April 25th to 27th 2023





EURASIS – **EUropean RAre Stable Isotope Supply**

- contribution to NuPECC Long Range Plan 2024

searching a way out from supply shortage

Mission statement

In our view this is a burning issue and finding a solution should be made a prominent topic of the next NuPECC LRP. We therefore propose to pursue this initiative under the acronym **EURASIS** (*EUropean RAre Stable Isotope Supply*). Its aim is to define a European strategy towards a guaranteed ESI supply for European research in Nuclear Physics and beyond.



Dieter Ackermann



Caen, France

Bormio, February 10th 2023



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Mission statement

searching a way out from supply shortage

The supply shortage of enriched stable isotopes (ESI), severely aggravated by the Russian aggression against Ukraine and its consequences, calls for a solution with the aim to warrant a secure provision of European research institutions. Without these basic materials essential fundamental research activities will come to a halt, once the still available limited reserves are consumed.

The situation is affecting not only the nuclear physics community and a concerted action plan is urgently needed, in synergy with all disciplines and communities concerned, in fields like e.g. research in nuclear medicine applications, Mössbauer spectroscopy and neutrinoless double-\(\beta \) decay. The international character of fundamental research and the respective scientific collaborations demand for an international and **discipline-overarching effort** to solve this global problem.

For some production schemes and isotopes, like ⁴⁸Ca enriched by the electromagnetic isotope separation (EMIS) technique, hitherto Russia played the lion's share world-wide. Measures to mitigate this dilemma could include the implementation of an EMIS facility in Europe, ideally embedded in an international network.

Aim:

define a European strategy towards a guaranteed ESI supply for European research in Nuclear Physics and beyond

Working group (all 4 disciplines represented)

Contact: Dieter Ackermann, GANIL, Caen, France

Edit Szilágyi, Wigner Research Centre for Physics, Budapest, Hungary

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Ulli Köster, Institut Laue-Langevin, Grenoble, France Julia Even, University of Groningen, The Netherlands Ralf Röhlsberger, Helmholtz Institute Jena, DESY, Hamburg, Germany

Paul Greenlees, JYFL Cyclotron Laboratory, Jyväskylä, Finland

Juan Esposito, INFN Laboratori Nazionali di Legnaro, Italy Christoph E. Düllmann, *Department of Chemistry, Mainz University, Germany*

Paweł J. Napiorkowski, HIL, University of Warsaw, Warsaw, Poland Araceli Lopez-Martens, IJCLab, Orsay, France

Webpage: https://nupecc.org/eurasis/

Darmstadt, April 27th 2023

EURASIS – **EUropean RAre Stable Isotope Supply**

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Enriched stable Isotope (ESI) needs

- (accelerator) labs
- beams and targets

Production methods and critical material

- ElectroMagnetic Isotope Separation EMIS
- ⁴⁸Ca et al.

Alliances and Synergies

- medical (physics) research
- Mössbauer spectroscopy
- neutrinoless double-β decay

Possible sources for isotope supply

- extra-European
- NIDC (U.S.A.) https://www.isotopes.gov/
- possible European facility

Task/action plan

- NuPECC LRP preparation
- towards secured supply possible European facility





Isotopes and Methods

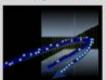
- needs to be established





Electromagnetic Isotope Separation (EMIS)

- Material feed is vaporized and ionized
- An electric field accelerates the ions to high speeds
- Magnetic field exerts force on the accelerated ions.



> First EMIS separations:

- ☐ Manhattan Project (1940s, USA)
- Soviet Atomic Project (1940s, Soviet Union)
 - Uranium-235,238 (UF₆)
 - Plutonium-239,240,241 (PuCl₃)
 - Lead-206,207,208

Area of use

Universal

Pros (+):

Ultra-high purity (> 94%)

Cons (-)

- Low production volume
- Low enrichment efficiency and selectivity
- High production cost

Annual production

Grams

Gaseous Centrifugation Isotope Separation (GCIS)



- Very high speed rotor generates centripetal force
- Heaver molecules concentrate closer to the rotor wall, lighter toward rotor
- Separation increases with rotor speed and length.

