BeYOND-IX
2022
9th Industrial Forum on Beryllium Opportunities & New Developments
Karlsruhe, Germany
16 September 2022

Proceedings of the 9th Industrial Forum on Beryllium Opportunities & New Developments (BeYOND-IX)

KBHF

Karlsruhe Beryllium Handling Facility (KBHF GmbH)
Eggenstein-Leopoldshafen, Germany

Proceedings of the 9th Industrial Forum on Beryllium Opportunities & New Developments (BeYOND-IX)

Publication Date: November 2022

Publishing Team:

Karlsruhe Beryllium Handling Facility (KBHF GmbH) Herrmann-von-Helmholtz-Platz 1 D-76344 Eggenstein-Leopoldshafen, Germany URL: KBHF | FUSION FOR FUTURE (fusion-for-future.de)	KBHF
Be4FUSION LLC 443 North Euclid Avenue Upland, California 91786-4733 U.S.A. URL: https://www.be4fusion.com	Be4FUSION Specialty Materials & Business Consulting
Lemmens Medien GmbH Matthias-Grünewald-Strasse 1-3 D-53175 Bonn, Germany URL: https://www.lemmens.de	LEMMENS Bildung, Forschung, Technologie
FUSION FOR FUTURE Website Home & Support URL: https://www.fusion-for-future.de	FUSION FOR FUTURE

For editorial inquiries about this publication, please contact:

Chris DORN, Corresponding Editor
EMAIL: chris.dorn@be4fusion.com

Published in Germany
ISBN 978 3 86856 027 5
DOI 10.53174/BeYOND/IX/2022

ISBN 978 3 86856 027 5
DOI 10.53174/BeYOND/IX/2022

Proceedings of the 9th Industrial Forum on Beryllium Opportunities & New Developments (BeYOND-IX)

Christopher DORN[1] and Aniceto GORAIEB[2] (Eds)

[1]Be4FUSION LLC, Upland, California, U.S.A.
[2]Karlsruhe Beryllium Handling Facility (KBHF GmbH), Eggenstein-Leopoldshafen, Germany

The 9th Industrial Forum on Beryllium Opportunities & New Developments (BeYOND-IX) was held on 16 September 2022 on the North Campus of the Karlsruhe Institute of Technology (KIT) in Eggenstein-Leopoldshafen, Germany, in conjunction with the 15th International Workshop on Beryllium Technology (BeWS-15) and with the Symposium on Fusion Technology (SOFT-32 in Dubrovnik, Croatia). The workshop has been held periodically since 2009.

These Proceedings of BeYOND-IX have been compiled from the documents generated by the workshop organizers, combined with the abstracts and presentation files submitted by the participants in the event.

The BeYOND-IX was organized by the Karlsruhe Beryllium Handling Facility (KBHF GmbH) with technical support from KIT (Karlsruhe Institute of Technology) in Germany, the UK Atomic Energy Authority (UKAEA) in the United Kingdom, and Be4FUSION LLC in the U.S. Participants came mainly from Germany, U.S.A., UK, France, Japan, Kazakhstan, Czech Republic, Portugal, Sweden, and Latvia.

Keywords: Beryllium, Fusion Engineering, Irradiation Effects, Beryllide Intermetallic Compounds, Plasma-Facing Materials, Neutron-Multiplier Materials, Health and Safety, Chronic Beryllium Disease, Beryllium Sensitization, Fusion Start-Ups, Molten Salt, FLiBe, Fusion for Future, Mankind Project, Karlsruhe Beryllium Handling Facility, KBHF

Table of Contents

Introduction & Executive Summary

The 9th Industrial Forum on Beryllium Opportunities & New Developments (BeYOND-IX) was held on 16 September 2022 on the North Campus of the Karlsruhe Institute of Technology (KIT) in Eggenstein-Leopoldshafen, Germany, in conjunction with the 15th International Workshop on Beryllium Technology (BeWS-15) and with the Symposium on Fusion Technology (SOFT-32 in Dubrovnik, Croatia). The workshop was held annually from 2009-2014, and generally once every two years since 2016.

The objective of the workshop for scientists and engineers around the world is to share the results of their efforts to develop technology in the application and safe use of beryllium in fusion energy research, with emphasis on making connections between established research institutes and commercial industry. This idea now takes on a higher level of importance with the founding of many fusion start-up companies in the past few years.

The BeYOND-IX workshop was organized by the Karlsruhe Beryllium Handling Facility (KBHF GmbH) with technical support from KIT (Karlsruhe Institute of Technology) in Germany, the UK Atomic Energy Authority (UKAEA) in the United Kingdom, and Be4FUSION LLC in the U.S. Participants came mainly from Germany, U.S.A., UK, France, Japan, Kazakhstan, Czech Republic, Portugal, Sweden, and Latvia. There were some new, first-time aspects to this year’s event:

- Held in conjunction with the BeWS-15, as part of a 3-day joint event
- Featured participation from fusion start-up companies
- Run in a hybrid format with both in-person and online attendees and presenters
- Included a tour of the Karlsruhe Beryllium Handling Facility (KBHF)

The program was comprised of 14 presentations, ranging from the goals of two fusion start-up companies, progressing to those focused on beryllium health and safety, and followed by a session on beryllium use in molten salts, a dormant area of energy research that is now seeing a resurgence in interest for both fission and fusion applications.

To foster networking and collaboration, the UK Atomic Energy Authority (UKAEA) presented about their Fusion Cluster initiative, an opportunity for interested parties to seek possible synergies across the global community of fusion companies and research institutes. On top of that, KBHF introduced its own "Fusion for Future" concept, which also includes the Mankind Project, a non-profit organization that is now positioned to play a role in expanding fusion cooperation in an even broader social sense.

The Dr. Glen Longhurst Memorial Award (GLMA) was established at BeYOND-IX to recognize outstanding contributions in fusion-related beryllium research. This year, Chris Dorn of Be4FUSION and UKAEA was the chosen recipient, based on his work in beryllium and fusion over the past 30 years.

The final BeYOND-IX program is included near the beginning of these Proceedings to introduce the abstracts and presentations that follow. A list of the registered participants may be found in the Appendices of this document.

Aniceto GORAIEB
BeYOND-IX Chair
Karlsruhe, October 2022

BeYOND-IX Final Technical Program

The technical program was organized by the BeYOND-IX Chair, Aniceto Goraieb of KBHF in Germany, with help from the BeWS-15 Chair, Dr. Pavel Vladimirov of KIT in Germany, Kathryn Creek of Beryllium Solutions International in Portugal, and Chris Dorn of UKAEA and Be4FUSION. This is the version of the program that was distributed to the participants at the workshop.

BeYOND-IX: 16.09.2022

Start	End	Time	Item	Presenter	Session	Chair
9:00 AM	10:00 AM	1:00	KBHF Lab-Tour	KBHF/GVT		
10:00 AM	10:20 AM	0:20	Shuttle-Service from Lab to Event-Location			
10:30 AM	10:55 AM	0:25	The Fusion Cluster at UKAEA	Valeri Jamieson	**Session 1**	Markus Lemmens
10:55 AM	11:20 AM	0:25	Presentation from MARVEL-Fusion	Marvel-FUSION		
11:20 AM	11:45 AM	0:25	Program FUSION @ KIT	Dirk Radloff		
11:45 AM	12:10 PM	0:25	Fusion-for-Future-Potential-Pathways-to-Fusion-Energy	M. Lemmens/A. Goraieb		
12:10 PM	1:25 PM	1:15	Lunch Break & Exhibition			
1:25 PM	1:45 PM	0:20	Beryllium Regulatory Review and Communications Update	Theodore Knudson	**Session 2**	Christopher Dorn
1:45 PM	2:05 PM	0:20	Beryllium End-Use Applications & Material Forms & Their Effects on Protection Programs for Workers & Consumers	Chris Dorn		
2:05 PM	2:25 PM	0:20	HLA-DPB1 E69 Genotype and Exposure in Beryllium Sensitization and Disea	Lisa Barker/M. Mroz		
2:25 PM	2:45 PM	0:20	Occupational safety in the environment containing beryllium dust at HELCZA	Lukáš Toupal		
2:45 PM	3:05 PM	0:20	Standardized methods for molecular fluorescence determination of beryllium	Kevin Ashley		
3:05 PM	3:30 PM	0:25	Break & Exhibition			
3:30 PM	3:50 PM	0:20	New Be-contamination testing method	GVT & R. Gaisin	**Session 3**	Kathryn Creek
3:50 PM	4:10 PM	0:20	Commercial Challenges and Opportunities Associated with FLiBe for Fusion	Richard Pearson		
4:10 PM	4:30 PM	0:20	The Possible Toxicity of Beryllium Salts	Michael McCawley (online)		
4:30 PM	4:50 PM	0:20	The argument for standardized training in the Beryllium industry	Beth Walker (online)		
4:50 PM	5:10 PM	0:20	Beryllium sensitization testing - what we know and where we need to go	Kathryn Creek		
5:10 PM			ADJOURN			
Total		**8:00**				
			Beryllium Facility Design	Kathryn Creek	**Poster**	

BeYOND International Advisory Committee

Region/Country	**Name**	**Organization**
Europe/Germany (Founder & Chair)	Aniceto GORAIEB	Karlsruhe Beryllium Handling Facility (KBHF)
Europe/Germany	Dirk RADLOFF	Karlsruhe Institute of Technology (KIT)
North America/U.S.A.	Keith SMITH	Materion Brush Inc.
Asia/Japan	Keigo NOJIRI	NGK Insulators Ltd.

BeYOND-IX Sponsor Organizations

The organizers of BeYOND-IX would like to thank the following sponsors for their support of the workshop:

Materion Brush Inc. Mayfield Heights & Elmore, Ohio, U.S.A.	KIT - Karlsruhe Institute of Technology Eggenstein-Leopoldshafen, Germany
Beryllium Solutions International LLC Lourinha, Portugal	UK Atomic Energy Authority Abingdon, Oxfordshire, United Kingdom
KBHF - Karlsruhe Beryllium Handling Facility Eggenstein-Leopoldshafen, Germany	Be4FUSION LLC Upland, California, U.S.A.

Session 1: Fusion Programs & Industry Status

Developing a Fusion Ecosystem

V. Jamieson (UK Atomic Energy Authority, UK)

Developing a Fusion Ecosystem

Valerie Jamieson

United Kingdom Atomic Energy Authority (UKAEA), Abingdon, UK

With world-leading fusion energy companies and public fusion programme, the UK is recognised globally as a go-to place for fusion. In this talk, Valerie Jamieson describes the fusion landscape in the UK and why a technology cluster focused on fusion will play an important role in establishing a start-up ecosystem.

Corresponding Author:

Dr. Valerie Jamieson
Development Manager, The Fusion Cluster
valerie.jamieson@ukaea.uk
UK Atomic Energy Authority
Culham Centre for Fusion Energy
Culham Science Centre
Abingdon, Oxfordshire OX14 3DB
UNITED KINGDOM

THE FUSION CLUSTER

Developing a Fusion Ecosystem

Valerie Jamieson,
Development Manager, The Fusion Cluster

valerie.jamieson@ukaea.uk

BEYOND-IX/ 16 SEPTEMBER 2022

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 2

Contents 00

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 3

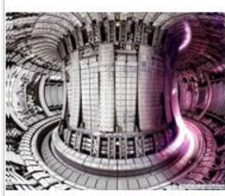
UK fusion 01

From research era to delivery era

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 4

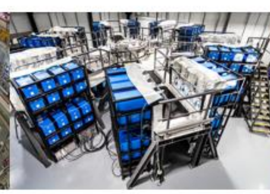
The fusion landscape in the UK

- World-leading fusion energy companies and public fusion programme.
- Recognised globally as a go-to place for fusion.



Joint European Torus broke fusion energy record in 2022

MAST-U tokamak divertor technology breakthrough 2021



First Light Fusion validate their innovative projectile approach in 2022

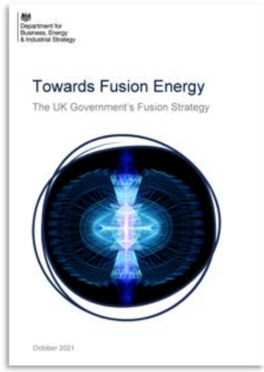
General Fusion building fusion demonstration plant

Tokamak Energy achieve 100 million degree plasma in 2022

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 5

The fusion landscape in the UK

- Regulatory framework for fusion that will accelerate innovation.
- Government has published a fusion strategy.
- Includes a programme to build a prototype fusion power plant, STEP.
- Includes UK fusion technology cluster.

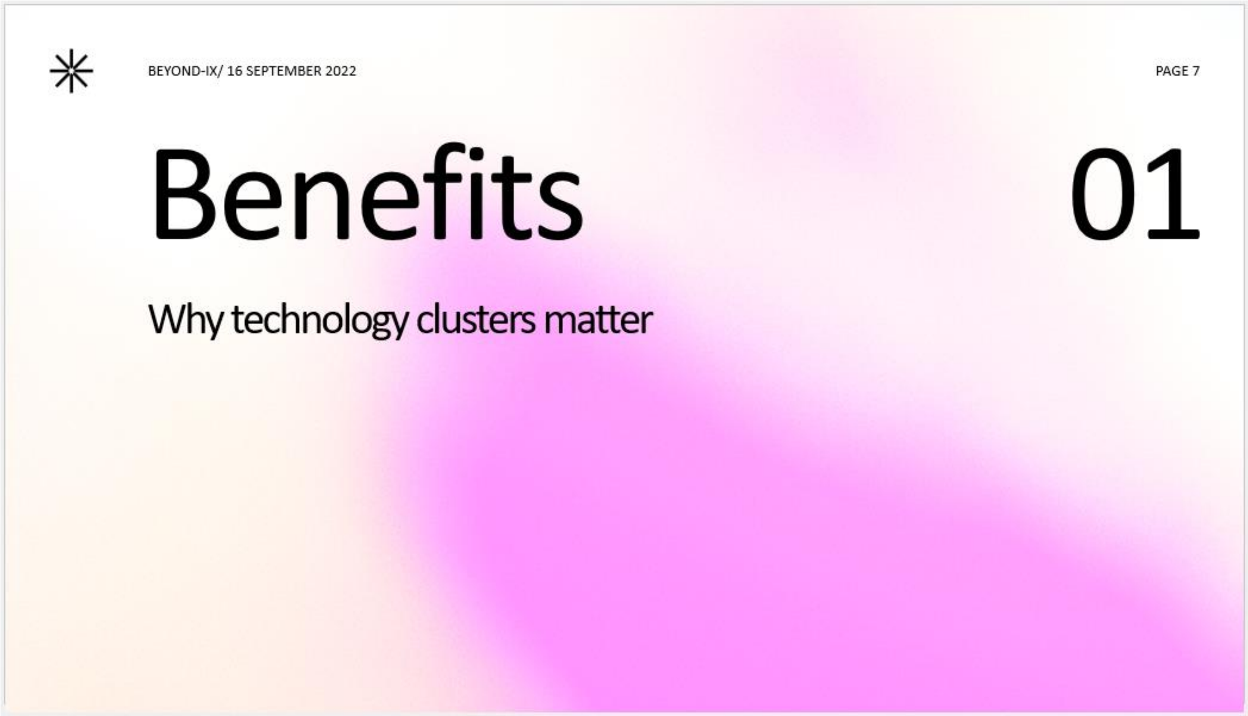


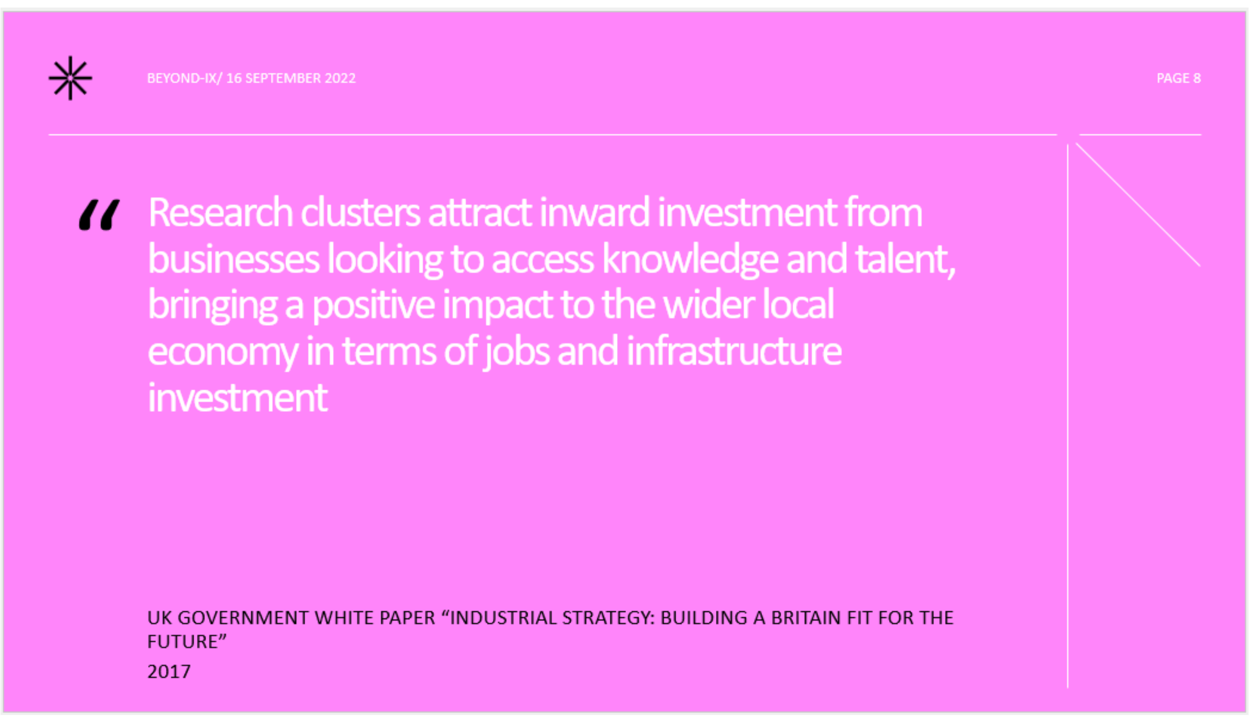
BEYOND-IX/ 16 SEPTEMBER 2022 6

STEP

Spherical tokamak connected to the National Grid and producing net energy from fusion. Not a commercially operating plant but will answer key questions about maintenance, operation and potential to produce its own fuel.

Phase 1 - concept design by 2024
Site shortlist and site selection 2022
Phase 2 – detailed engineering design
Phase 3 – construction with completion around 2040


BEYOND-IX/ 16 SEPTEMBER 2022
PAGE 7
Benefits
01
Why technology clusters matter


BEYOND-IX/ 16 SEPTEMBER 2022
PAGE 8
"Research clusters attract inward investment from businesses looking to access knowledge and talent, bringing a positive impact to the wider local economy in terms of jobs and infrastructure investment
UK GOVERNMENT WHITE PAPER "INDUSTRIAL STRATEGY: BUILDING A BRITAIN FIT FOR THE FUTURE"
2017

US technology clusters

10 technology clusters account for 70% of inventors in computer science

Productivity increases by 12% when inventors move from small technology clusters to large ones

Drop of 13% in computer science patents if clusters were disbanded

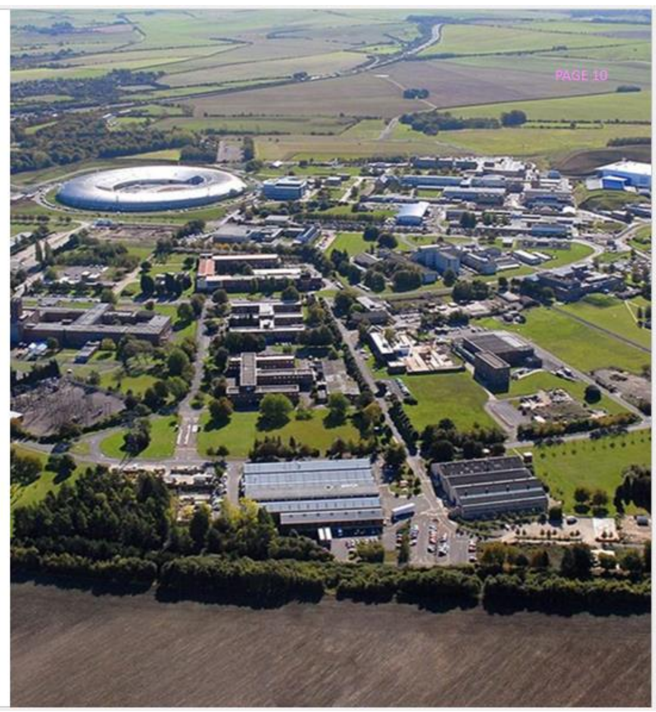
Enrico Moretti, "The Effect of High-Tech Clusters on the Productivity of Top Inventors" NBER Working Paper 26270

Harwell Space Cluster

Gateway to the UK space sector

105 space organisations
1,100 people

16% annual growth in employees



BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 11

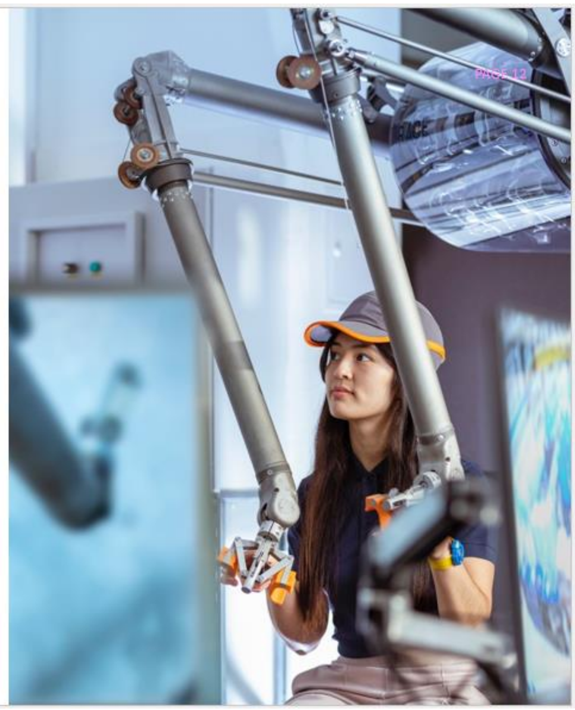
Mission 02

The Fusion Cluster brings the right organisations and people together to get to fusion faster.

