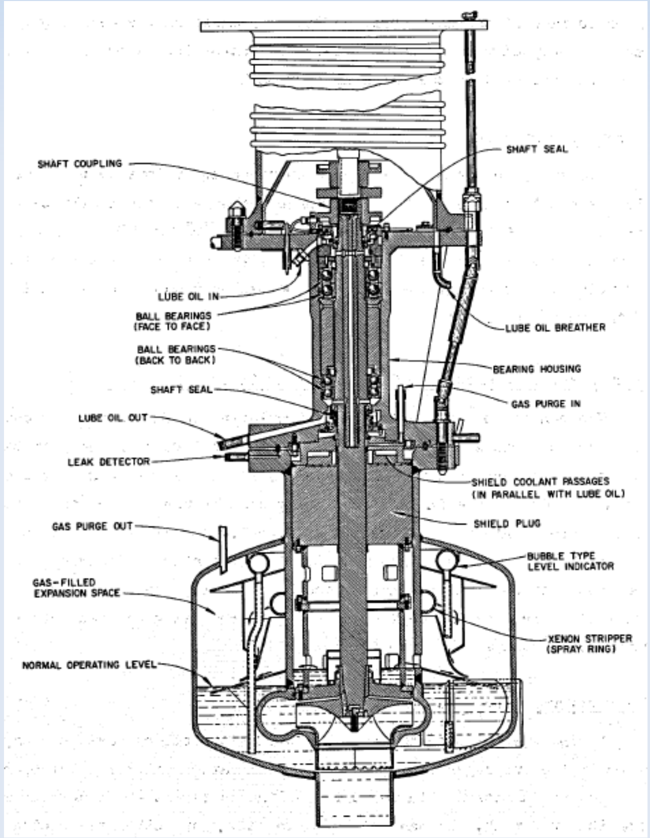
# Production of $^{18}$Ne ions for beta beams

## Pumps:

Cross section of Mark-2 Fuel-Salt Pump

| Model | Fluid[a] | Head (ft) | Flow (gal/min) | Speed (rpm) | Temperature (°F) | Number built | Total hours |
|---|---|---|---|---|---|---|---|
| LFB | Na, NaK, and MS | 92 | 5 | 6000 | 1100–1400 | 46 | 466,000 |
| DANA | Na, NaK, and MS | 300 | 150 | 3750 | 1000–1500 | 10 | 57,000 |
| DAC | MS | 50 | 60 | 1450 | 1000–1400 | 3 | 4,000 |
| In-Pile Loop | MS | 10 | 1 | 3000 | | 8 | 14,000 |
| MF | NaK and MS | 50 | 700 | 3000 | 1100–1500 | 3 | 41,000 |
| PKA | NaK and MS | 400 | 375 | 3550 | 700–1500 | 2 | 21,500 |
| PKP | NaK and MS | 380 | 1500 | 3500 | 700–1500 | 4 | 45,000 |
| MSRE fuel salt pump | MS and Helium | 50 | 1200 | 1175 | 1000–1225<br>100–1200 | 2 | 31,600<br>6,000 |
| MSRE coolant salt pump | MS and Helium | 78 | 800 | 1775 | 1000–1225<br>100–1200 | 2 | 24,600<br>4,000 |
| MSRE Mark-2 fuel salt pump | MS | 50 | 1200 | 1175 | 1000–1300 | 1 | 14,000 |
| ALPHA | MS | 300 | 30 | 6500 | 850–1400 | 1 | 6,000 |

C.W. Forsberg, ORNL/TM-2006/92




P.G. Smith, ORNL/TM-2987 TN (1970)

# Outlook

The goal is to provide a proposal with as close as possible technologies which are realistic. In particular, 100's kW rather than MW target dimensioning.

From present 1st order estimates, we need 6 mA, 160 MeV proton Linac, 700kW target loop technology, and ~ 8 years of operation to deliver the integrated 1.1e19 $\nu$.
This will certainly still evolve. Some experimental data are absolutely required.

# Acknowledgements

E. Noah during EURISOL-DS for the molten metal loop prototype at IPUL

O. Beneš et al., ITU, JRC

E. Wildner, V. Vlachoudis, J. Lettry, R. Garoby, M. Vretenar, …

Thank you!