American Centrifuge Plant





Area of use

Gas phase

Chemical Exchange or

Cryogenic Distillation

Lighter isotope will be distilled over

first, leaving the heavier one behind

Used for Hg isotopes where frozen Hg

from the cooled surface is removed,

melted and evaporated under vacuum

Pros (+)

again.

- Mass effective
- Low production cost
- Mature & large scale

Cons (-) for cryogenic distillation

High E consumption Annual production

Tonnes

Area of use

Gas phase

Pros (+)

- Mass effective
- Low production cost

Cons (-)

- Requires many steps
- Lower purity compared to EMIS

Annual production

Thousands of tonnes

Gaseous diffusion has been replaced by the centrifuge technology (currently the main market production method) after 50 years...

Dieter Ackermann Darmstadt, April 27th 2023

taken from IDEAAL project – report Magdalena Kurzyp 31.08.2020 – courtesy Marek Lewitowicz



Isotopes and Methods

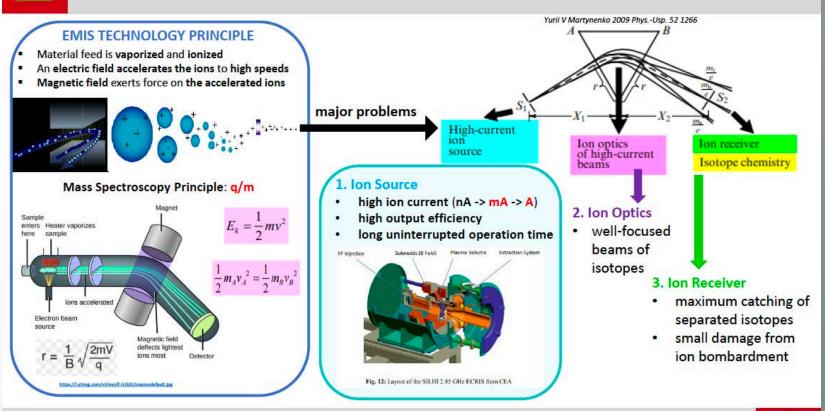
- EMIS







ELECTROMAGNETIC ISOTOPE SEPARATION: PRINCIPLE AND MAJOR PROBLEMS



Commissariat à l'énergie atomique et aux énergies alternatives

Dieter Ackermann

10

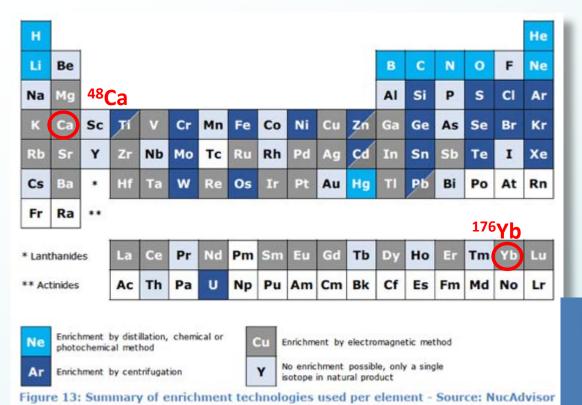
Darmstadt, April 27th 2023

Isotopes and Production Methods

- critical: separation by EMIS only (grey squares)







Nuclear Physics:

• ⁴⁸Ca crisis

Medical research and applications

176Yb – seed for 177Yb/177Lu

Mössbauer spectroscopy

57Fe/57Co

Neutrinoless double- β decay

48Ca

Co-ordinated Approach to the Development and Supply of Radionuclides in the EU

N°ENER/D3/2019-231

Final Report

https://op.europa.eu/en/publication-detail/-/publication/4599de47-3ac6-11ec-89db-01aa75ed71a1/language-en