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 12

Established November 2021, supported by UKAEA

- Fusion energy is too complex for any one organisation to achieve alone.
- The Fusion Cluster brings together businesses, academia, investors and government to create the conditions for success. It combines all the elements needed to help achieve fusion faster.
- We won’t achieve fusion energy immediately – there are still challenges to overcome – but for the first time practical fusion in within our reach. There will be benefits along the way, from new advances to spin-off technologies. The cluster will help realise them.



What the cluster offers

- Access to talent
- Access to national facilities
- Knowledge sharing
- Showcasing fusion
- Support for start-ups

National facilities

- Materials Research Facility – prepares and examples radioactive samples to assess their performance in nuclear environments.
- RACE – remote applications in challenging environments.
- H3AT – infrastructure to feed, recover, store and recycle tritium.
- CHIMERA – test component prototypes in high temperatures and magnetic fields.
- Central Laser Facility at Rutherford Appleton Laboratory.
- National quantum computing centre at Harwell.
- Hartree centre – high performance computing.

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 15

Our values.
Collaboration. Clarity. Community.

- We'll only achieve fusion together. We collaborate on areas where it makes sense. When one of us wins, we all win.
- Anyone can join without contracts, MOUs or NDAs. Whether big or small, new or established the cluster is for everyone working in fusion.
- We aim to cut through the complexity to enable collaboration and encourage more people to get involved.

BEYOND-IX/ 16 SEPTEMBER 2022 PAGE 16

In good company. And growing …

Alemnis + Alten + AMEG + Assystem + Atkins + AVI + Bay Fusion + Be4Fusion + Birch Fontaine + Booth Industries International + C E Turner + Centronic Limited + Commonwealth Fusion Systems + Createc + Dassault Systemes UK + Doosan Babcock + Ecclesian Consulting + EGB Engineering + Element Six + Energy Systems Catapult + Environment Agency + First Light Fusion + Frazer Nash Consultancy + FTI + Fujitsu + Fusion Energy Insights + General Fusion + Graham Engineering + GSF UK + Harwell Campus + i4cnc + IBM + ICD Applied Technologies + Intelligent Business Links + Jacobs + James Walker UK Ltd + JCS Nuclear Solutions + Kognitiv Spark + Konecranes Demag + Kyoto Fusioneering + Laser 2000 UK + Laser Additive Solutions Ltd + Leybold + M5tec + MACE + Magdrive + Manufacturing Technology Centre + Marvel Fusion + Mirion Technologies + Mott MacDonald Ltd + National Physical Laboratory + Nelson Tool Co + Novintec + Nuclear AMRC + Nuclear Industry Association + Nuvia + Oxford Innovation Ltd + Oxford Science Enterprises + Oxford Sigma + OxLEP + Porvair Filtration Group + Prorsus + Renaissance Fusion + Sika + Steel Dynamics + STFC + Studsvik AB + Swiftool Precision Engineering + Tokamak Energy + Turner & Townsend + TUV Nord + TWI + UKAEA + UKISS + University of Oxford + Woodruff Scientific


THE FUSION CLUSTER
Thank you
TheFusionCluster.com

Energy for Humanity: A Presentation of Marvel Fusion

Heike Freund and Dan Nebe

Marvel Fusion GmbH, Munich, Germany

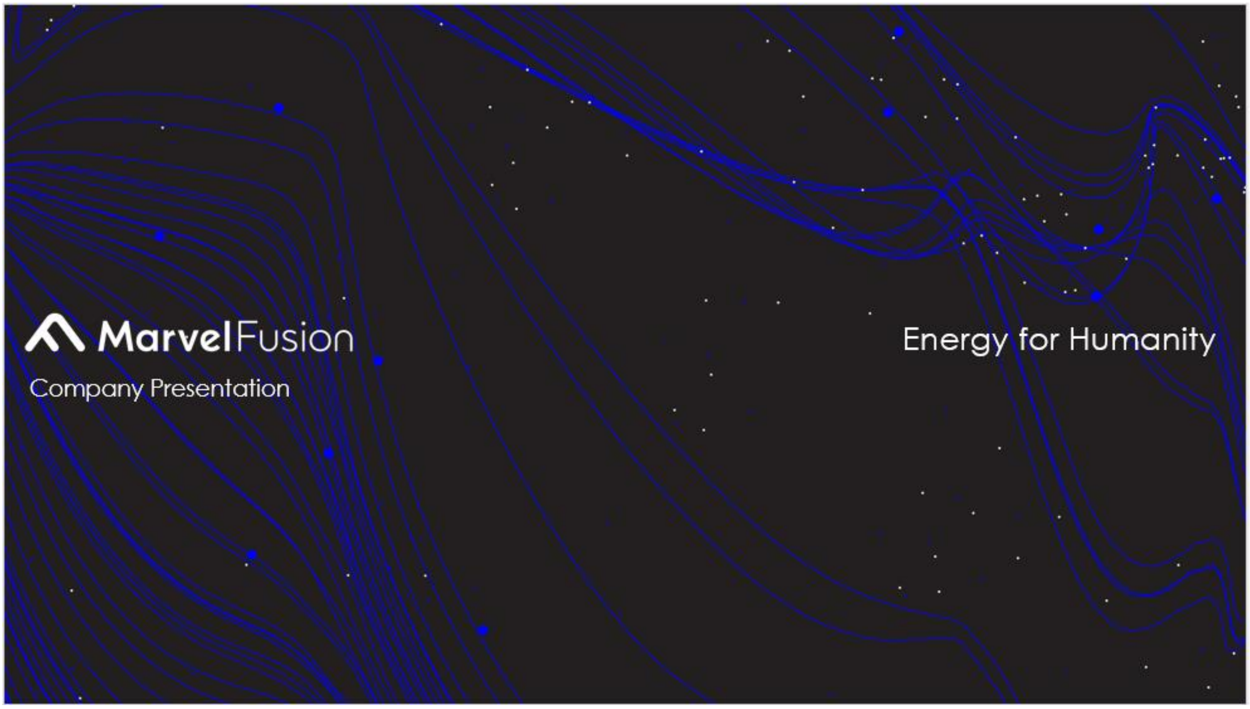
Marvel Fusion was founded in 2019 by Moritz von der Linden, Dr. Karl-Georg Schlesinger, Dr. Georg Korn, and Dr. Pasha Shabalin. Chief Operating Officer Heike Freund joined in 2020. The company, pre-seeded by BlueYard Capital, pursues a new and fast-track route to the commercial application of fusion energy.

The company has gathered a unique team behind their mission to solve one of the biggest challenges of mankind: the creation of unlimited zero-emission energy. Scientists from the Ludwig-Maximilians-University in Munich, the University of Stanford, and the Massachusetts Institute of Technology (MIT) have recently joined forces with Marvel Fusion to bring its fusion concept to fruition.

To further advance its technology development, Marvel Fusion raised EUR 35 million in its Series A, led by Earlybird with significant contributions from ATHOS Venture GmbH, PRIMEPULSE, Tobi Lütke and Fiona McKean's Thistledown Capital, Taavet Hinrikus & Sten Tamviki (OÜ Notorius), Nicolas Berggruen Charitable Trust and Heinz Dürr Invest GmbH among others. Existing investors Hartmut Neven, Albert Wenger, and Chris Hitchen's Possible Ventures also participated in the round. To date, the company has raised EUR 60 million in total funds.

Source: https://marvelfusion.com/about-us/ accessed on 21-Oct-2022

Corresponding Author:
Ms. Heike Freund
heike.freund@marvelfusion.com
Marvel Fusion GmbH
Blumenstrasse 28
D-80331 München (Munich)
GERMANY

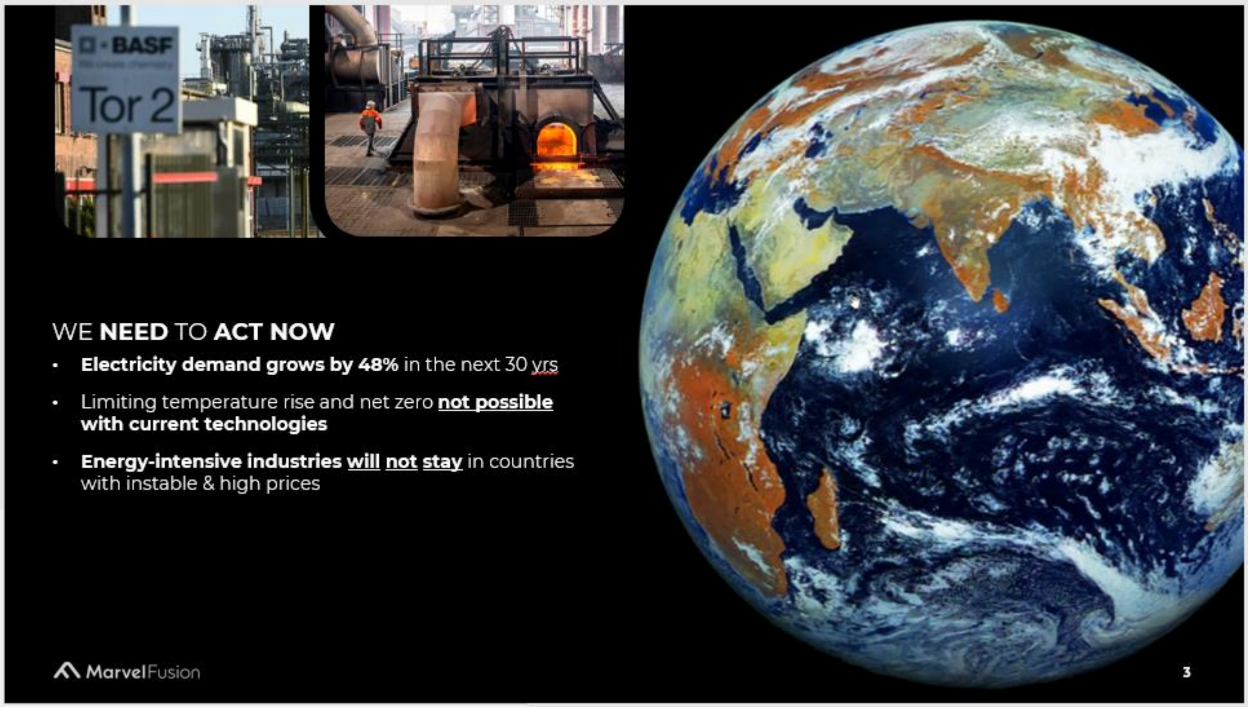


Why Marvel Fusion?

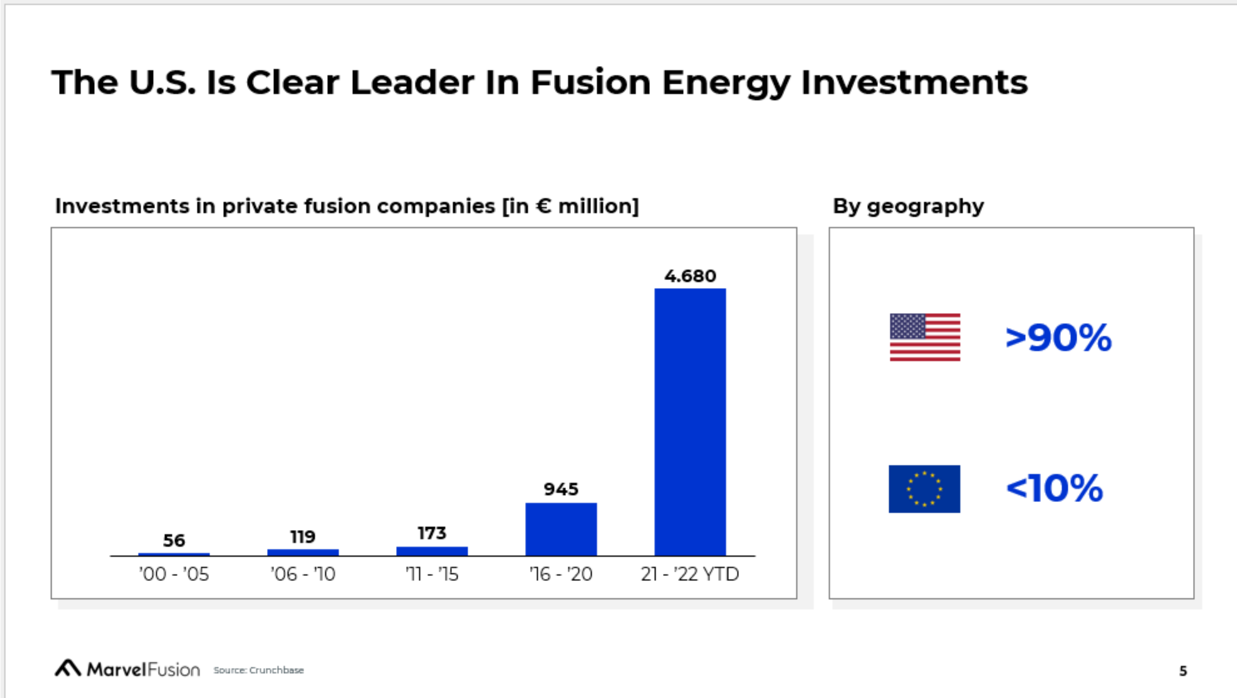
TRANSFORMING ENERGY FOR HUMANITY FOR DECADES TO COME

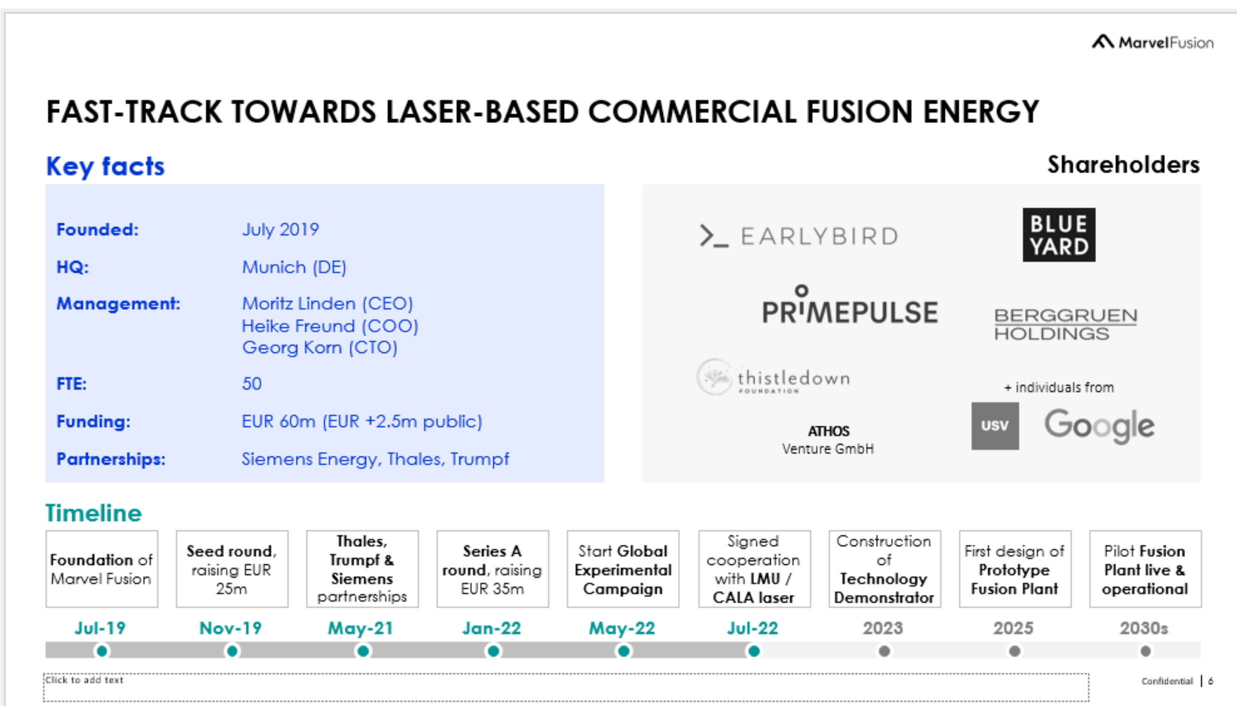
- Novel **approach to reach fusion**, possible due to **substantial technological progress**
- **Commercially viable concept** for a fusion power plant
- Theoretical model predicting **significant energy yield**
- Experiments providing first **empirical validation of core physics**
- **Energy gain in the next years**, significant Q-values in the long-term
- **Commercial** pilot power plant **in 2030s**

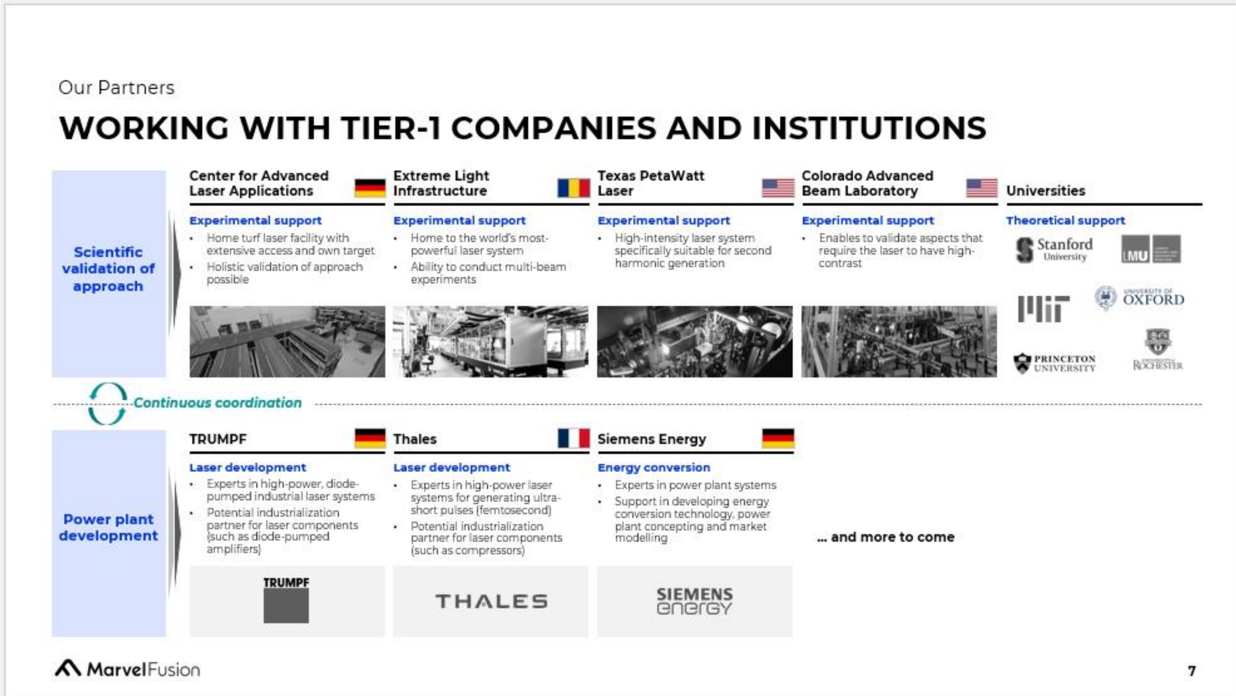
MarvelFusion 2

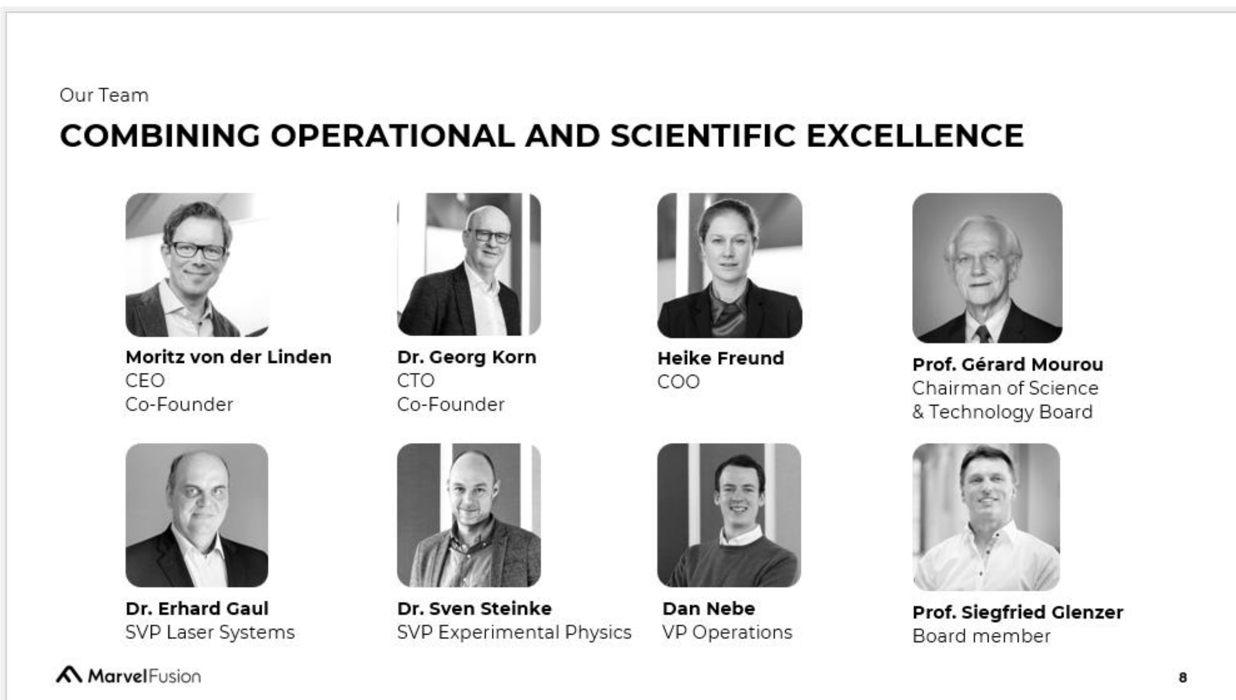

BASF
Tor 2
WE NEED TO ACT NOW
• Electricity demand grows by 48% in the next 30 yrs
• Limiting temperature rise and net zero not possible with current technologies
• Energy-intensive industries will not stay in countries with instable & high prices
MarvelFusion
3

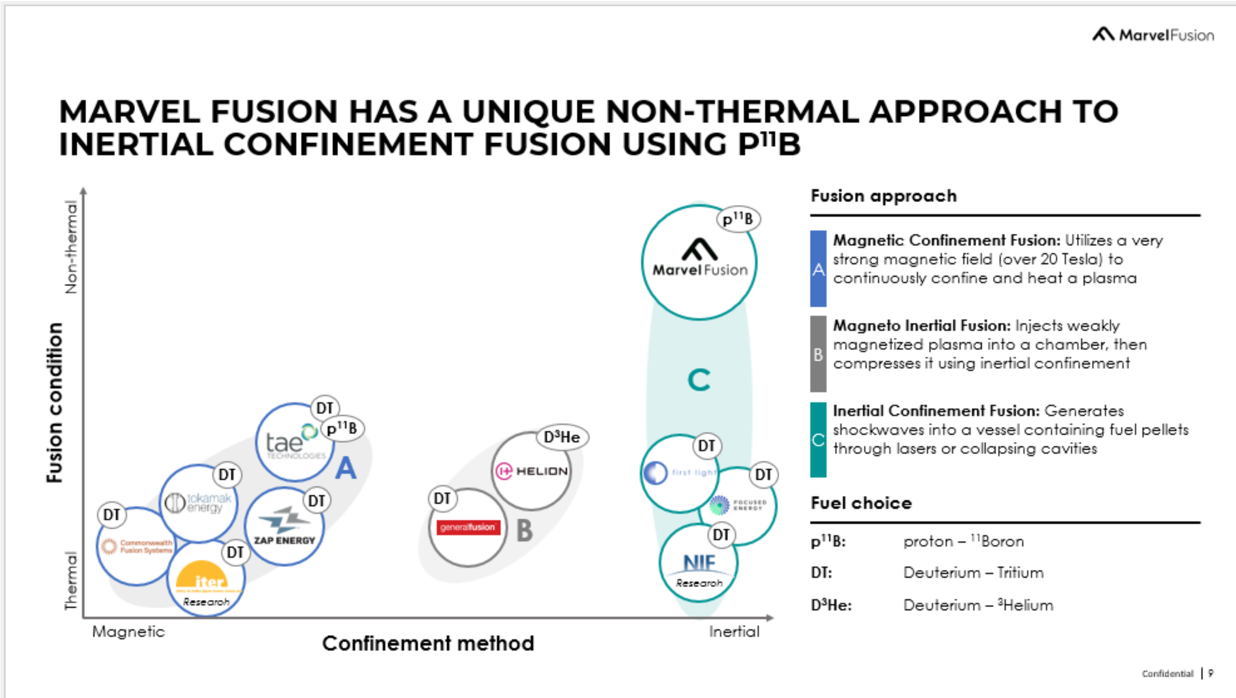

Fusion Companies Around the World
Canada
1
USA
21
UK
3
Germany
1
France
1
1
Italy
1
Israel
1
China
2
Japan
1
Australia
MarvelFusion
Source: Fusion Industry Association
4

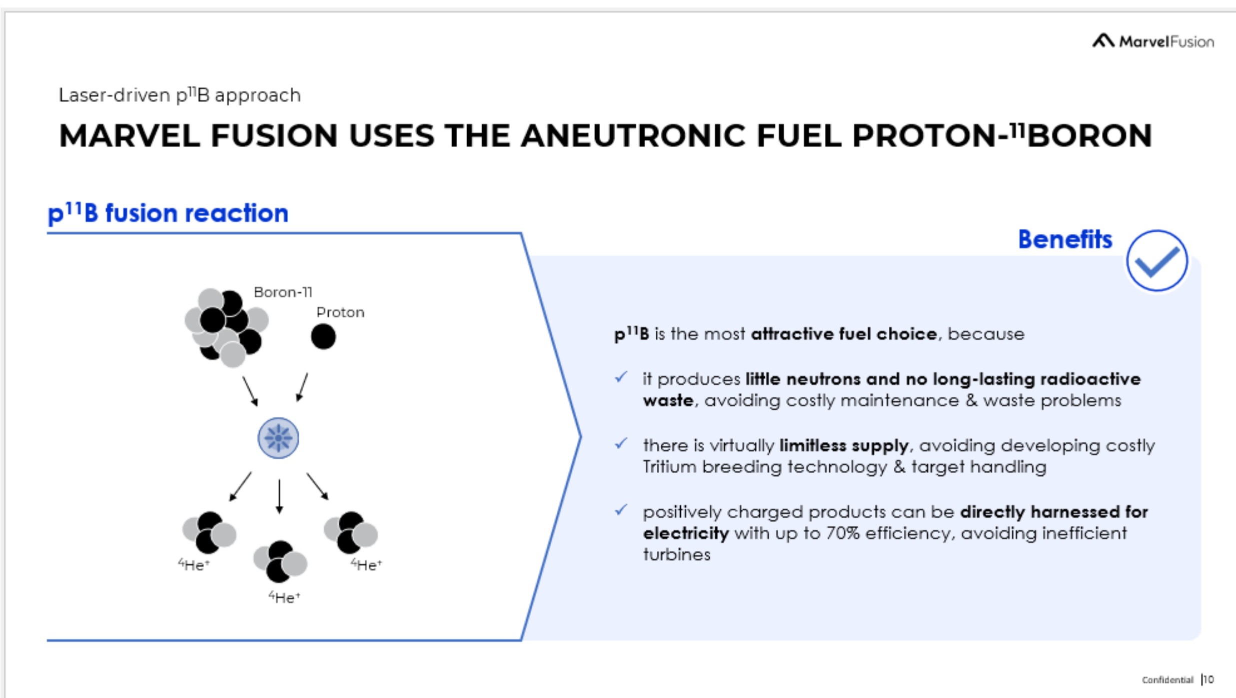

The U.S. Is Clear Leader In Fusion Energy Investments
Investments in private fusion companies [in € million]
56
119
173
945
4.680
'00 - '05
'06 - '10
'11 - '15
'16 - '20
21 - '22 YTD
By geography
>90%
<10%
MarvelFusion
Source: Crunchbase
5

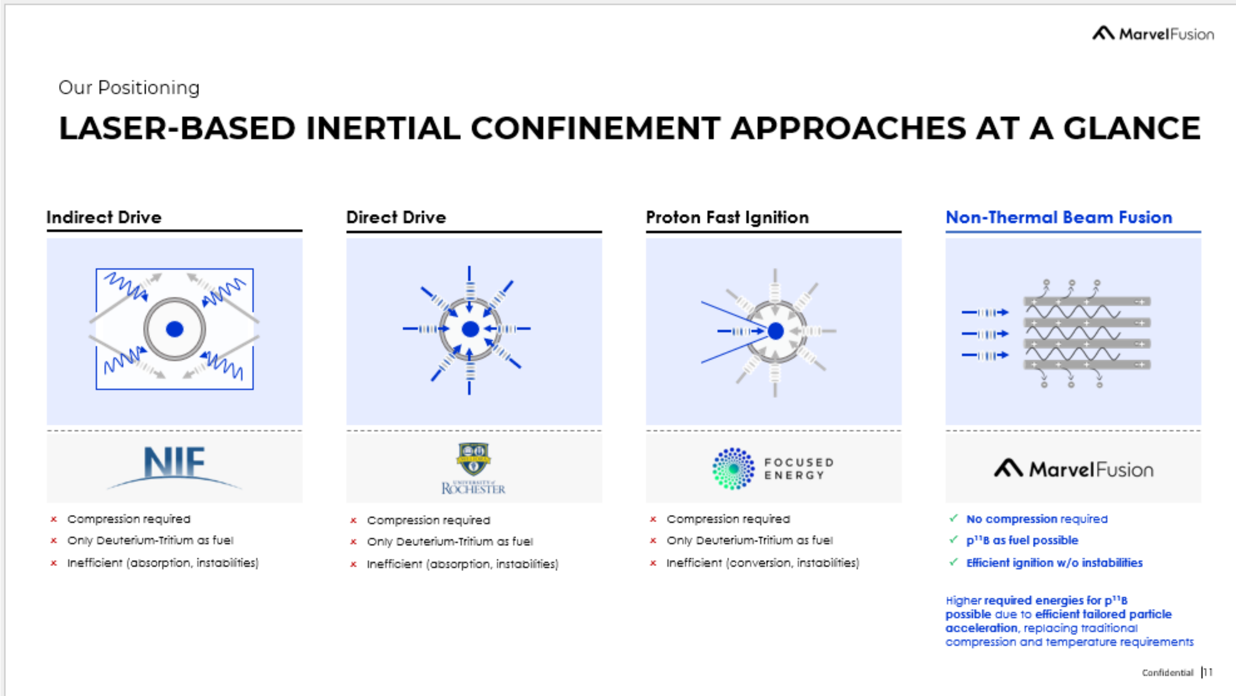

MarvelFusion
FAST-TRACK TOWARDS LASER-BASED COMMERCIAL FUSION ENERGY
Key facts
Founded: July 2019
HQ: Munich (DE)
Management: Moritz Linden (CEO)
Heike Freund (COO)
Georg Korn (CTO)
FTE: 50
Funding: EUR 60m (EUR +2.5m public)
Partnerships: Siemens Energy, Thales, Trumpf
Shareholders
EARLYBIRD
BLUE YARD
PRIMEPULSE
BERGGRUEN HOLDINGS
thistledown FOUNDATION
+ individuals from
ATHOS Venture GmbH
USV
Google
Timeline
Foundation of Marvel Fusion
Seed round, raising EUR 25m
Thales, Trumpf & Siemens partnerships
Series A round, raising EUR 35m
Start Global Experimental Campaign
Signed cooperation with LMU / CALA laser
Construction of Technology Demonstrator
First design of Prototype Fusion Plant
Pilot Fusion Plant live & operational
Jul-19
Nov-19
May-21
Jan-22
May-22
Jul-22
2023
2025
2030s
Click to add text
Confidential | 6

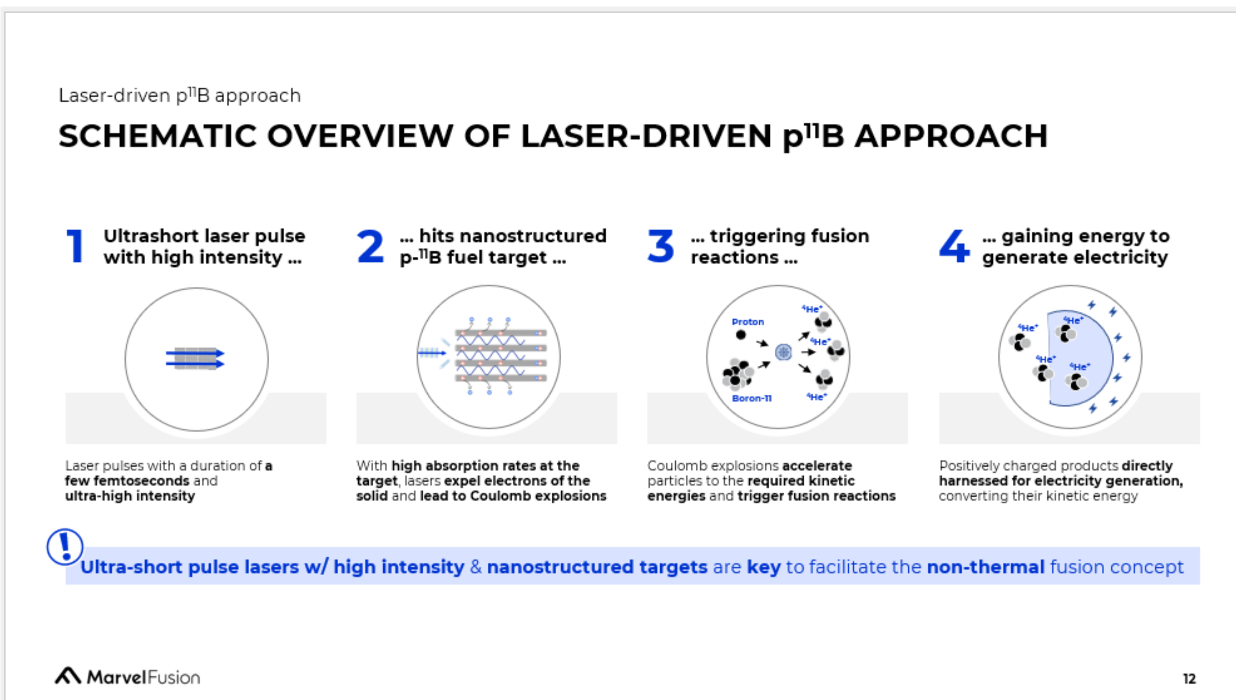

Our Partners
WORKING WITH TIER-1 COMPANIES AND INSTITUTIONS
Scientific validation of approach
Center for Advanced Laser Applications
Experimental support
Home turf laser facility with extensive access and own target
Holistic validation of approach possible
Extreme Light Infrastructure
Experimental support
Home to the world's most-powerful laser system
Ability to conduct multi-beam experiments
Texas PetaWatt Laser
Experimental support
High-intensity laser system specifically suitable for second harmonic generation
Colorado Advanced Beam Laboratory
Experimental support
Enables to validate aspects that require the laser to have high-contrast
Universities
Theoretical support
Stanford University
LMU
MIT
University of Oxford
Princeton University
Rochester
Continuous coordination
Power plant development
TRUMPF
Laser development
Experts in high-power, diode-pumped industrial laser systems
Potential industrialization partner for laser components (such as diode-pumped amplifiers)
Thales
Laser development
Experts in high-power laser systems for generating ultra-short pulses (femtosecond)
Potential industrialization partner for laser components (such as compressors)
Siemens Energy
Energy conversion
Experts in power plant systems
Support in developing energy conversion technology, power plant concepting and market modelling
... and more to come
TRUMPF
THALES
SIEMENS energy
MarvelFusion
7


Our Team
COMBINING OPERATIONAL AND SCIENTIFIC EXCELLENCE
Moritz von der Linden
CEO
Co-Founder
Dr. Georg Korn
CTO
Co-Founder
Heike Freund
COO
Prof. Gérard Mourou
Chairman of Science
& Technology Board
Dr. Erhard Gaul
SVP Laser Systems
Dr. Sven Steinke
SVP Experimental Physics
Dan Nebe
VP Operations
Prof. Siegfried Glenzer
Board member
MarvelFusion
8


MarvelFusion
MARVEL FUSION HAS A UNIQUE NON-THERMAL APPROACH TO INERTIAL CONFINEMENT FUSION USING P11B
Fusion condition
Non-thermal
Thermal
Magnetic
Confinement method
Inertial
A
B
C
DT
p11B
D3He
tae
tokamak energy
ZAP ENERGY
HELION
generalfusion
iter
Research
NIF
Research
Marvel Fusion
Fusion approach
A Magnetic Confinement Fusion: Utilizes a very strong magnetic field (over 20 Tesla) to continuously confine and heat a plasma
B Magneto Inertial Fusion: Injects weakly magnetized plasma into a chamber, then compresses it using inertial confinement
C Inertial Confinement Fusion: Generates shockwaves into a vessel containing fuel pellets through lasers or collapsing cavities
Fuel choice
p11B: proton – 11Boron
DT: Deuterium – Tritium
D3He: Deuterium – 3Helium
Confidential | 9

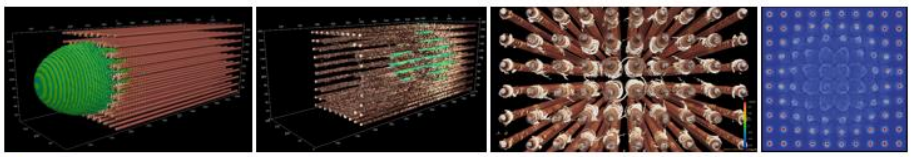

MarvelFusion
Laser-driven p11B approach
MARVEL FUSION USES THE ANEUTRONIC FUEL PROTON-11BORON
p11B fusion reaction
Boron-11
Proton
4He+
4He+
4He+
Benefits
p11B is the most attractive fuel choice, because
it produces little neutrons and no long-lasting radioactive waste, avoiding costly maintenance & waste problems
there is virtually limitless supply, avoiding developing costly Tritium breeding technology & target handling
positively charged products can be directly harnessed for electricity with up to 70% efficiency, avoiding inefficient turbines
Confidential |10


MarvelFusion
Our Positioning
LASER-BASED INERTIAL CONFINEMENT APPROACHES AT A GLANCE
Indirect Drive
NIF
Compression required
Only Deuterium-Tritium as fuel
Inefficient (absorption, instabilities)
Direct Drive
ROCHESTER
Compression required
Only Deuterium-Tritium as fuel
Inefficient (absorption, instabilities)
Proton Fast Ignition
FOCUSED ENERGY
Compression required
Only Deuterium-Tritium as fuel
Inefficient (conversion, instabilities)
Non-Thermal Beam Fusion
MarvelFusion
No compression required
p¹¹B as fuel possible
Efficient ignition w/o instabilities
Higher required energies for p¹¹B possible due to efficient tailored particle acceleration, replacing traditional compression and temperature requirements
Confidential 11


Laser-driven p¹¹B approach
SCHEMATIC OVERVIEW OF LASER-DRIVEN p¹¹B APPROACH
1 Ultrashort laser pulse with high intensity …
2 … hits nanostructured p-¹¹B fuel target …
3 … triggering fusion reactions …
4 … gaining energy to generate electricity
Proton
Boron-11
⁴He⁺
Laser pulses with a duration of a few femtoseconds and ultra-high intensity
With high absorption rates at the target, lasers expel electrons of the solid and lead to Coulomb explosions
Coulomb explosions accelerate particles to the required kinetic energies and trigger fusion reactions
Positively charged products directly harnessed for electricity generation, converting their kinetic energy
Ultra-short pulse lasers w/ high intensity & nanostructured targets are key to facilitate the non-thermal fusion concept
MarvelFusion
12

How will we get there?

LASER ABSORPTION, PROPAGATION & COLOUMB EXPLOSIONS KEY TO REACH ENERGY GAIN, VALIDATION ALREADY STARTED

	Laser Absorption	Laser Propagation	Coulomb Explosions
Physics Process	**>90% efficient laser absorption** of high intensity laser pulse	**Propagation of laser** pulses **through nanostructures** without self-focusing	Ionized **nanostructures "explode"** due to strong electric fields
Parameters to Validate	**Laser-target interaction** with controlled laser pulse shape	Target with **near-critical density**, **high aspect ratio** and **high focused laser intensity** for full ionization throughout target volume	**Structure size**, **distance** and **material composition** tune ion energy spectral distribution to reach fusion cross section peak
Process Insights			

Access to existing laser facilities secured and **validation ongoing** (CALA, CSU and ELI-NP)

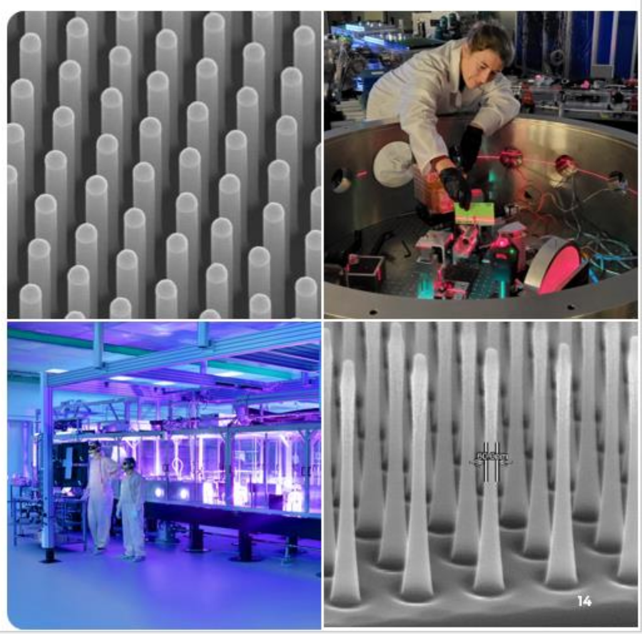
Building blocks paper by **Ruhl and Korn: "A laser-driven mixed fuel nuclear fusion reactor concept"**; Reactor concept paper by Ruhl and Korn to be published soon

MarvelFusion 13

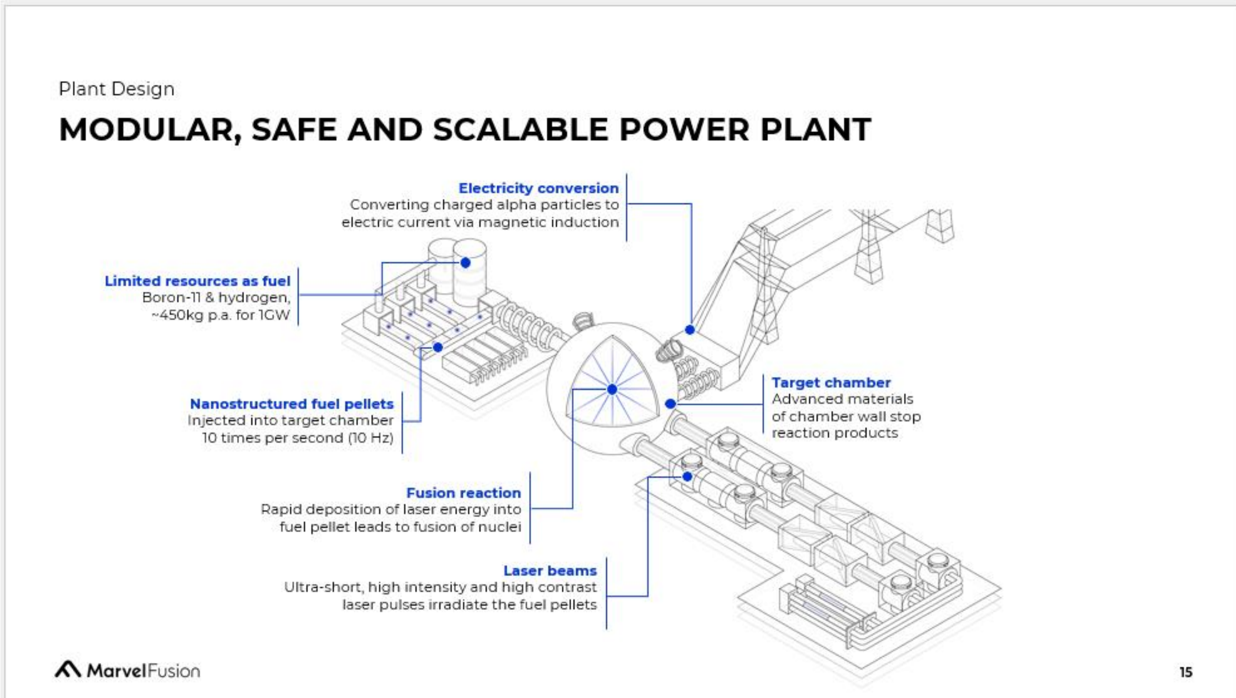
Why now?