Science communities and synergies

- presently signing the EURASIS intiative





Nuclear physics and chemistry

⁴⁸Ca for SHN/SHE, light n-rich by fragmentation → extremely critical "⁴⁸Ca crisis" other isotopes needed:

ion beams: ^{40,-46}Ca, ⁴⁶⁻⁵⁰Ti, ⁵⁰⁻⁵⁴Cr, ⁵⁴⁻⁵⁸Fe, ⁵⁹Co, ^{58-,64}Ni, ^{63,65}Cu, ^{64,66,67,68,70}Zn, ^{74,76}Ge, ... targets: great variety including lanthanides (e.g. ytterbium isotopes) and actinides

Nuclear medicine research

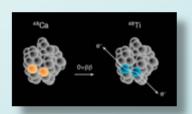
Stable isotopes, e.g. ¹⁷⁶Yb → also in SAMIRA – Europe's Beating Cancer Plan "SAMIRA Action Plan: Radiological and nuclear technology in support of Europe's Beating Cancer Plan".

Action proposed before Russia's attack on Ukraine

"Coordinated Approach to the Development and Supply of Radionuclides in the EU", N°ENER/D3/**2019**-231, Final Report.

Neutrinoless double-β decay

⁴⁸Ca also here the "work horse" – quantities from kg to tons (but less enriched)



Mössbauer spectroscopy

⁵⁷Fe major isotope for 90% of worldwide research of this large community



Dieter Ackermann Darmstadt, April 27th 2023

Possible supply sources

- urgent need for action





Possible supply sources

ROSATOM daughter: ElectroHimPribor-Atom EHP in Lesnoy (+ Obninsk and St. Petersburg) «Электрохимприбор» – ЭХП – <u>www.ehp-atom.ru/</u>

→ presently **not accessible** due to the situation created by the Russian attack on Ukraine and its geopolitical consequences - **future unclear**

China project of a magnetic separator by *China Institute of Atomic Energy* (CIAE)

→ problems: accessibility and supply reliability not established and uncertain

USA <u>Stable Isotope Production and Research Center (SIPRC)</u> at ORNL, Oak Ridge

→ under construction; preferential supply of USA laboratories but open for fundamental research on an international scale

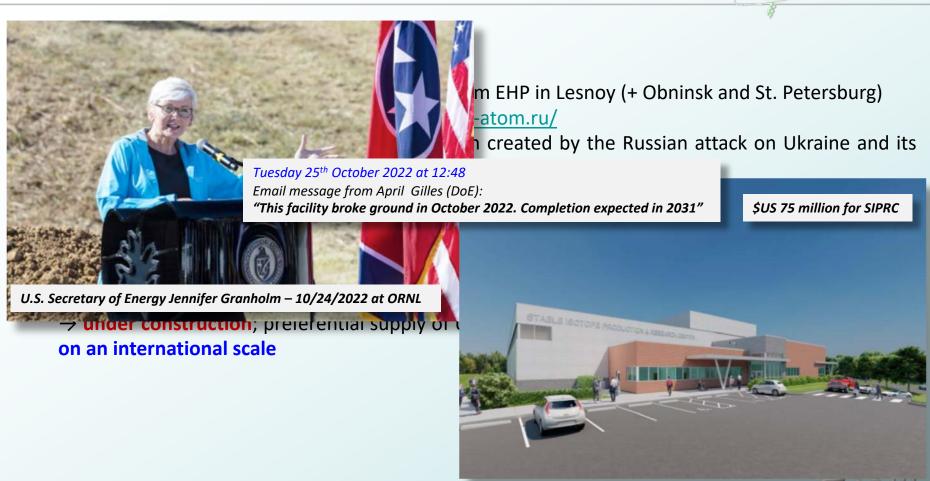


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Possible supply sources

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Possible supply sources

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Europe possible European project making Europe independent from extra-European supply

→ new project to be planned from scratch (EURASIS initiative)



Dieter Ackermann Darmstadt, April 27th 2023

NSAC LONG RANGE PLAN

- Town hall meeting - November 14th - 16th 2022







- EURASIS initiative presented in the isotopes working group meeting
- exchange our mutual progress continuously, given the common problems and interest
- EURASIS contribution to the White Paper (basis for the NSAC LRP)
- contact:

Sherry Yennello from TAMU (<u>yennello@chem.tamu.edu</u>) Etienne Vermeulen from LANL (etienne@lanl.gov)