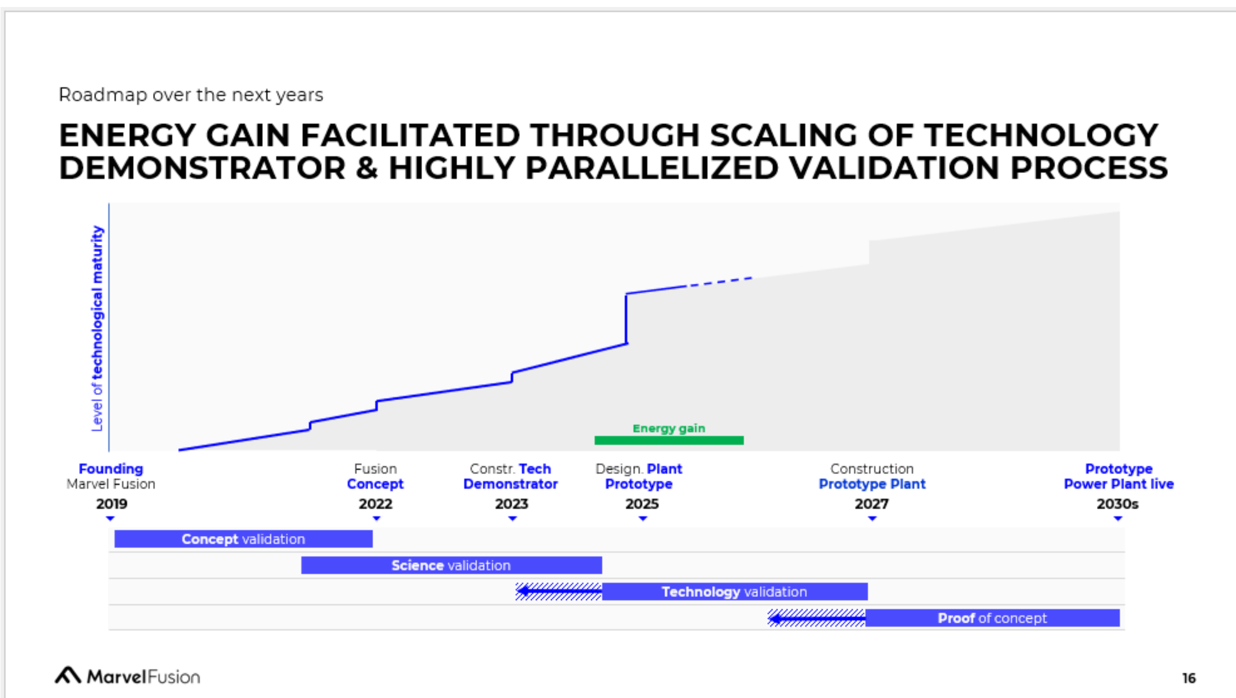
REQUIRED TECHNOLOGIES FOR OUR FUSION CONCEPT ARE WITHIN REACH

- Technological **concepts to produce required laser systems exist** and are also pursued by other fusion endeavors (e.g., NIF)
- **Existing technology** to produce materials for batteries & photovoltaic cells **can be used for producing nanostructured targets**
- **Significantly decreasing prices for laser diodes ($/W)** are supporting economics of laser-based approaches



MarvelFusion 14


Plant Design
MODULAR, SAFE AND SCALABLE POWER PLANT
Electricity conversion
Converting charged alpha particles to electric current via magnetic induction
Limited resources as fuel
Boron-11 & hydrogen, ~450kg p.a. for 1GW
Nanostructured fuel pellets
Injected into target chamber 10 times per second (10 Hz)
Target chamber
Advanced materials of chamber wall stop reaction products
Fusion reaction
Rapid deposition of laser energy into fuel pellet leads to fusion of nuclei
Laser beams
Ultra-short, high intensity and high contrast laser pulses irradiate the fuel pellets
MarvelFusion
15


Roadmap over the next years
ENERGY GAIN FACILITATED THROUGH SCALING OF TECHNOLOGY DEMONSTRATOR & HIGHLY PARALLELIZED VALIDATION PROCESS
Level of technological maturity
Energy gain
Founding Marvel Fusion 2019
Fusion Concept 2022
Constr. Tech Demonstrator 2023
Design. Plant Prototype 2025
Construction Prototype Plant 2027
Prototype Power Plant live 2030s
Concept validation
Science validation
Technology validation
Proof of concept
MarvelFusion
16

DISCLAIMER

CONTACT
Marvel Fusion GmbH
Blumenstraße 28
80331 München
moritz@marvelfusion.com

MarvelFusion

The KIT Fusion Program – Introduction and Overview

Dirk Radloff

Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany

Short overview on the KIT Fusion Program including more detailed explanations of the following subtopics:

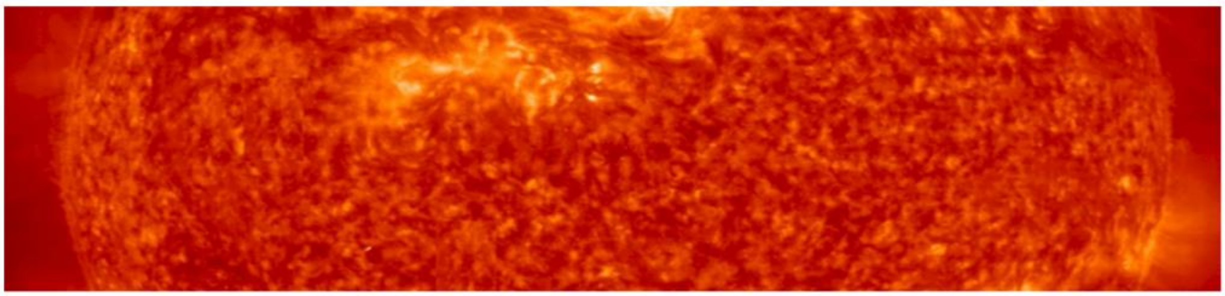
- Fuel Cycle
- Breeding Blanket Development
- Structural Materials for in-Vessel Components
- Fusion Magnets & Magnet Components Microwave Heating
- Manufacturing & Joining Technologies
- Early neutron source – IFMIF
- Divertor Technology
- Fusion Safety
- Neutronics and FPP Integration & Efficiency

Corresponding Author:
Dr. Dirk Radloff
dirk.radloff@kit.edu
Karlsruhe Institute of Technology (KIT)
Fusion Program
Hermann-von-Helmholtz-Platz 1
D-76344 Eggenstein-Leopoldshafen
GERMANY

Karlsruhe Institute of Technology

The KIT Fusion Program – Introduction and Overview

BeYOND IX, 16. September 2022



KIT – The Research University in the Helmholtz Association

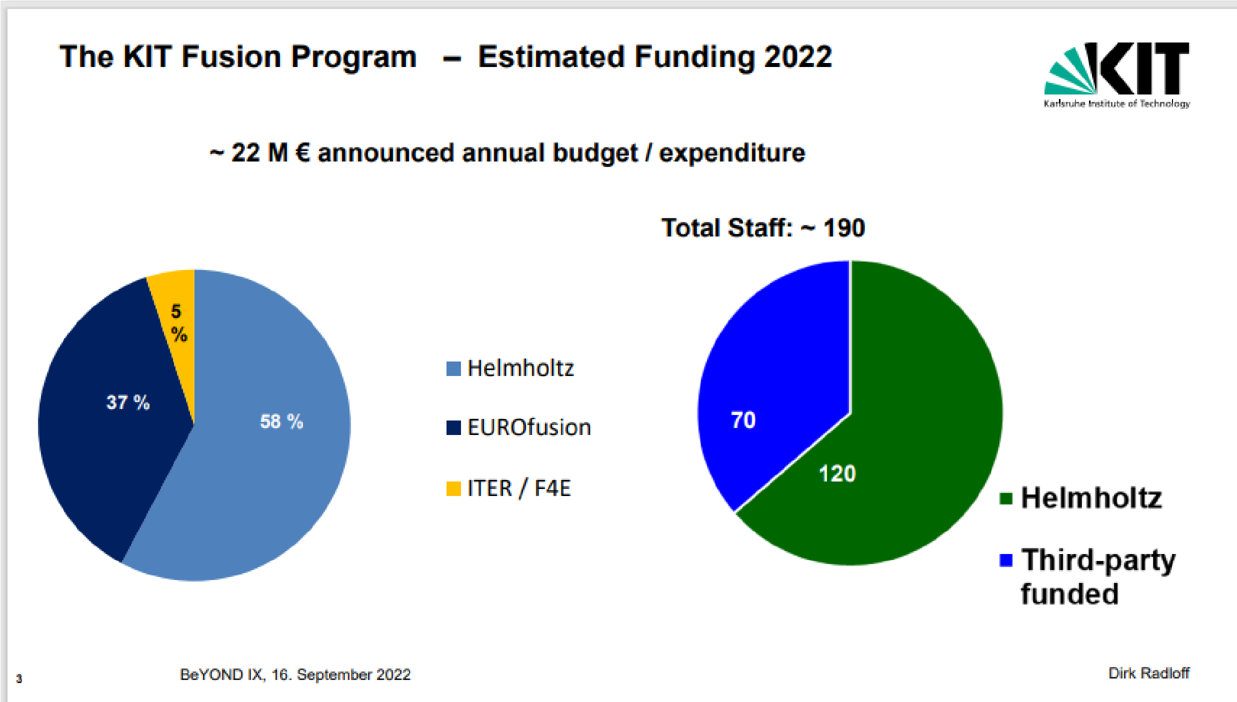
www.kit.edu

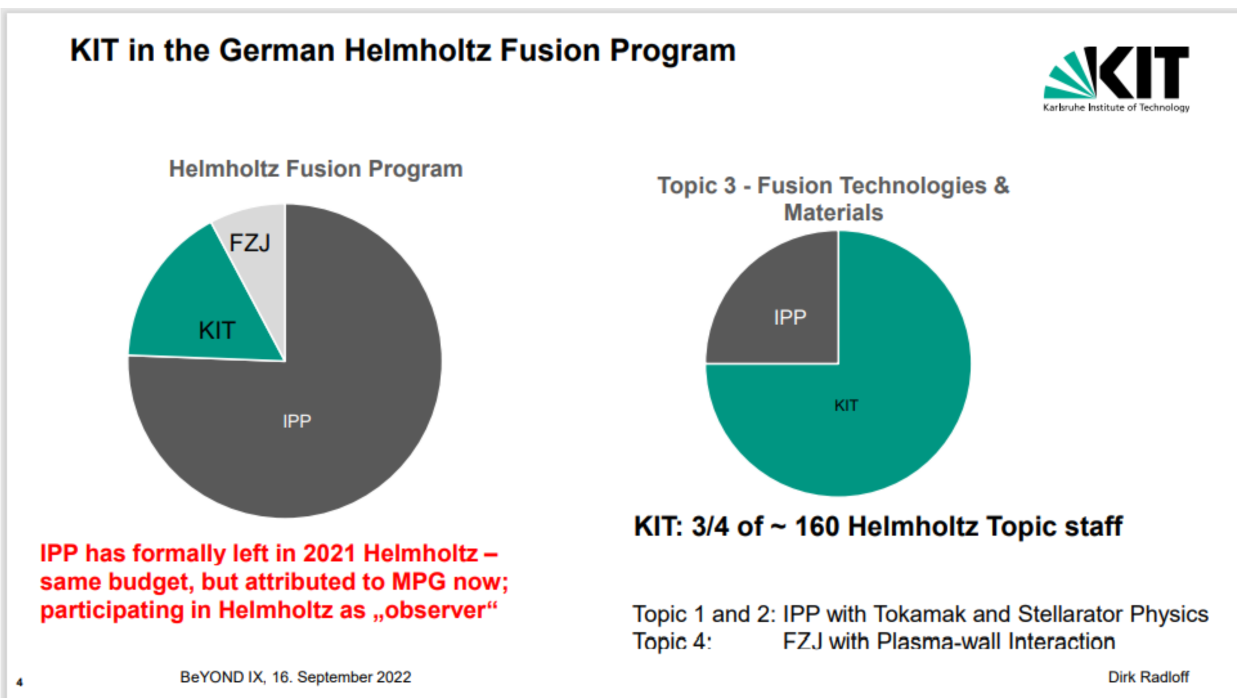
The KIT Fusion Program - Overview

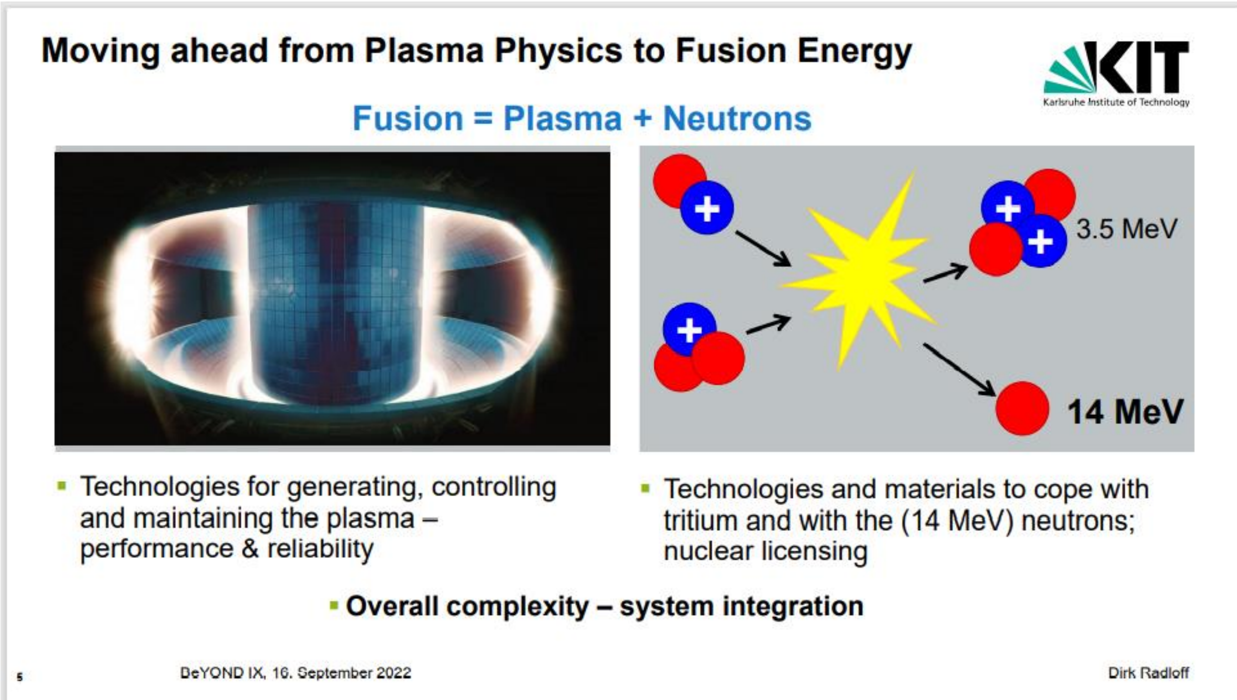
Karlsruhe Institute of Technology

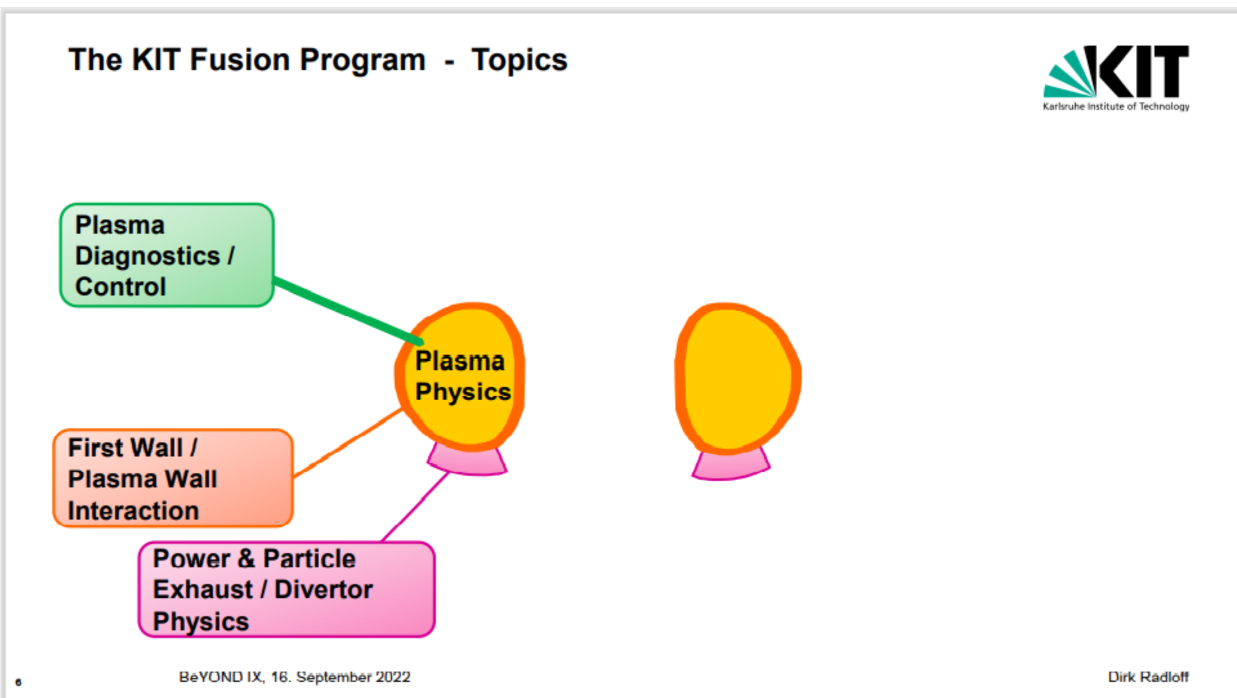
- **Objective:**
  Development of key technologies & materials for fusion energy
- **Focus on three lines of fusion experiments:**
  - Design, engineering, realisation and testing of components and systems for ITER
  - Key developments towards DEMO and Fusion Power Plant
    (inter alia: Broader Approach, Fusion Neutron Source)
  - Contributions to Wendelstein 7-X
- **Figures (estimate 2022):**
  - ~ 190 scientists, engineers and support staff
  - From 8 KIT institutes
  - ~ 22 M€ annual budget [expenditure incl. manpower]

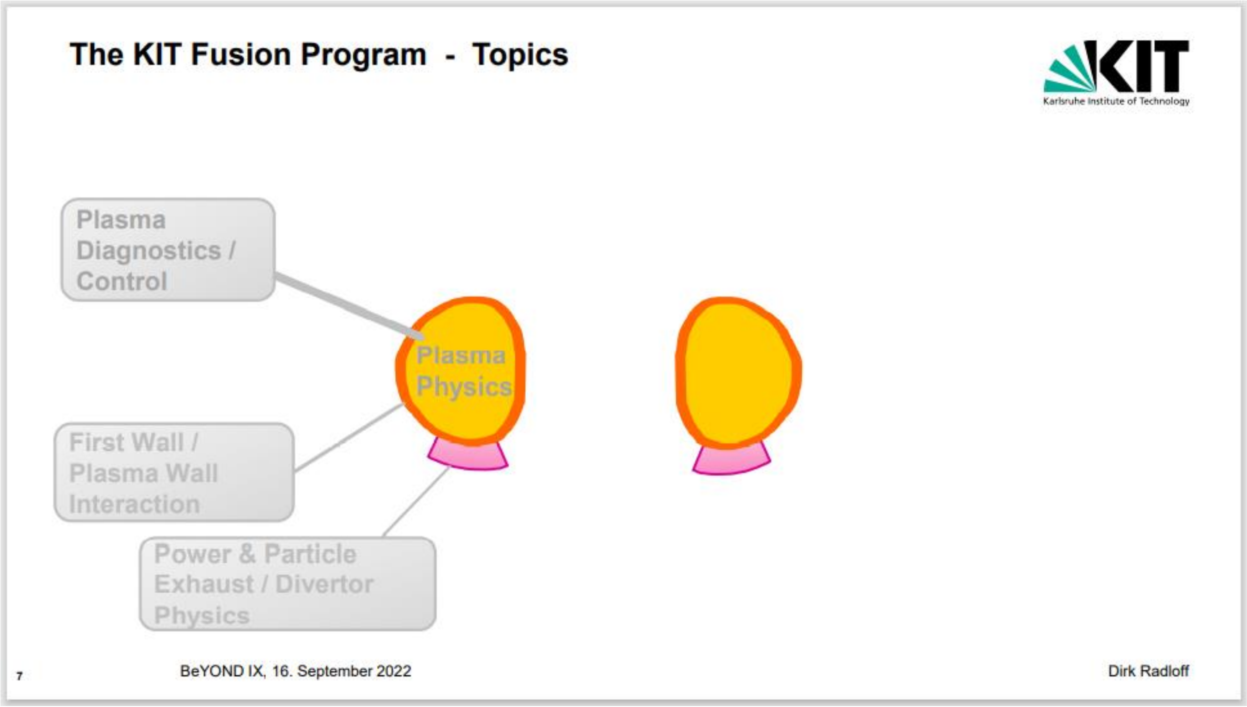
2 BeYOND IX, 16. September 2022 Dirk Radloff

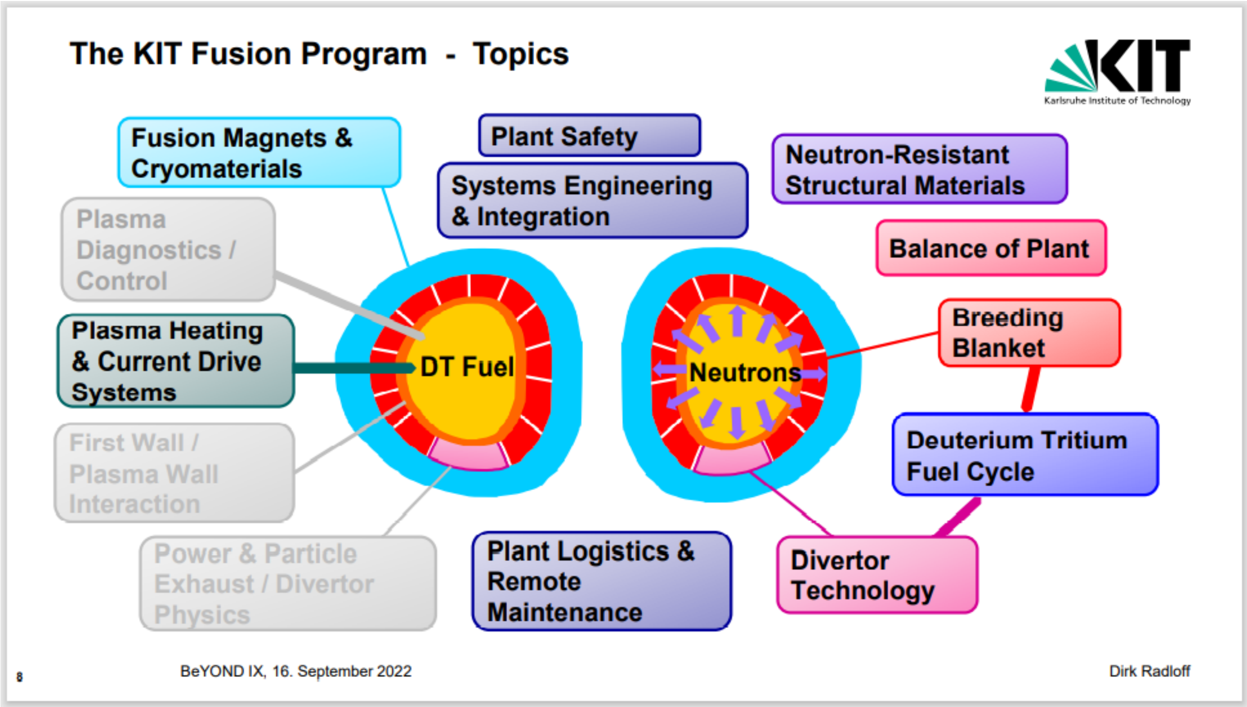

The KIT Fusion Program – Estimated Funding 2022
Karlsruhe Institute of Technology
~ 22 M € announced annual budget / expenditure
5 %
37 %
58 %
Helmholtz
EUROfusion
ITER / F4E
Total Staff: ~ 190
70
120
Helmholtz
Third-party funded
3
BeYOND IX, 16. September 2022
Dirk Radloff

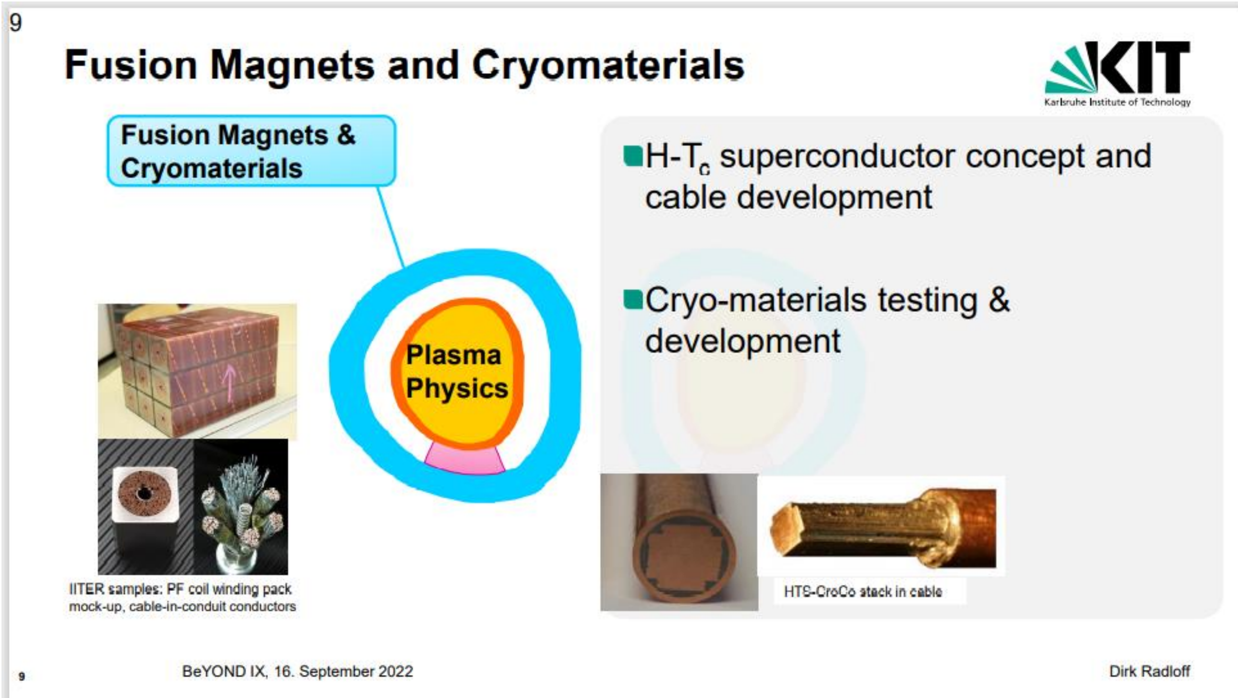

KIT in the German Helmholtz Fusion Program
Karlsruhe Institute of Technology
Helmholtz Fusion Program
FZJ
KIT
IPP
IPP has formally left in 2021 Helmholtz – same budget, but attributed to MPG now; participating in Helmholtz as „observer“
Topic 3 - Fusion Technologies & Materials
IPP
KIT
KIT: 3/4 of ~ 160 Helmholtz Topic staff
Topic 1 and 2: IPP with Tokamak and Stellarator Physics
Topic 4: FZJ with Plasma-wall Interaction
4
BeYOND IX, 16. September 2022
Dirk Radloff

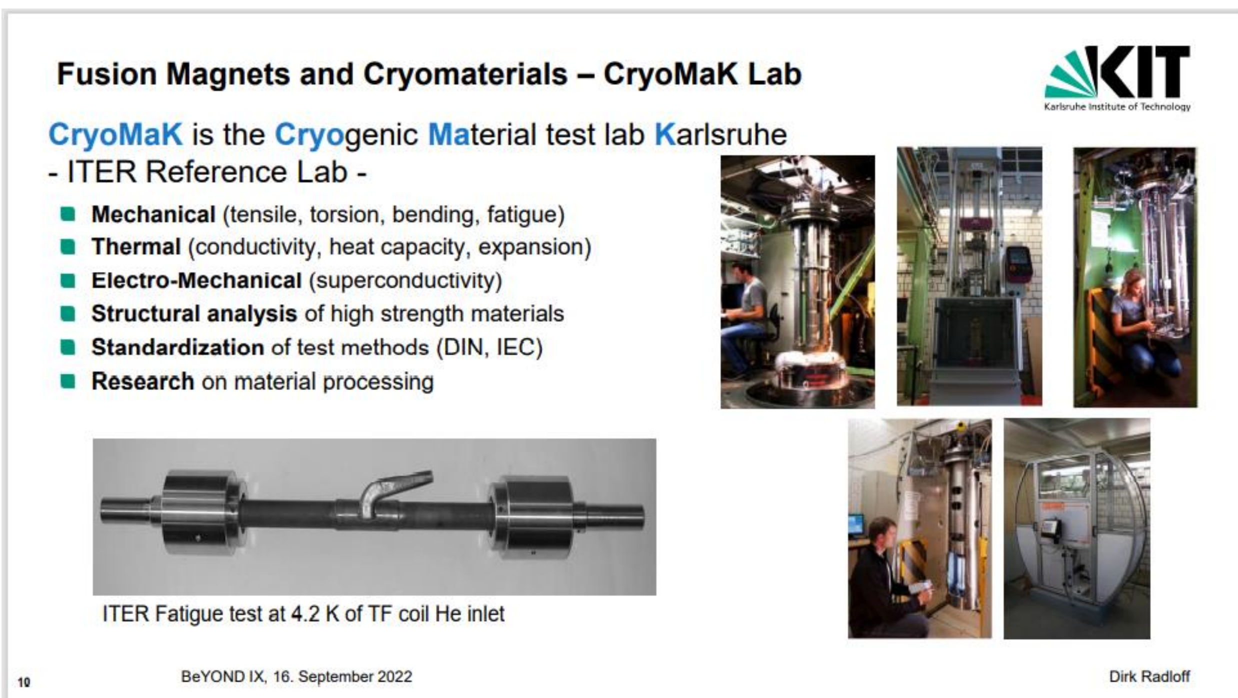

Moving ahead from Plasma Physics to Fusion Energy
Karlsruhe Institute of Technology
Fusion = Plasma + Neutrons
3.5 MeV
14 MeV
Technologies for generating, controlling and maintaining the plasma – performance & reliability
Technologies and materials to cope with tritium and with the (14 MeV) neutrons; nuclear licensing
Overall complexity – system integration
5
BeYOND IX, 16. September 2022
Dirk Radloff


The KIT Fusion Program - Topics
Karlsruhe Institute of Technology
Plasma Diagnostics / Control
Plasma Physics
First Wall / Plasma Wall Interaction
Power & Particle Exhaust / Divertor Physics
6
BeYOND IX, 16. September 2022
Dirk Radloff


The KIT Fusion Program - Topics
Karlsruhe Institute of Technology
Plasma Diagnostics / Control
Plasma Physics
First Wall / Plasma Wall Interaction
Power & Particle Exhaust / Divertor Physics
7
BeYOND IX, 16. September 2022
Dirk Radloff


The KIT Fusion Program - Topics
Karlsruhe Institute of Technology
Fusion Magnets & Cryomaterials
Plant Safety
Systems Engineering & Integration
Neutron-Resistant Structural Materials
Balance of Plant
Plasma Diagnostics / Control
Plasma Heating & Current Drive Systems
DT Fuel
Neutrons
Breeding Blanket
Deuterium Tritium Fuel Cycle
First Wall / Plasma Wall Interaction
Power & Particle Exhaust / Divertor Physics
Plant Logistics & Remote Maintenance
Divertor Technology
8
BeYOND IX, 16. September 2022
Dirk Radloff

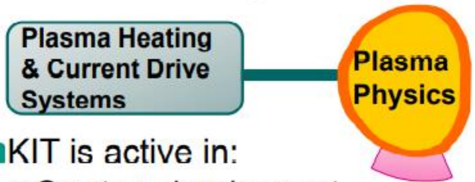

9
Fusion Magnets and Cryomaterials
Karlsruhe Institute of Technology
Fusion Magnets & Cryomaterials
Plasma Physics
H-T$_c$ superconductor concept and cable development
Cryo-materials testing & development
IITER samples: PF coil winding pack mock-up, cable-in-conduit conductors
HTS-CroCo stack in cable
9
BeYOND IX, 16. September 2022
Dirk Radloff


Fusion Magnets and Cryomaterials – CryoMaK Lab
Karlsruhe Institute of Technology
CryoMaK is the Cryogenic Material test lab Karlsruhe
- ITER Reference Lab -
Mechanical (tensile, torsion, bending, fatigue)
Thermal (conductivity, heat capacity, expansion)
Electro-Mechanical (superconductivity)
Structural analysis of high strength materials
Standardization of test methods (DIN, IEC)
Research on material processing
ITER Fatigue test at 4.2 K of TF coil He inlet
10
BeYOND IX, 16. September 2022
Dirk Radloff

Plasma Heating and Current Drive Systems

Electron Cyclotron Resonance Heating

- ECRH is EUROfusion primary choice for DEMO



- KIT is active in:
  - Gyrotron development
  - Launcher & Port Cell development
  - Diamond microwave windows

KIT gyrotron family: W7-X series tube, ITER industrial prototype, 2MW coaxial prototype tube

11 BeYOND IX, 16. September 2022 Dirk Radloff

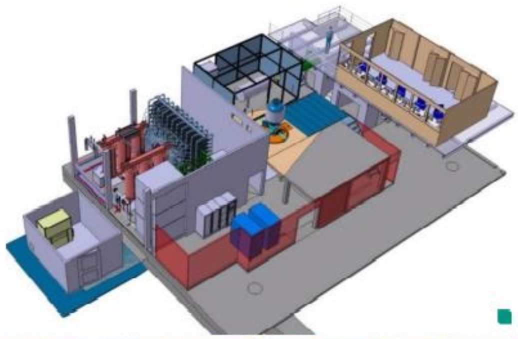
12

Gyrotron R&D at KIT

- Leading role w.r.t. output power enhancement, multi-frequency / multi-purpose operation and multi-stage depressed collector design
- Close collaboration with European partners
- Industrial partner THALES (gyrotrons for Wendelstein 7-X, TCV, ITER, i-DTT, …)

12 BeYOND IX, 16. September 2022 Dirk Radloff

13 **FUsion Long-Pulse Gyrotron LabORatory (FULGOR)**
- Experimental verification of multi-MW gyrotrons



- **Enhanced operating parameters**
  - Voltage: up to 130 kV (90 kV (anode) + 40 kV (body))
  - Current: up to 120 A
- **Operation at long pulses**
  - 2 MW at continuous wave (CW)
  - 4 MW up to 1 h at 50 % duty cycle

+ Operation of Multi-stage Depressed Collector (MDC)

+ Verification according to latest industrial standard

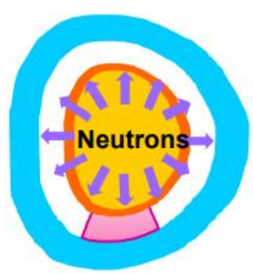
- June 2022: Start of operation

13 BeYOND IX, 16. September 2022 Dirk Radloff

Deuterium Tritium Fuel Cycle

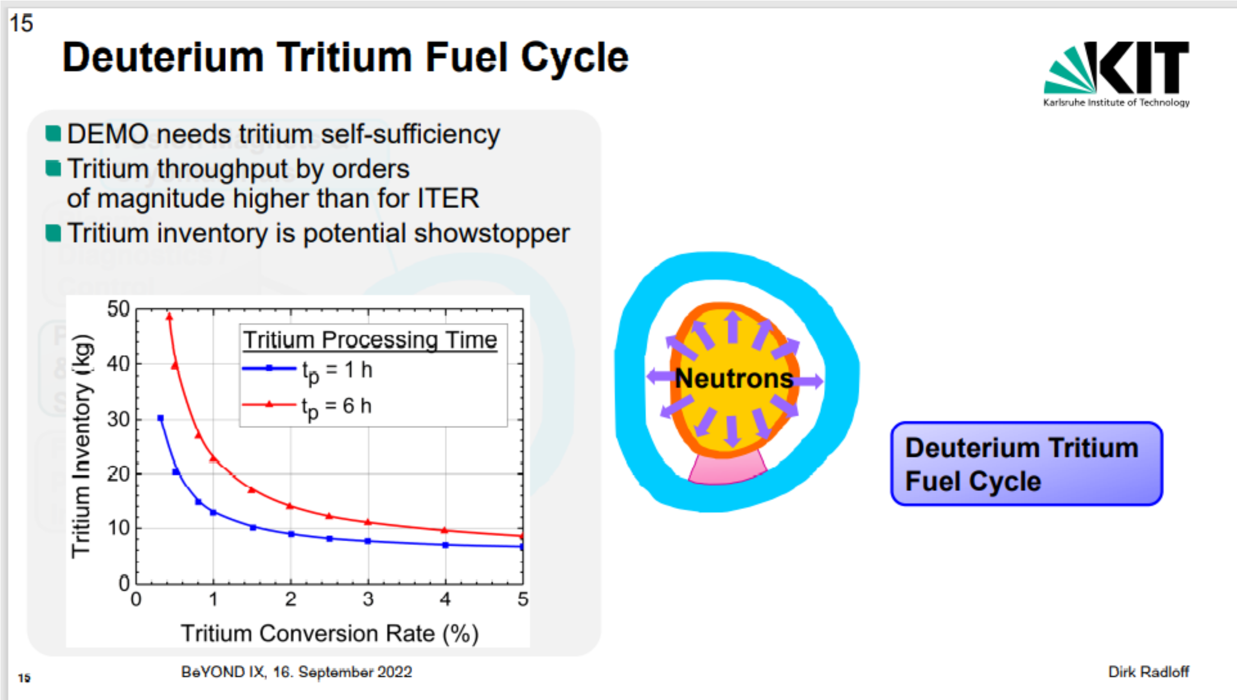
Test facility for the ITER Isotope Separation System at the Tritium Laboratory Karlsruhe

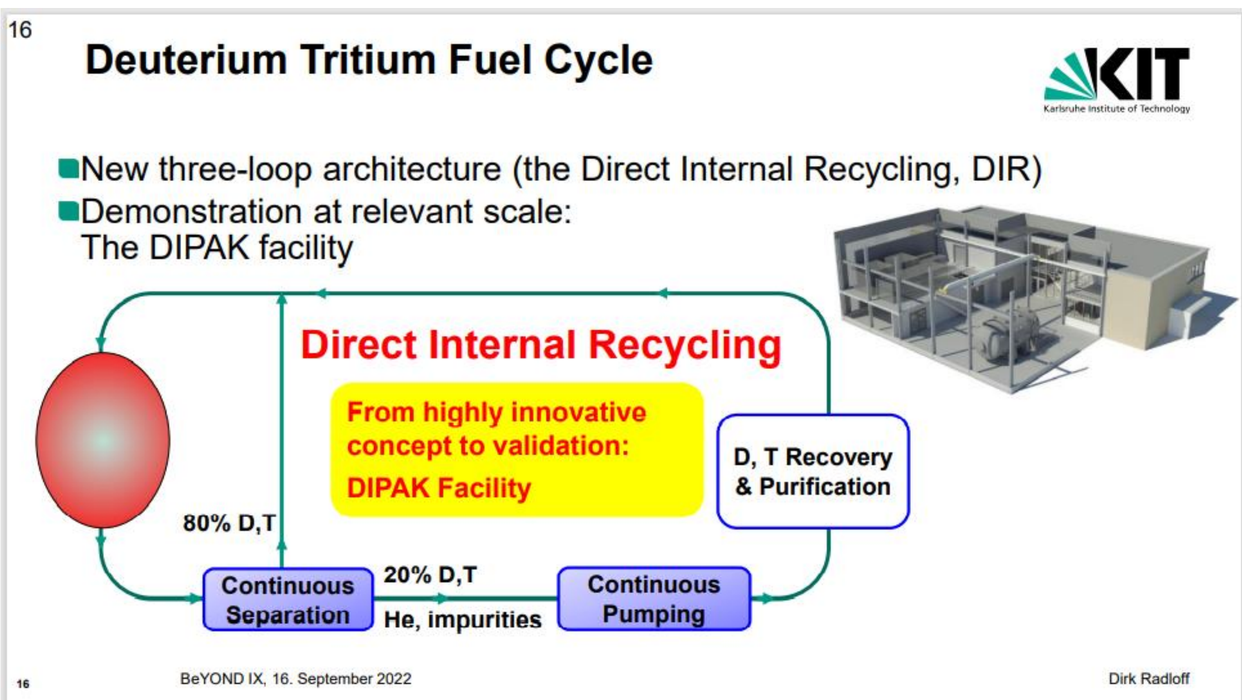
- Tritium processing
- Limiting the tritium inventory