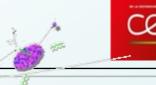
Importance of the synergies between USA and Europe concerning the isotope crisis was recognized

Dieter Ackermann



Action plan I

– first steps



Creation of a working group

• ideally with members of all interested labs 🗸

5-page document for NuPECC LPR until October 1st 2022

• accepted by NuPECC: https://indico.ph.tum.de/event/7050/abstracts/1563/ ✓

Production of the final NuPECC LPR contribution – in conjunction – continuous effort

• synergy with the preparation of NSAC LPR being prepared at the same time in the U.S.A. – contact stablished

creation of a EURASIS internet presence ✓

online

Envisaged actions during the period covered by the next LPR (and beyond) – continuous effort

- list of needed stable isotopes
- design of a possible European project for a EMIS facility
 - technical requirements
 - funding options
 - possible location of an EMIS facility in Europe

• ..





EURASIS webpage – on the **Null** website

- https://nupecc.org/eurasis/





Searching for a way out of the supply shortage

The inherent theme of science is to understand the fundamental principles of nature and to serve the progress of mankind in peace and harmony with nature

Mission statement

The supply shortage of enriched stable samples (ESI), severely aggravated by the Russian aggression against Ukraine and its consequences, calls for a solution with the aim to warrant a secure provision of European research institutions. Without these basic materials essential fundamental research activities will come to a halt, once the still available limited reserves are consumed.

The situation is affecting not only the nuclear physics community and a concerted action plan is urgently needed, in synergy with all disciplines and communities concerned, in fields like e.g. research in nuclear medicine applications, Mössbauer spectroscopy and neutrinoless double-β decay. The international character of fundamental research and the respective scientific collaborations demands for an international and discipline-overarching effort to solve this global problem.

For some production schemes and isotopes, like ⁴⁸Ca and other isotopes enriched by the electromagnetic isotope separation (EMIS) technique, hitherto Russia played the lion's share world-wide. Measures to mitigate this dilemma could include the implementation of an EMIS facility in Europe, ideally embedded in an international network.

In this situation EURASIS (EUropean RAre Stable Isotope Supply) has the aim to define a European strategy towards a guaranteed ESI supply for European research in Nuclear Physics and beyond.





Action plan II

next steps





Collection of isotope needs in Europe

envisaged completion date May, 26th 2023

Collection of isotope sources

• envisaged completion date May, 26th 2023

EURASIS document as input for the NuPECC LRP TWGs

envisaged completion date July, 28th 2023
 The document will be an extension of the NuPECC LRP proposal and will include the lists of isotopes and suppliers mention above. It will be published on the EURASIS webpage

R&D and strategy for a European EMIS facility

- France: SIDONIE
- combination of EMiS with various enrichment methods
 - Chemistry
 - Molten Salt Counter Current Electromigration MS-CCEM
 - laser Isotope separation LIS

• ..

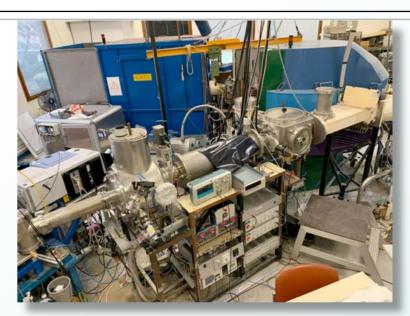




EMIS R&D

- example: isotope separator SIDONIE, IJCLab, Orsay, France





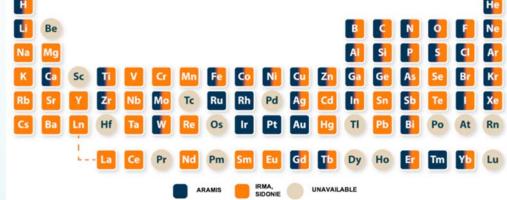
SIDONIE (commissioning 1958)

Ion source Nier-Bernas

acceleration 40 kV bending angle 135°

resolution R>1000

impurity rate <10⁻⁵



Objectives

- creation of targets for fundamental nuclear physics,
- creation of standards (metrology)
- supply of isotopes of the highest purity for medicine