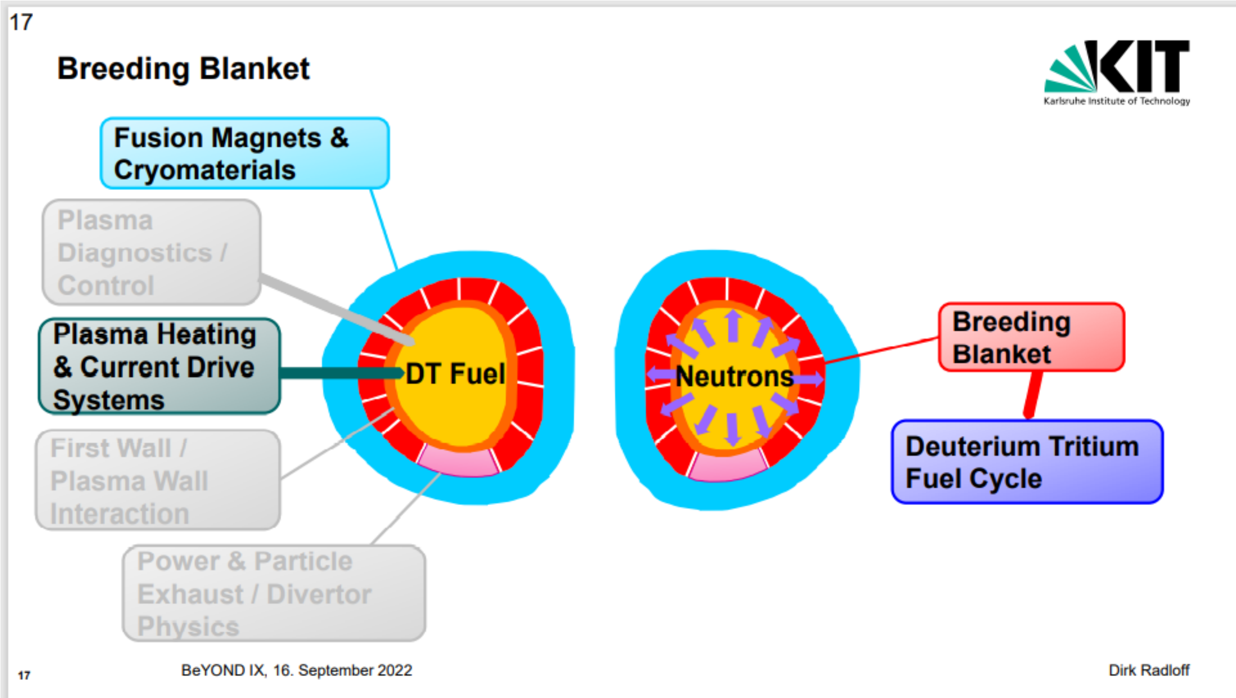


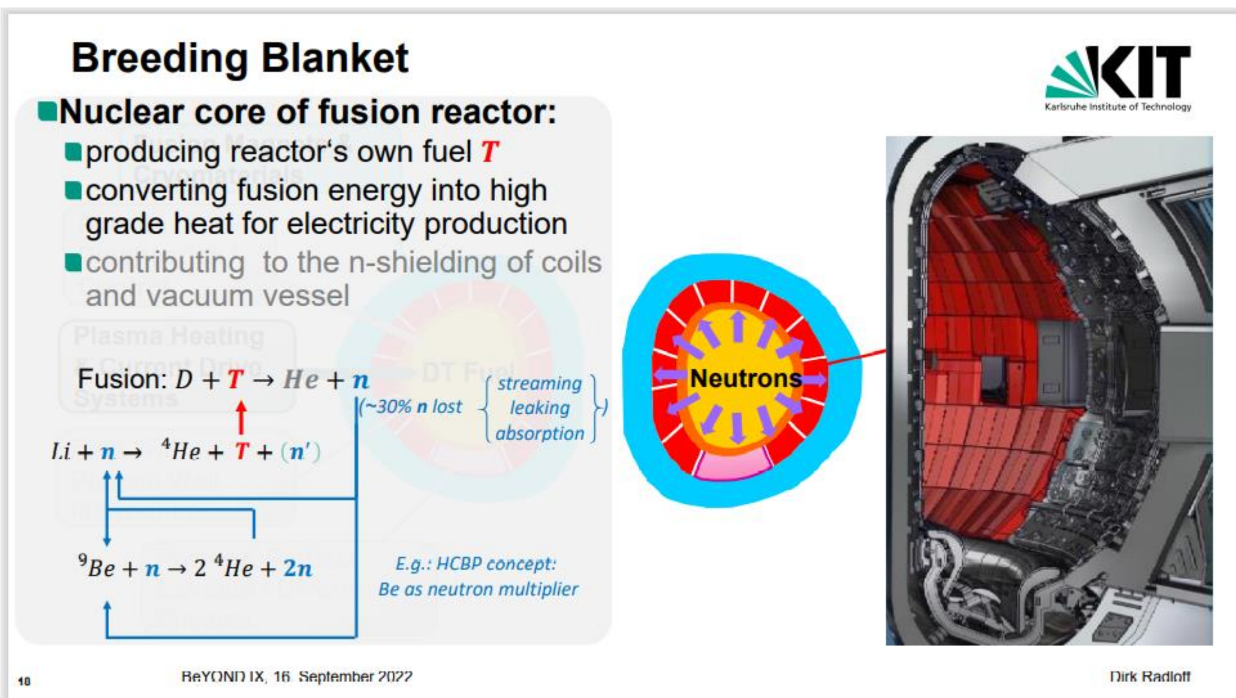
Deuterium Tritium Fuel Cycle

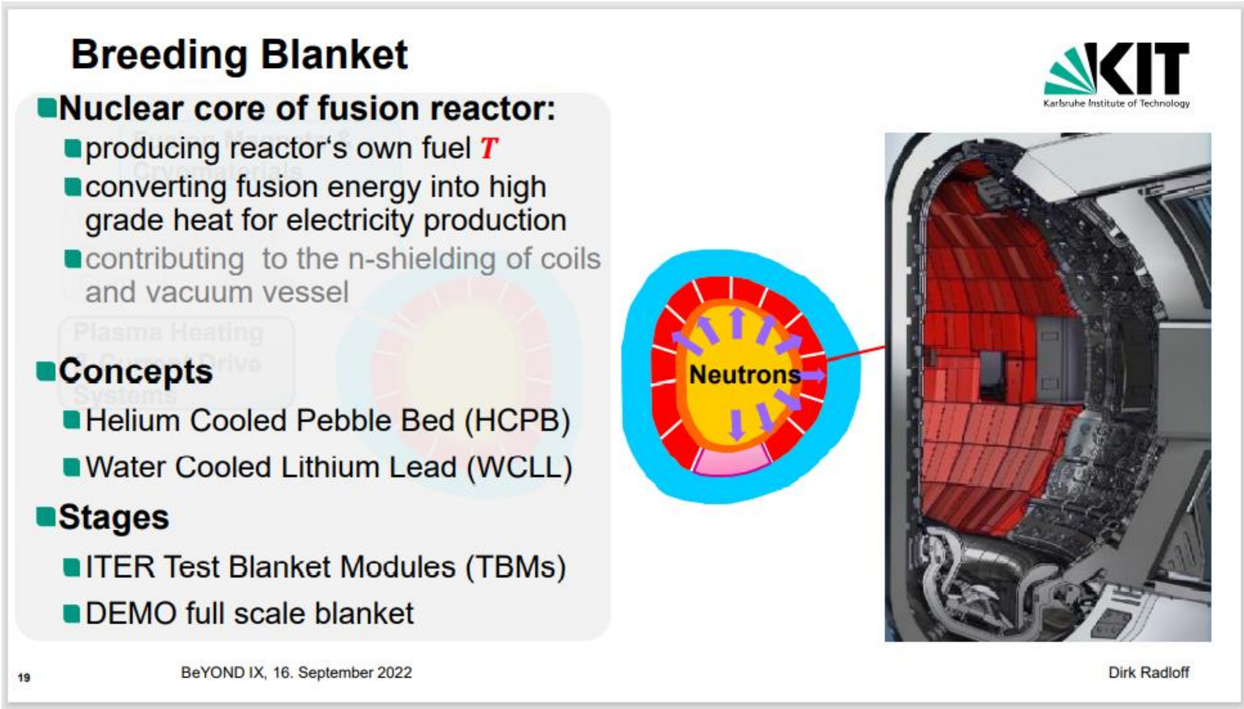
14 BeYOND IX, 16. September 2022 Dirk Radloff

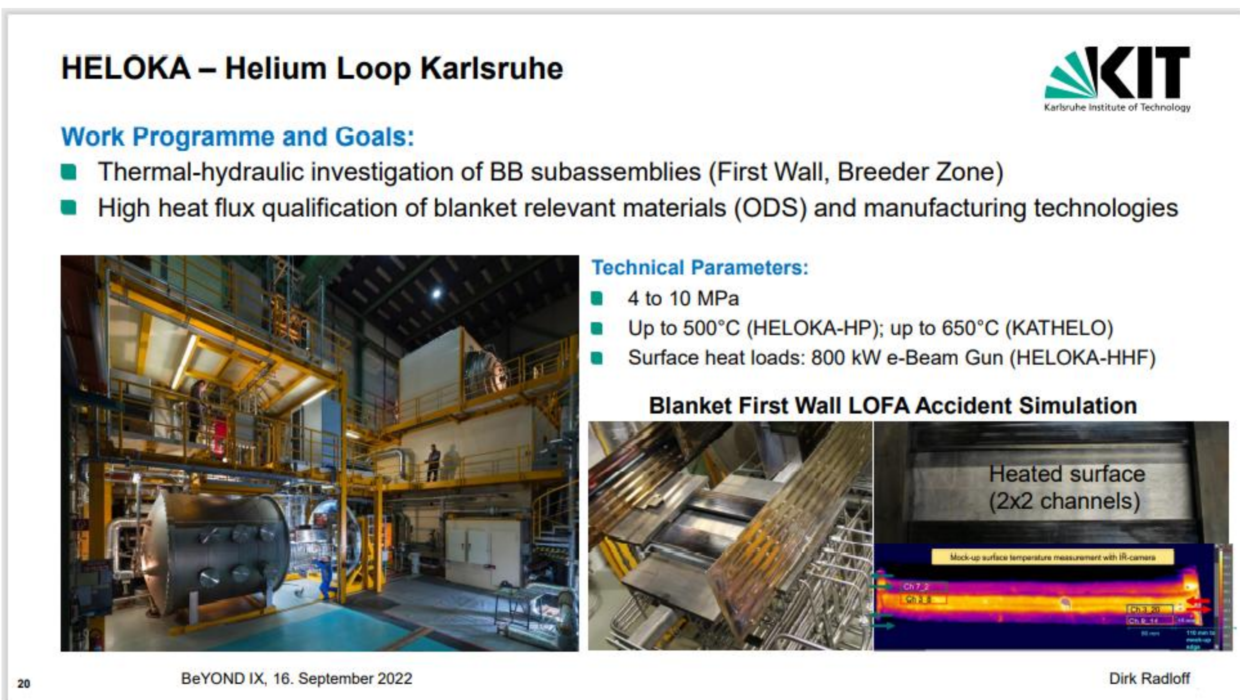

15
Deuterium Tritium Fuel Cycle
KIT
Karlsruhe Institute of Technology
DEMO needs tritium self-sufficiency
Tritium throughput by orders of magnitude higher than for ITER
Tritium inventory is potential showstopper
Tritium Processing Time
tp = 1 h
tp = 6 h
Tritium Inventory (kg)
Tritium Conversion Rate (%)
Neutrons
Deuterium Tritium Fuel Cycle
BeYOND IX, 16. September 2022
Dirk Radloff


16
Deuterium Tritium Fuel Cycle
KIT
Karlsruhe Institute of Technology
New three-loop architecture (the Direct Internal Recycling, DIR)
Demonstration at relevant scale:
The DIPAK facility
Direct Internal Recycling
From highly innovative concept to validation:
DIPAK Facility
D, T Recovery & Purification
80% D,T
20% D,T
Continuous Separation
He, impurities
Continuous Pumping
BeYOND IX, 16. September 2022
Dirk Radloff


17
Breeding Blanket
Karlsruhe Institute of Technology
Fusion Magnets & Cryomaterials
Plasma Diagnostics / Control
Plasma Heating & Current Drive Systems
First Wall / Plasma Wall Interaction
Power & Particle Exhaust / Divertor Physics
DT Fuel
Neutrons
Breeding Blanket
Deuterium Tritium Fuel Cycle
17
BeYOND IX, 16. September 2022
Dirk Radloff

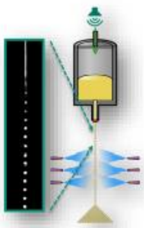

Breeding Blanket
Karlsruhe Institute of Technology
Nuclear core of fusion reactor:
producing reactor's own fuel T
converting fusion energy into high grade heat for electricity production
contributing to the n-shielding of coils and vacuum vessel
Fusion: D + T → He + n
(~30% n lost
streaming
leaking
absorption
Li + n → 4He + T + (n')
9Be + n → 2 4He + 2n
E.g.: HCBP concept:
Be as neutron multiplier
Neutrons
18
BeYOND IX, 16. September 2022
Dirk Radloff

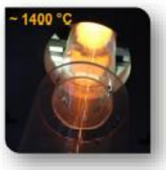

Breeding Blanket
Karlsruhe Institute of Technology
Nuclear core of fusion reactor:
producing reactor's own fuel T
converting fusion energy into high grade heat for electricity production
contributing to the n-shielding of coils and vacuum vessel
Concepts
Helium Cooled Pebble Bed (HCPB)
Water Cooled Lithium Lead (WCLL)
Stages
ITER Test Blanket Modules (TBMs)
DEMO full scale blanket
Neutrons
19
BeYOND IX, 16. September 2022
Dirk Radloff

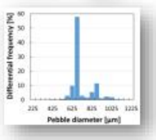

HELOKA – Helium Loop Karlsruhe
Karlsruhe Institute of Technology
Work Programme and Goals:
Thermal-hydraulic investigation of BB subassemblies (First Wall, Breeder Zone)
High heat flux qualification of blanket relevant materials (ODS) and manufacturing technologies
Technical Parameters:
4 to 10 MPa
Up to 500°C (HELOKA-HP); up to 650°C (KATHELO)
Surface heat loads: 800 kW e-Beam Gun (HELOKA-HHF)
Blanket First Wall LOFA Accident Simulation
Heated surface (2x2 channels)
Mock-up surface temperature measurement with IR-camera
20
BeYOND IX, 16. September 2022
Dirk Radloff

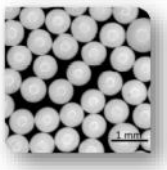
KALOS - Karlsruhe Lithium Ortho-Silicate

Melt-based process for the fabrication of Advanced Ceramic Breeder (ACB) pebbles composed of Li_4SiO_4 and Li_2TiO_3









Facility upgrade under construction:

- Transfer to continuous process
- Production rate of 5-10 kg/day
  - further enhance process stability and product quality
  - secure supply of breeder pebbles for the 1st ITER TBM
  - increase readiness level of Advanced Ceramic Breeder production for DEMO
  - demonstrate the transferability to an industrial scale production

Commissioning 2022

21 BeYOND IX, 16. September 2022 Dirk Radloff

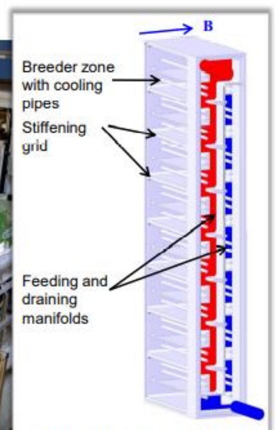
MEKKA - Magneto-Hydrodynamics for Liquid Metal Blankets

Work Programme and Goals:

- Tests of scaled mockups of WCLL ITER-TBMs
- MHD code development for WCLL numerical simulation in DEMO relevant conditions and application for complex structures
- WCLL typical manifold experiment / code validation

Experiments with model fluid NaK:

- High electric conductivity
- Fusion-relevant parameters at moderate magnetic fields and room temperature



Planned experiment: WCLL-TBM for ITER
Design of blanket mockup

22 BeYOND IX, 16. September 2022 Dirk Radloff

MaPLE - Magneto-Hydrodynamic PbLi Experiment

Transferred to KIT from UCLA in 2021; re-assembly ongoing; Commissioning until end of 2022

Work Programme and Goals:

- Determination of heat transfer coefficients in blanket-typical geometries
- Characterization of heat transfer in MHD flows with different orientation of test sections with respect to gravity and different orientations of the magnetic field (horizontal, inclined and vertical gaps

Characteristics:

- Real fusion breeder material PbLi
- 1.8 T magnet rotating in space
- 300 – 550°C
- Pressure head up to 5 bar

23 BeYOND IX, 16. September 2022 Dirk Radloff

24

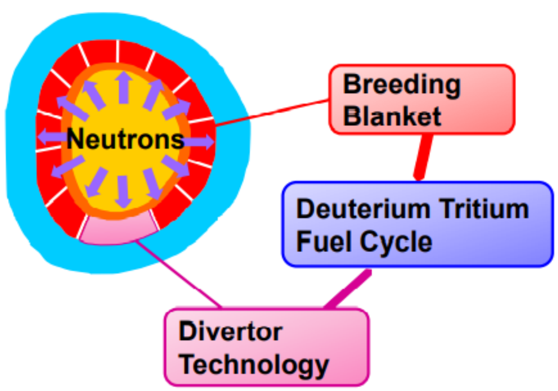
Divertor Technology

- New engineering solutions for power exhaust – water and helium cooled approaches
- based upon emerging structural materials; integration with armor

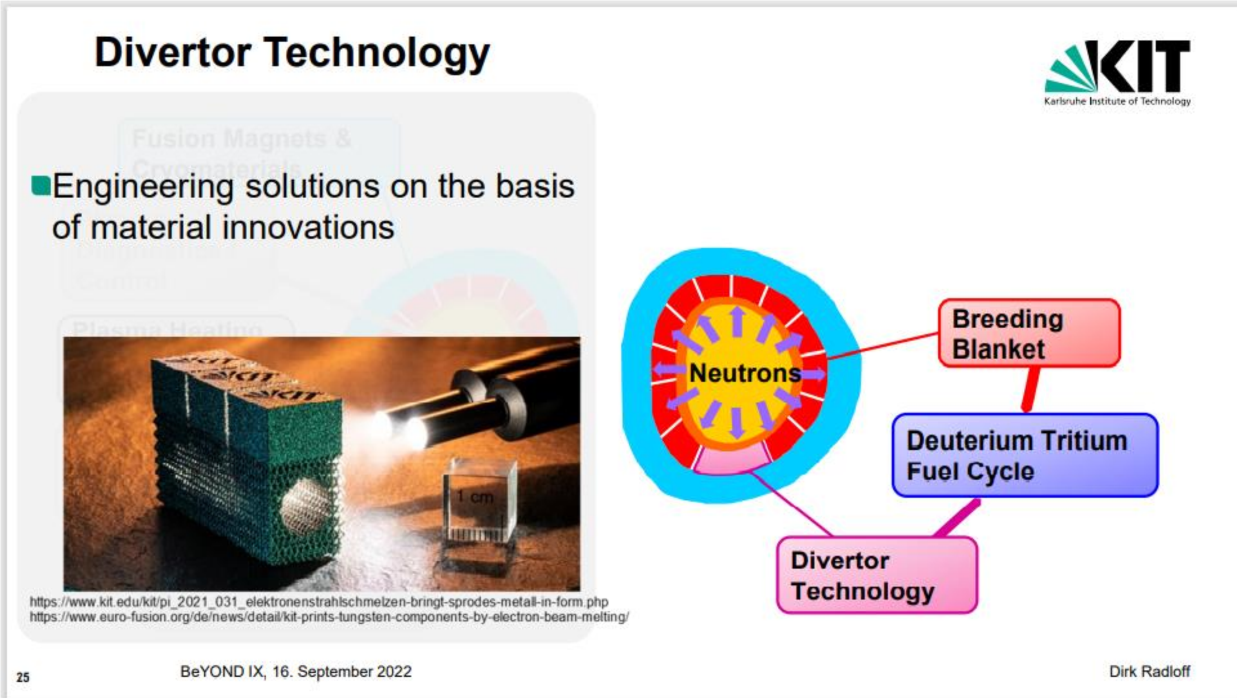
HELOKA – High Temperature Branch KATHELO

Parameters:

- 4 to 10 MPa
- up to 650°C
- up to 800 kW heat load



24 BeYOND IX, 16. September 2022 Dirk Radloff


Divertor Technology
KIT Karlsruhe Institute of Technology
Engineering solutions on the basis of material innovations
1 cm
https://www.kit.edu/kit/pi_2021_031_elektronenstrahlschmelzen-bringt-sprodes-metall-in-form.php
https://www.euro-fusion.org/de/news/detail/kit-prints-tungsten-components-by-electron-beam-melting/
Neutrons
Breeding Blanket
Deuterium Tritium Fuel Cycle
Divertor Technology
25
BeYOND IX, 16. September 2022
Dirk Radloff


26
Electron Beam Melting of Tungsten (W-EBM)
KIT Karlsruhe Institute of Technology
Infiltration of the Tungsten grid with Copper: Fabrication of components
W-EBM part infiltrated with Cu
W-EBM part
Ready for High-Heat-Flux Testing
26
BeYOND IX, 16. September 2022
Dirk Radloff

27

Neutron-Resistant Structural Materials

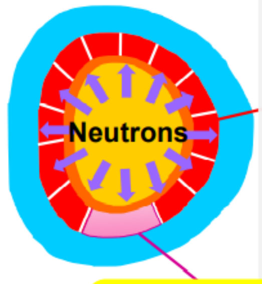
Impact of 14 MeV neutrons:

- Displacement damage: recoil cascades
- Transmutation damage: activation, He and H production
- Activation: avoid long-lived radio-isotopes
- dpa and He bubbles: embrittlement, mechanical degradation

Work program:

- Fission reactor irradiations – lead
- PIE characterization, modeling, **design rules** - lead -

Neutron-Resistant Structural Materials



Standard:
EUROFER

Advanced:
EUROFER ODS
Ductile Tungsten
EBM Tungsten

Developed at KIT

Fusion Neutron Source - Proposal for participation in IFMIF-DONES (Spain)

27 BeYOND IX, 16. September 2022 Dirk Radloff

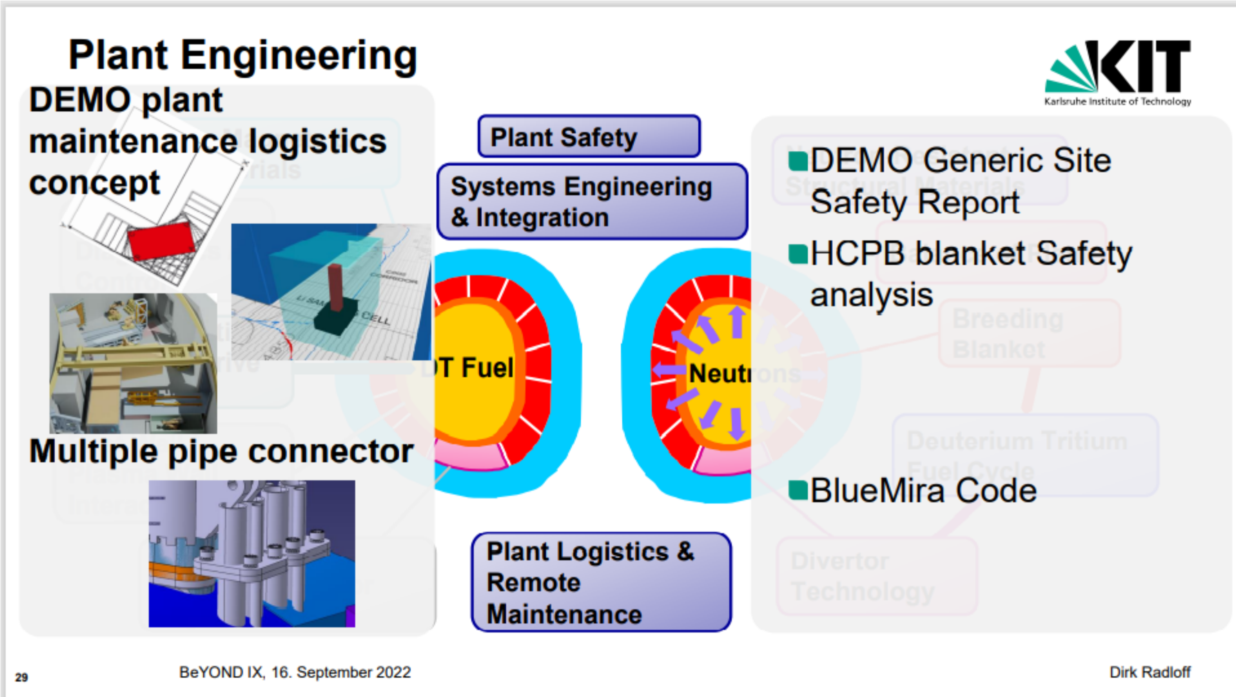
Neutron-Resistant Structural Materials

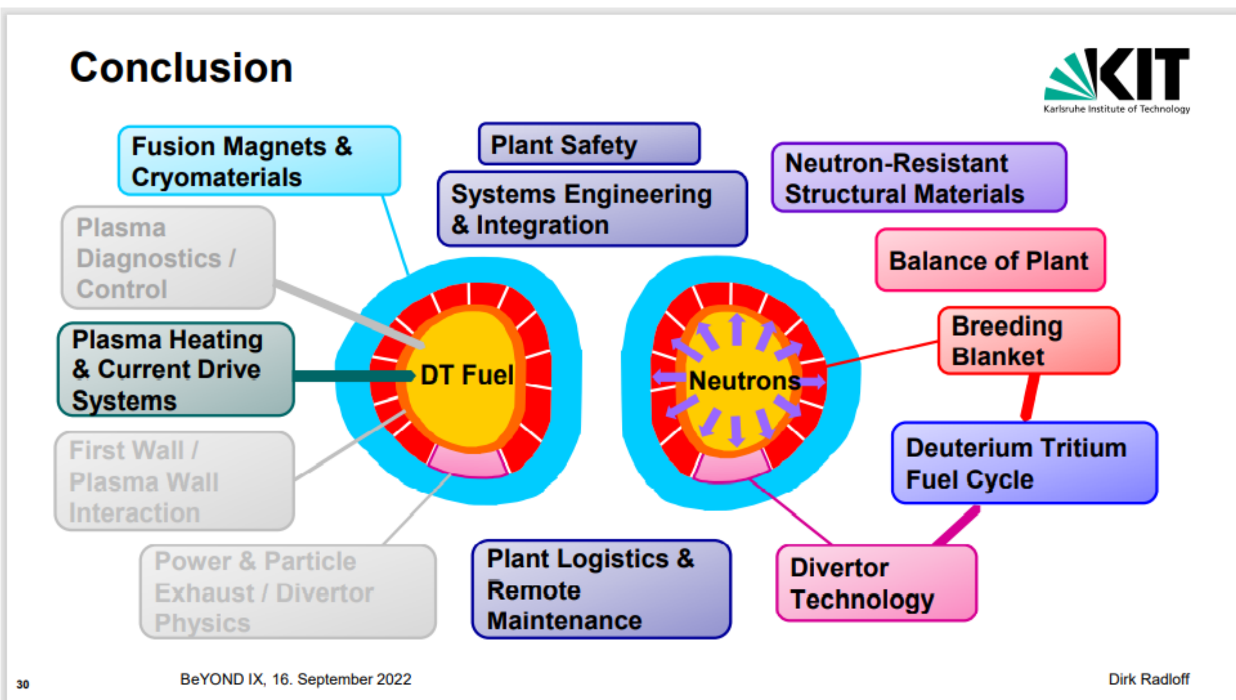
Impact of 14 MeV neutrons:

- Activation: avoid long-lived radio-isotopes
- dpa and He bubbles: mechanical degradation embrittlement
- Materials development
- Materials Property Handbook
- Neutron irradiation program
- Fusion spectrum neutron source IFMIF/DONES

Neutron-Resistant Structural Materials

28 BeYOND IX, 16. September 2022 Dirk Radloff

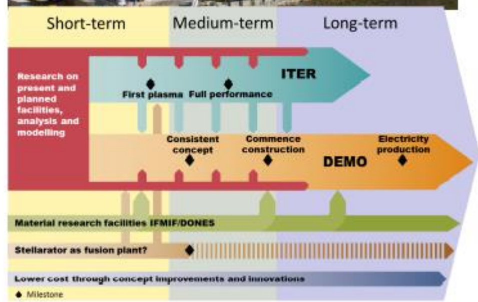

Plant Engineering
DEMO plant maintenance logistics concept
Multiple pipe connector
Plant Safety
Systems Engineering & Integration
DT Fuel
Neutrons
Plant Logistics & Remote Maintenance
DEMO Generic Site Safety Report
HCPB blanket Safety analysis
BlueMira Code
29
BeYOND IX, 16. September 2022
Dirk Radloff


Conclusion
Fusion Magnets & Cryomaterials
Plasma Diagnostics / Control
Plasma Heating & Current Drive Systems
First Wall / Plasma Wall Interaction
Power & Particle Exhaust / Divertor Physics
Plant Safety
Systems Engineering & Integration
DT Fuel
Neutrons
Plant Logistics & Remote Maintenance
Neutron-Resistant Structural Materials
Balance of Plant
Breeding Blanket
Deuterium Tritium Fuel Cycle
Divertor Technology
30
BeYOND IX, 16. September 2022
Dirk Radloff

KIT Karlsruhe Institute of Technology

Strategic Goal:
Early Deployment of Fusion Energy

- Provide the necessary support to the completion of **ITER**
  - ~ 2025 First Plasma
  - Deuterium-tritium operation ~ 2035
- R&D beyond ITER following the **EUROfusion Roadmap**
  - DEMO Conceptual Design
  - Materials irradiation data base, design rules
  - Support for **W7-X** and the stellarator line



31 ■ Train the next Generation for ITER and DEMO

Dirk Radloff

KIT Karlsruhe Institute of Technology

Thank you for your attention!

32 BeYOND IX, 16. September 2022 Dirk Radloff

Fusion-for-Future: Bridge to Private Invested Companies in Fusion Energy

Markus Lemmens[1,2] and Aniceto Goraieb[2]

[1]Lemmens Medien GmbH, Bonn, Germany
[2]Karlsruhe Beryllium Handling Facility (KBHF), Eggenstein-Leopoldshafen, Germany

Beside the well-established big science projects in Fusion, about three dozen Start-ups or private invested companies are competing in "building a star on earth". It is not unlikely that one of them will succeed within this or early in the next decade. But the star will need a bottle, an oven where it can be safely handled. Scientists call this bottle a blanket, and it has three major roles:

- First to hold the energy long enough insight to keep the fire burning
- Second, to produce additional fuel for the process (especially for the D-T concepts)
- Third, to build a biological shield towards the environment

In most concepts, the blanket is nearly as complex as the reactor core. Even if one of these Fusion machines will reach break-even (energy necessary equal to energy produced) the blanket might need another decade to be ready to use.

We at KBHF Karlsruhe are running a “Spin-In”, a private organized infrastructure on a research campus and have more than 30 years of experience in Fusion research while living in the field of tension between science and industry. Therefore, our intension is to bridge into the private invested cooperate world. More than 20 years ago, a non-profit-organization was founded by our company to communicate science to the public. This club could eventually be the germination cell for a new undertaking towards Fusion based on cooperation and collaboration.

Corresponding Author:
Dr. Markus Lemmens
lemmens@lemmens.de
Lemmens Medien GmbH
Matthias-Gruenewald Strasse 1-3
D-53175 Bonn
GERMANY

Linking Fundamental Research & Private Invested Companies

Aniceto Goraieb and Markus Lemmens, GVT & KBHF, Karlsruhe

- ***An easygoing start:*** We notice the growing activities in private invested and Fusion Energy related companies worldwide.
    - **But we do nothing and keep calm!**
- ***A stronger note:*** We can ignore the good thirty start ups and slightly mature enterprises in Fusion collecting nearly 4 Billion dollars in venture capital soon.
    - **Then we will lose time in building a strong global network!**
- ***An urgent attitude:*** We risk the European (pole) position in Fusion in case politicians will no longer follow because industry finds too little to put into practice.
    - **Can we still hide the advantages of a pragmatic Public Private Partnership?**

2

…is this what we want?

Certainly not!

- So we thought about a few things, how to create the **Future-for-Fusion landscape**.
- We would like to suggest an **agile network** of established labs and promising start-ups.

3

The Start-Up GVT was founded in 1993

Aniceto Goraieb

The initial situation (4 slides)

- My thesis in "Nuclear Engineering" was part of the Fusion Blanket Design.
- One option in solid form is using Beryllium and Lithium-Ceramics as a pebble bed.
- No laboratory for the use of Beryllium was available, so I built up my own.
- The first 10 years were focused on materials testing, like thermo-hydraulic tests.
- Our first own research activity on FLiBe in 2002 brought us to material design.

4

The Club MKP – Mankind Project came to life in 2000

- "Nurture of the human mind for the future of the humankind".
- Research and technology should be dedicated to wishes and visions of mankind.
- Start a communication process between science, industry, politics, and the public.
- Improvement of knowledge about current research projects and alternatives.
- Initiate, promote, and finance our own meaningful research activities based on that.

5

The Spin-In KBHF was founded in 2009

- The constantly growing infrastructure made it necessary to change the legal form.
- Additional studies "Research Management" brought me to the idea of a "Spin-In".
- KIT and my shareholder Markus Lemmens helped me to found KBHF GmbH at KIT.
- A Spin-In is operated by an intrapreneur and is focused on Deep-Tech (long-term technology transfer).
- Last year my MBA-Thesis showed the similarity to the Fusion-Start-Up-Scene.

6

FUSION FOR FUTURE ↔ the MKP – Mankindproject

- Mankind projects have long transit times and discontinuities in technology transfer.
- A non-profit organization would be a good accompanying partner in this case.
  - MKP ↔ LTT ↔ Non-Profit (LTT = Long-Term Technology Transfer)
  - Deep-Tech ↔ Spin-In ↔ Intrapreneurship
- Since the pandemic, Deep-Tech seems to be the new expression for LTT.
- If we put LTT = Deep-Tech, we get the equation: MKP ↔ Spin-In ↔ Non-Profit.
- Now bringing all of them together: FUSION ↔ KBHF ↔ Fusion-for-Future.
- Fusion-for-Future can be a project of the non-profit-association Mankind Project e.V.

7

The beyond 2023 agile network

Markus Lemmens

The idea for tomorrow (3 slides)

1. Identifying research & development needs and practical feasibilities (tech landscape).
2. Solve technical problems by bringing "suppliers" and "consumers" together (demands).
3. Establishing the mediation role and building an agile organization (coordination).
4. Ensure that established partners are informed / involved, for example: Fusion Industry Association, EuroFusion, Fusion Industry Liaison Office (strong community).
5. Convince the individual companies with a lean entity that ensures the "time-to-market requirement" as well as the solid "fundamental research expertise".
6. Let´s join The Club: the non-profit-association MKP from 2023 onwards... to create in the 2020s the industrial and in the 2030s the commercial market(s).

8


THE COMPANY´S WORLDMAP
Building an Agile Network of Research, Development and Technology with high impact in energy supply of global civil societies – the *Fusion for Future*.
Canada
Seattle
Washington
Nevada
California
Colorado
New Mexico
Canada
Massachusetts
New Jersey
Virginia
Tennessee
United Kingdom
Germany
France
Japan
Australia
9


SAVE THE DATE
FUSION
FOR FUTURE
ONLINE CONFERENCE
MANKIND PROJECT 2.0
February 23, 2023
Our vision for the future is to build a Star on Earth.
Are you ready to be part of this journey in 2023?
www.fusion-for-future.de
10

Session 2: Beryllium Health & Safety in Fusion Research

Beryllium Regulatory Review and Communications Update

T. Knudson (Materion Brush Inc., U.S.A.)

Beryllium Regulatory Review and Communications Update

Theodore Knudson

Materion Brush Inc., Mayfield Heights, Ohio, U.S.A.

Beryllium is a critical material for DT fusion reactors, particularly for its use as a neutron multiplier in tritium breeding blankets. However, the requirement for just one GW-e scale fusion DEMO reactor is around 400 tons and the global beryllium industry produces just 300 to 400 tons per year.

Current and proposed regulations related to occupational health and safety, critical raw materials and substance bans and restrictions in the European Union, the United States and other jurisdictions have the potential to significantly impact the supply, use and handling of beryllium and beryllium-containing materials in various industrial sectors and markets. Several of these regulations have required the development of additional communications regarding the safe handling and use of beryllium and beryllium-containing materials.

This presentation will identify and review the above referenced current and proposed regulations and discuss how these regulations have or will impact supply, use and handling of beryllium and beryllium-containing materials. Additionally, the presentation will discuss the current status of these regulations and the actions being taken by the beryllium industry to minimize the potential impact and comply with these regulations.

In addition to the above, the presentation will include information on the most recent communication tools developed by the beryllium industry to assist with handling these materials safely.

Corresponding Author:

Mr. Theodore Knudson, MS, CIH
Senior Director, Regulatory Affairs and Product Stewardship
theodore.knudson@materion.com
Materion Brush Inc.
6070 Parkland Boulevard
Mayfield Heights, Ohio 44124
U.S.A.

Beryllium Regulatory Review

- Beryllium Science & Technology Association
- Occupational Exposure Limits (OEL)
  - EU Binding OEL
  - OSHA Beryllium Standard
- RoHS – Restriction on Hazardous Substances in EEE
- REACH - Registration, Evaluation, Authorization and Restriction of Chemicals.
- EU Regulations/Programs Under Development
- Rest-of-World (ROW) Regulations
- BeST Communications – Be Responsible

MATERION

2

Beryllium Science and Technology (BeST)

- **BeST – Beryllium Industry Association in EU**
- **Directorate (Ridens Public Affairs) located in Brussels, Belgium**
- **Members**
  - Materion Corporation
  - NGK Berylco France
  - Tropag
- **Associate Members**
  - Schmeltzmetall AG
  - CBL
  - UK Atomic Energy Authority
  - BGV Group Management

3

Beryllium Science and Technology (BeST)

Our Mission:

Promotion of sound policies, regulations, science and actions related to the use of beryllium and serve as an expert resource for the international community on the benefits and criticality of Beryllium applications.

Promotion of good practices at the workplace.

Our expertise has been gained through our research efforts and the solid evidence from epidemiology and medical studies.

More importantly, we have workplace experience in protecting workers.

Our success has been demonstrated through numerous studies and reviews.

4

Occupational Exposure Limits - EU

- After several years of study and consideration, the EU set a binding worker protection standard for beryllium under the Carcinogens and Mutagens Directive (CMD).
- The limit was based on prevention of CBD due to the relative uncertainty surrounding carcinogenicity.
- The new Occupational Exposure Limit (OEL) is:
  - 0.6 µg/m^3, Inhalable fraction, 8-hour TWA for a 7-year transitional period (until July 11, 2026)
  - 0.2 µg/m^3, Inhalable fraction, 8-hour TWA after transitional period
- Member States were required to bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 11 July 2021.

MATERION

5

Occupational Exposure Limits - US

- OSHA published the final Beryllium Standard for General Industry on July 14, 2020 (29 CFR 1910.1024)
- All elements of the Beryllium Standard became enforceable on September 15, 2020
- The Permissible Exposure Limit (PEL) is 0.2 µg/m^3, 8-hour TWA.
- The Short-Term Exposure Limit (STEL) is 2 µg/m^3 determined over a 15-minute period.
- The Action Level (AL) is 0.1 µg/m^3, 8-hour TWA.
- Exposures at or above these levels prompt implementation of other provisions.

MATERION

6

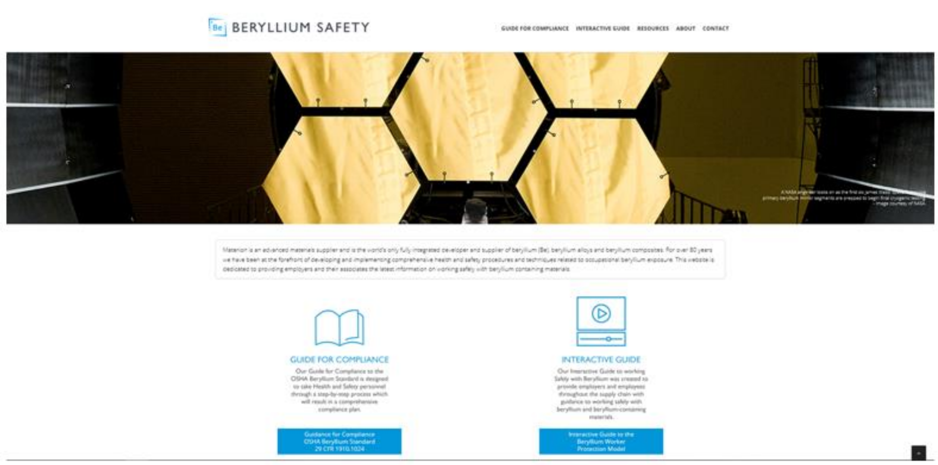
Occupational Exposure Limits - US

The provisions of the OSHA Beryllium Standard (29 CFR 1910.1024) include:

- **Scope**
- **Permissible Exposure Limits**
- **Exposure Monitoring**
- **Beryllium Work and Regulated Areas**
- **Methods of Compliance**
- **Written Exposure Control Plan**
- **Engineering and Work Practice Controls**
- **Respiratory Protection**
- **Protective Clothing and Equipment**
- **Hygiene Areas and Practices**
- **Housekeeping**
- **Medical Surveillance**
- **Medical Removal**
- **Communication of Hazards**
- **Recordkeeping**

MATERION

7



www.berylliumsafety.com

MATERION

8

RoHS

- **Beryllium and beryllium-containing materials were not included in the European Union Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) (2011/65/EU), 2011/65/EU (RoHS 2) and 2015/863/EU (RoHS3).**
- **RoHS restricts the use of lead, cadmium, hexavalent chromium, mercury, PBB, PBDE, DBP, BBP, DEHP and DIBP in most electrical and electronic products.**

MATERION

RoHS

- **Beryllium was one of seven materials under review as part of the European Commission (EC) "Study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2" that began in January 2018.**
- **During the study consultation conducted by the EC consultant, BeST provided information as to the importance of beryllium in Electrical and Electronic Equipment (EEE), the minimal risk in the use of beryllium in EEE and the consequences for restricting beryllium in EEE.**
- **The EC consultant's assessment of beryllium was published on September 26, 2019 and updated on March 25, 2020 based on the information provided during the assessment review. The EC consultant recommended that beryllium not be included on the RoHS restricted substance list.**
- **Action on the recommendations is expected in 2023 as part of the RoHS General Review.**

MATERION

REACH Regulation Summary

- **REACH is the European Union (EU) Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals.**
- **It entered into force on June 1, 2007 and required manufacturers and importers to register substances.**
- **Beryllium, Beryllium Oxide and all of the elements contained in beryllium-containing alloys have been registered with ECHA as required.**

MATERION

11

REACH Regulation Summary

- **Massive forms of beryllium metal, beryllium alloys and beryllia ceramic are classified as "articles" and therefore were not required to be registered under REACH.**
- **CoRAP and RMOA conducted for beryllium by German BAuA.**
- **Final recommendation was <u>not</u> to classify beryllium as a Substance of Very High Concern (SVHC), for industry to develop a Voluntary Product Stewardship Program and for EU to identify a binding Occupational Exposure Limit (OEL) for beryllium.**

MATERION

12

EU Regulations/Programs Under Development

BeST Watchlist

- Chemical Strategy for Sustainability (EU Green Deal)
- Essential Use Concept (EUC)
- Generic Risk Approach (GRA)
- Green Public Procurement (GPP)
- Circular Economy
- Critical Raw Materials

13

MATERION

Rest-of-World (ROW) Regulations

OELs/REACH/RoHS Regulations

- UK
- Australia
- India
- Bangladesh
- China

14

MATERION

BeST Communications – Be Responsible

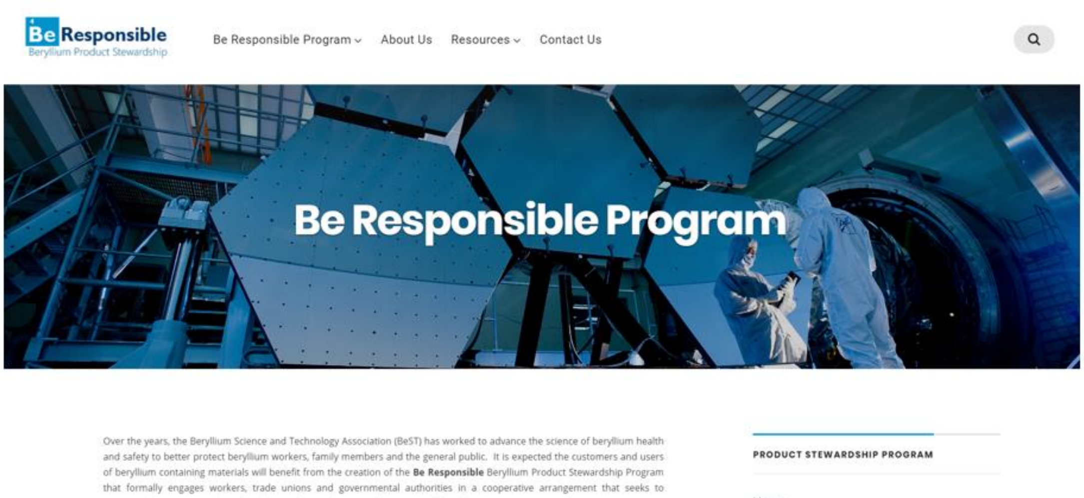
- Industry led program launched in March 2017

- Includes a web-based format featuring 12 process specific guides in EN, FR, DE, IT, ES, presentations and videos accessible at www.berylliumsafety.eu

- Describes the potential health risks associated with the exposure to airborne beryllium, the main sources of exposure and the measures to be implemented to control dust emission and dispersion for the most frequent operations

MATERION

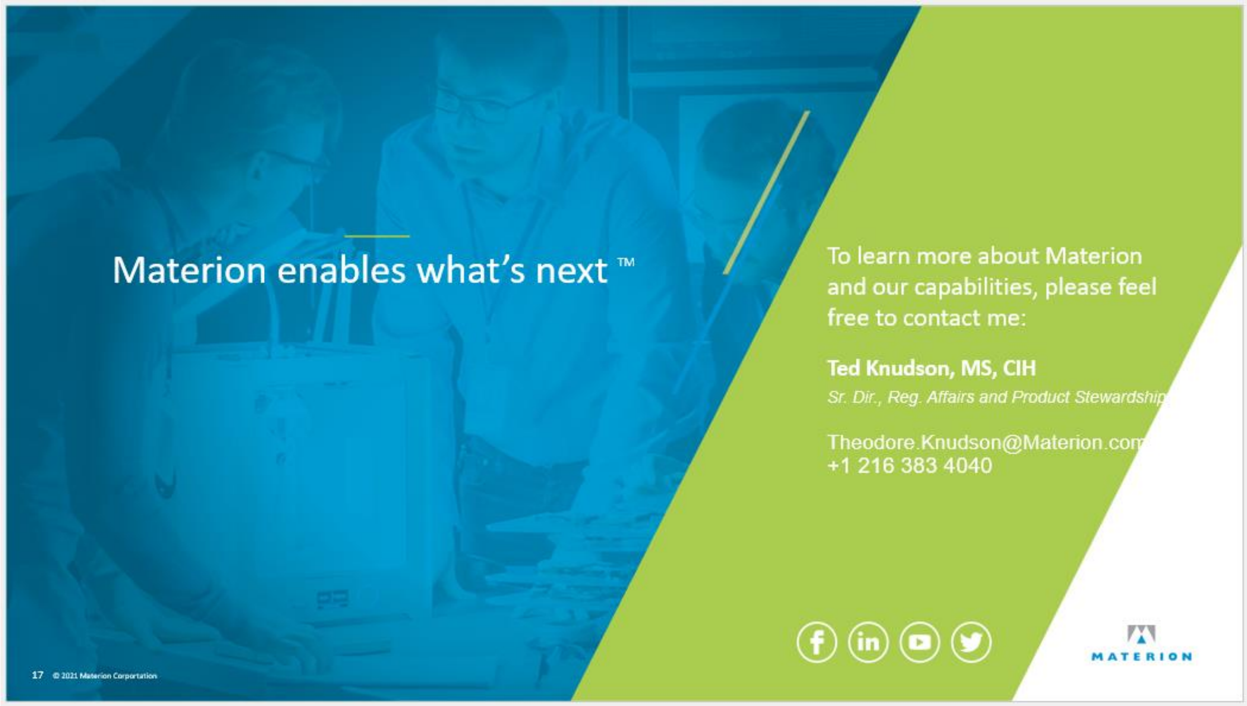
15 © 2021 Materion Corporation



www.berylliumsafety.eu

MATERION

16 © 2021 Materion Corporation


Materion enables what's next ™
To learn more about Materion and our capabilities, please feel free to contact me:
Ted Knudson, MS, CIH
Sr. Dir., Reg. Affairs and Product Stewardship
Theodore.Knudson@Materion.com
+1 216 383 4040
MATERION
17 © 2021 Materion Corporation

Beryllium End-Use Applications & Material Forms and Their Effects on Protection Programs for Workers & Consumers

Christopher K. Dorn[1] and Kathryn Creek[2]

[1]Be4FUSION LLC, Upland, California, U.S.A.
[2]Beryllium Solutions International LLC, Lourinha, Portugal

Scientists who are familiar with metallic beryllium and its uses in aerospace and defense as well as in various types of nuclear research, including fusion energy, may be under the impression that these applications constitute the most common end-uses for beryllium, but in fact, they do not.