Yields

10 % isotope partition: **50 μg/cm²/day**

Aurelie Gentils et al.

https://jannus-scalp.ijclab.in2p3.fr/en/irradiations/sidonie-2/



Darmstadt, April 27th 2023

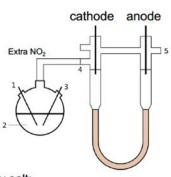
Enrichment methods

- example: Molten Salt Counter Current Electromigration - MS-CCEM









Ternery salt:

42% Ca(No₃)₂

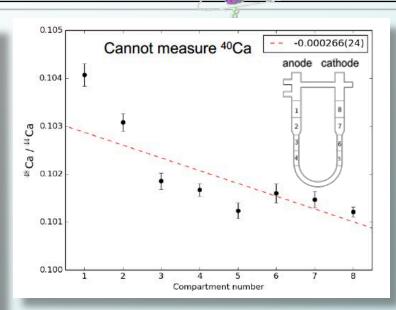
43% KNO₃
 15% NaNO₃

Melting point 130° C!

NdG, Levi Sleegers Presented at NNV subatomic physics (2018)

10-2-2023





Results:

- 80V, 8mA, 9 days (6.2kC)
- · 2% enrichment

Lessons learned:

- Coarser sand, higher current
- Better electrodes

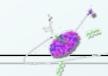
Nicolo de Groot, Radboud Univ. and Nikhef, Nijmegen, The Netherlands EURASIS WS, Bormio 10.02.2023

Dieter Achermann Darmstadt, April 27^{st.} 2023

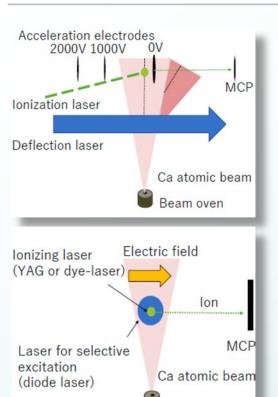


Enrichment methods

- example: laser Isotope separation (LIS) - deflection and ionization methods







Beam oven

Deflection

- ⁴⁸Ca vapor
- momentum transfer by repeating excitation and de-excitation of atoms few 100x with photons from a diode laser
- stable concentration

recovery plate at 4.1 mm:
recovery rate 19.6%
enrichment 5.5%

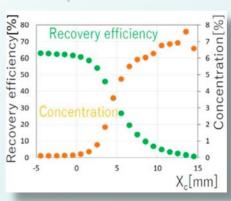
Ionization

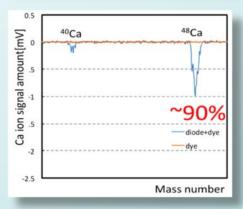
- ⁴⁸Ca vapor
- selective 1st excitation by diode laser
- ionization by absorbing two photons from dye laser

enrichment up to 90%

comparison to deflection:

concentration rate higher recovery rate per unit time lower





K. Matsuoka et al., J. Phys.: Conf. Ser. 1468)2020) 012199

Dieter Achermann Darmstadt, April 27th 2023

Institutions and contacts – the EURASIS Working group

- institution, contacts and mission statement





Grand Accélérateur National d'Ions Lourdes – GANIL, Caen France
Wigner Research Centre of Physics, Budapest, Hungary
GSI/FAIR, Darmstadt, Germany
Institute Laue-Langevin, Grenoble, France
Van Swinderen Inst. f. Particle Phys. and Gravity
Hdelmholtz Inst. Jena and Desy, Hamburg, Germany
JYFL Cyclotron Laboratory, Jyväskylä, Finland
INFN Laboratori Nazionali di Legnaro

Laboratoire de Physique des 2 Infinis Irène Joliot-Curie, Orsay France

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- Ulli Köster
- Julia Even
- Ralf Röhlsberger
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- Pawel Napiorkowski
- Araceli Lopez-Martens

Mission statement

Department of Chemistry, Mainz University, Germany

Heavy Ion Lab. at the University of Warsaw, Poland

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