The overwhelming majority of primary beryllium made each year is not found in the form of metallic beryllium, but rather it goes into the production of low beryllium-content alloys, such as copper-beryllium, nickel-beryllium, and aluminum-beryllium. In addition, compounds such as beryllium oxide ceramics are also produced in significant quantities.

New applications in nuclear energy may also see a large increase in the use of beryllium fluoride in its compound form. Up until recently, beryllium fluoride has mainly been encountered as an intermediate material in the Kroll process for refining metallic beryllium. The recent interest in this compound stems from its use in the form of FLiBe (fluoride-lithium-beryllium), a molten salt that is already slated for use in small modular reactors (fission), and it may also have potential use in a fusion reactor.

This presentation gives an overview on beryllium's useful properties, the global market, industries where beryllium is found, typical applications for beryllium-containing materials in their various forms, and exposure assessments by industry. In support of safe handling of beryllium and the furtherance of protection programs for the environment, industry workers, and consumers, this presentation highlights that low beryllium-content materials are a much more commonly encountered form of the material than beryllium metal, which is important to understand since health and safety requirements are the same regardless of the form of the material.

Corresponding Author:
Christopher Dorn
chris.dorn@be4fusion.com
Be4FUSION LLC
Postal address:
1528 North Granite Avenue
Ontario, California 91762-1200
U.S.A.

bsi

Be4FUSION
Specialty Materials & Business Consulting

Beryllium End-Use Applications & Material Forms & Their Effects on Protection Programs for Workers & Consumers

BeWS-15 2022
15th International Workshop On Beryllium Technology
Karlsruhe, Germany
14-15 September 2022

SPECIAL JOINT EVENT

BeYOND-IX 2022
9th Industrial Forum on Beryllium Opportunities & New Developments
Karlsruhe, Germany
16 September 2022

Christopher DORN • Be4FUSION & Kathryn CREEK, CIH, MS • Beryllium Solutions International

15th International Workshop on Beryllium Technology
9th BeYOND Industrial Forum

September 2022

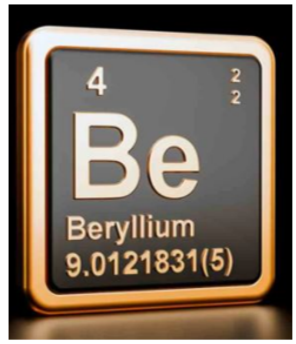
Presentation Outline

- Overview on Beryllium End-Uses
- Global Market for Beryllium
  - Beryllium Markets by End-Use Application
- Material Forms of Beryllium
- Why Beryllium? – Useful Properties
  - Properties: Beryllium-Containing Alloys
- End-Use Applications: Alloys & Compounds
  - Typical Cu-Be Alloy Applications
  - Typical BeO Ceramic Applications
  - New End-Use Applications: Molten Salt Reactors
- Industries Where Beryllium is Found in Some Form
- Impact on Protection for Workers & Consumers

bsi

Be4FUSION

Overview on Beryllium End-Uses



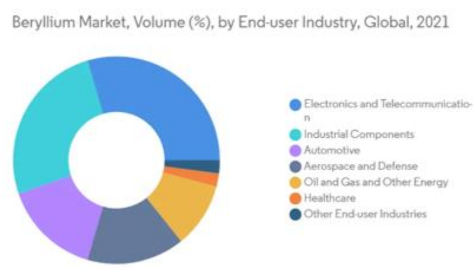
- There is a great deal of misinformation about beryllium (especially in online sources) due to misunderstandings about the various forms in which beryllium is found
- In fusion, one may think that "beryllium" refers to Be metal or high-Be content materials (e.g., beryllide compounds), but those materials actually represent only a small fraction of the forms of beryllium most commonly found
- Copper-beryllium (Cu-Be) alloys, which are generally <2% Be content, represent the most common form by far in which beryllium is encountered
- Beryllium oxide (BeO) ceramics are also more frequently found in commercial applications than Be metal

bsi

Be4FUSION

Global Market for Beryllium

Study Period:	2017-2027
Base Year:	2021
Fastest Growing Market:	Asia-Pacific
Largest Market:	North America
CAGR:	>2 %

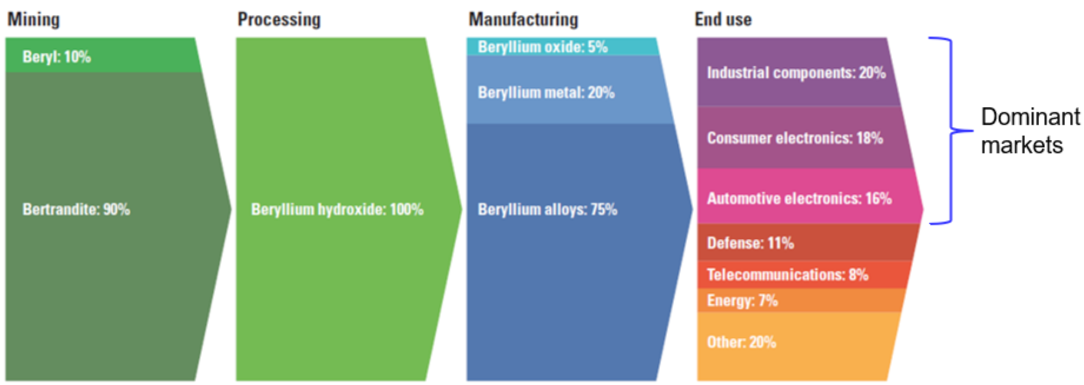


Source: Mordor Intelligence
https://www.mordorintelligence.com/industry-reports/beryllium-market

bsi

Be4FUSION

Beryllium Markets by End-Use Application



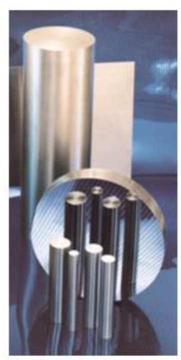
Source: Materion Corp., 2016
Cited by USGS: FactSheet 2col v 3.5.1 (usgs.gov)

bsi

Be4FUSION

Material Forms of Beryllium

- Metallic Element
- Precious Gem Forms
- Be-Bearing Ores
- Largest End-Use/ Forms
  - Alloys
  - Metal & Composites
  - Compounds
- Technical Terms
  - Alloy Naming Convention



Beryllium Metal

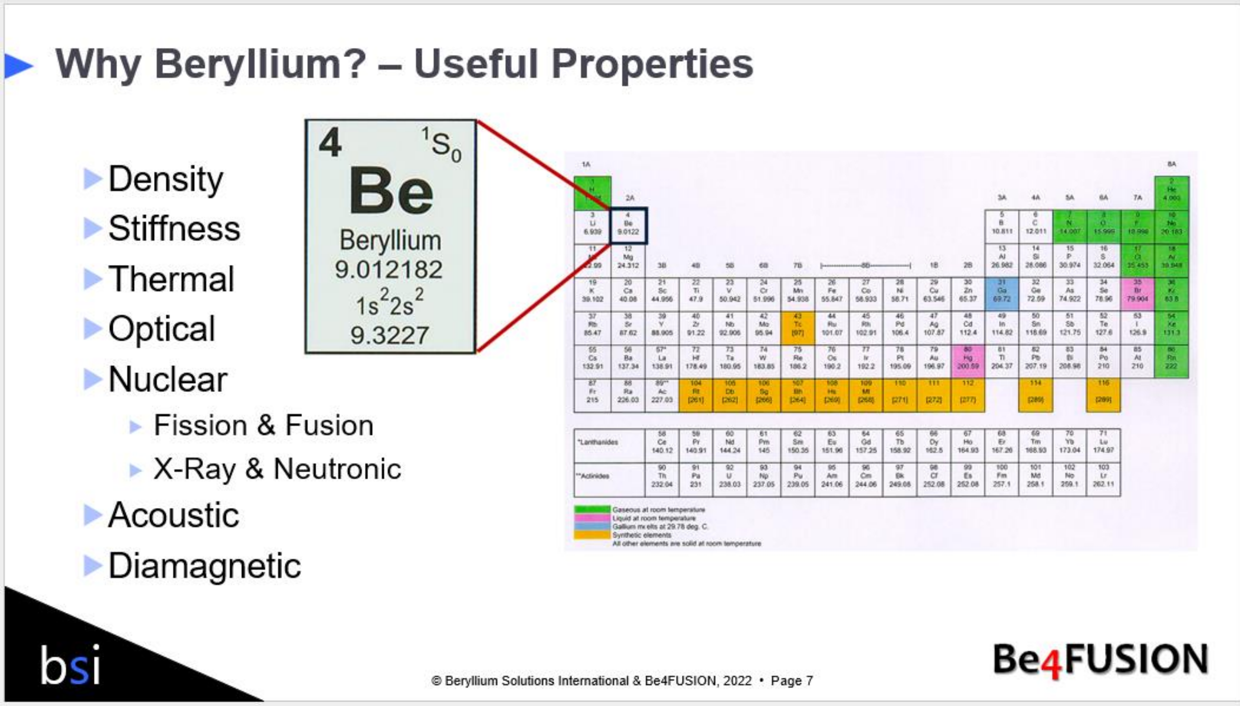
Copper-Beryllium Alloy Strip Coil

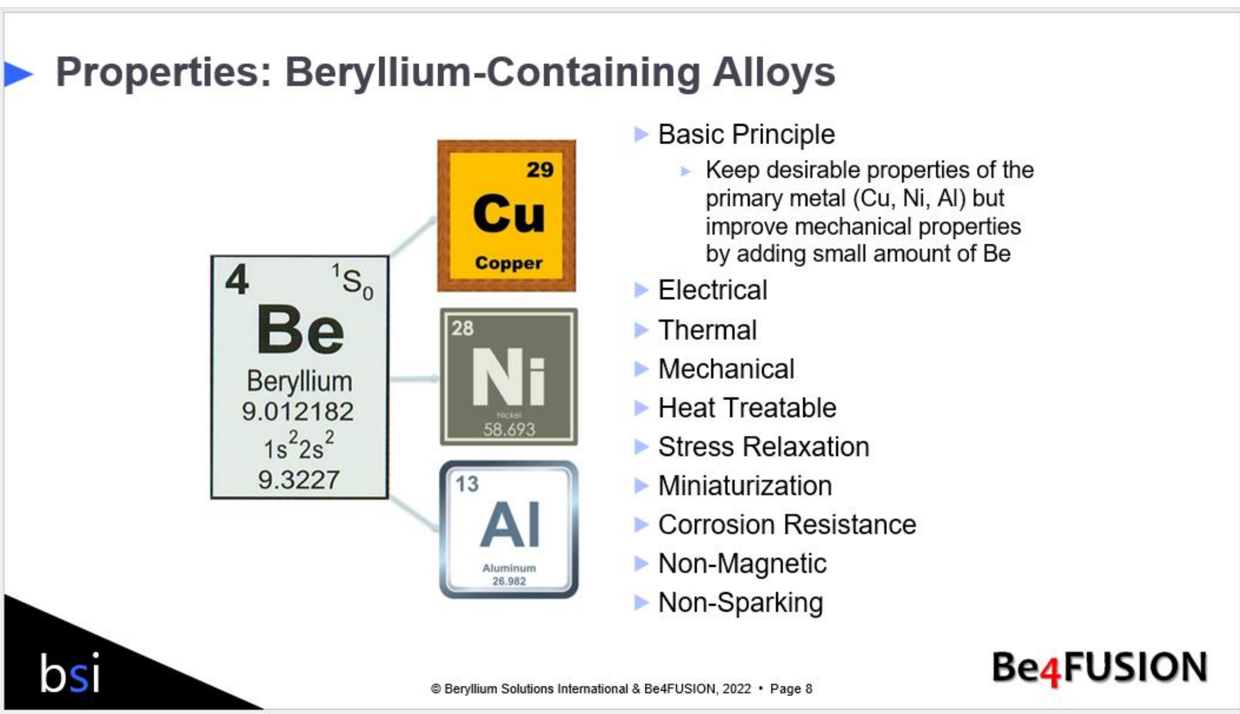
Beryl Photo from MII
Source: Smithsonian Institution

Beryllium Oxide Ceramics

bsi

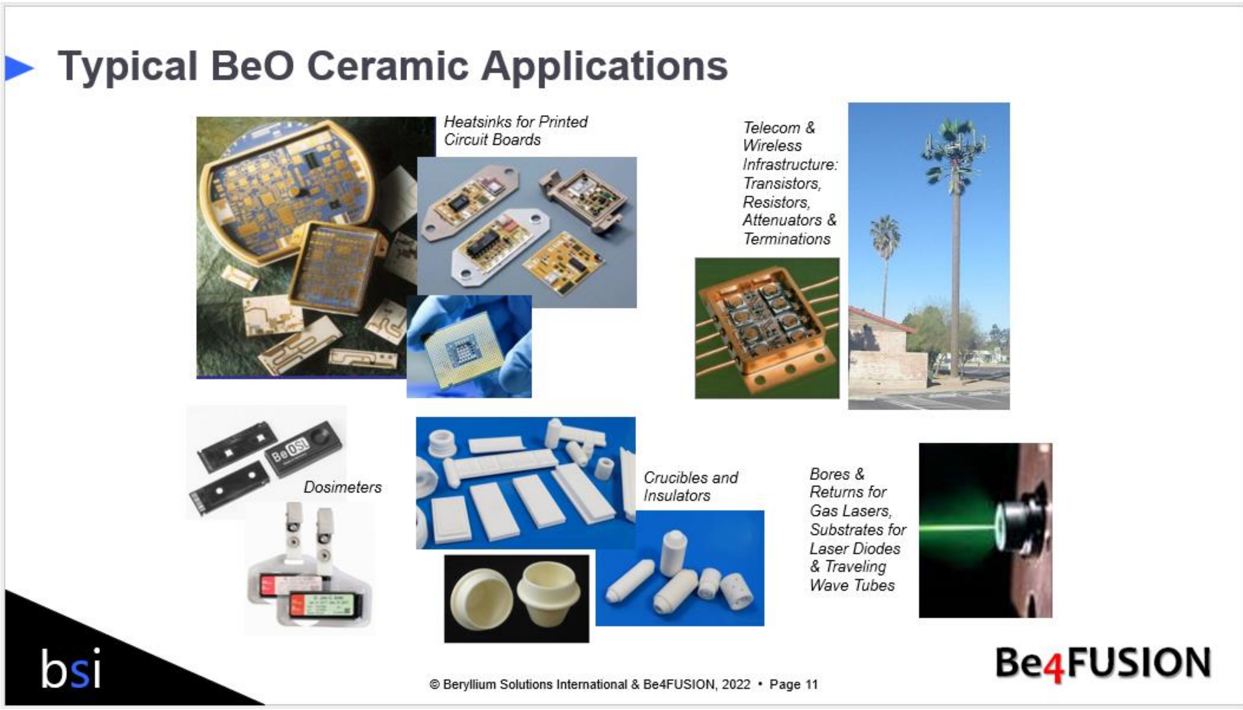
Be4FUSION

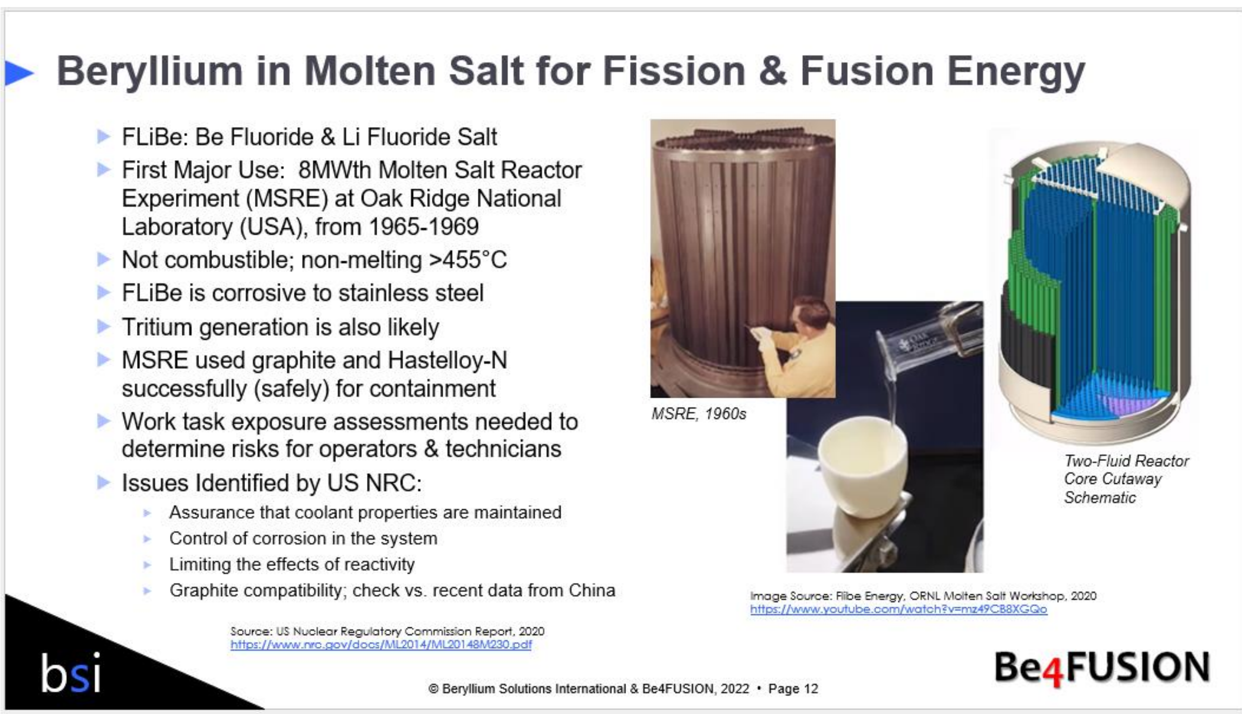

Why Beryllium? – Useful Properties
Density
Stiffness
Thermal
Optical
Nuclear
Fission & Fusion
X-Ray & Neutronic
Acoustic
Diamagnetic
4
$^1S_0$
Be
Beryllium
9.012182
$1s^2 2s^2$
9.3227
bsi
© Beryllium Solutions International & Be4FUSION, 2022 • Page 7
Be4FUSION


Properties: Beryllium-Containing Alloys
4
$^1S_0$
Be
Beryllium
9.012182
$1s^2 2s^2$
9.3227
29
Cu
Copper
28
Ni
Nickel
58.693
13
Al
Aluminum
26.982
Basic Principle
Keep desirable properties of the primary metal (Cu, Ni, Al) but improve mechanical properties by adding small amount of Be
Electrical
Thermal
Mechanical
Heat Treatable
Stress Relaxation
Miniaturization
Corrosion Resistance
Non-Magnetic
Non-Sparking
bsi
© Beryllium Solutions International & Be4FUSION, 2022 • Page 8
Be4FUSION


Typical Copper-Beryllium Alloy Applications
Electrical Contacts & Connectors
Oil & Gas: Heads & Components for Downhole Drilling
Dies & Inserts for Plastic Molding
Bulk Products: Rod, Bar & Tube Used in a wide variety of industries
Non-Sparking Tools
bsi
© Beryllium Solutions International & Be4FUSION, 2022 • Page 9
Be4FUSION


Other Beryllium-Containing Alloy Applications
High-Reliability Springs
Cu-Be & Ni-Be
Widely used in sprinkler heads
Golf Club Heads
Cu-Be & Ni-Be Irons & Putters
Al-Be Irons & Putters
Mass production in 1990s but still readily found today from both original makers and after-market sources
Al-Be Master Alloy Ingot for Smelting of Aluminum, Nickel & Magnesium Alloys and Be Ingot for Refining of High-Purity Magnesium
bsi
© Beryllium Solutions International & Be4FUSION, 2022 • Page 10
Be4FUSION


Typical BeO Ceramic Applications
Heatsinks for Printed Circuit Boards
Telecom & Wireless Infrastructure: Transistors, Resistors, Attenuators & Terminations
Dosimeters
Crucibles and Insulators
Bores & Returns for Gas Lasers, Substrates for Laser Diodes & Traveling Wave Tubes
bsi
© Beryllium Solutions International & Be4FUSION, 2022 • Page 11
Be4FUSION


Beryllium in Molten Salt for Fission & Fusion Energy
FLiBe: Be Fluoride & Li Fluoride Salt
First Major Use: 8MWth Molten Salt Reactor Experiment (MSRE) at Oak Ridge National Laboratory (USA), from 1965-1969
Not combustible; non-melting >455°C
FLiBe is corrosive to stainless steel
Tritium generation is also likely
MSRE used graphite and Hastelloy-N successfully (safely) for containment
Work task exposure assessments needed to determine risks for operators & technicians
Issues Identified by US NRC:
Assurance that coolant properties are maintained
Control of corrosion in the system
Limiting the effects of reactivity
Graphite compatibility; check vs. recent data from China
MSRE, 1960s
Two-Fluid Reactor Core Cutaway Schematic
Image Source: Flibe Energy, ORNL Molten Salt Workshop, 2020
https://www.youtube.com/watch?v=mz49CB8XGQo
Source: US Nuclear Regulatory Commission Report, 2020
https://www.nrc.gov/docs/ML2014/ML20148M230.pdf
bsi
© Beryllium Solutions International & Be4FUSION, 2022 • Page 12
Be4FUSION

Industries Where Beryllium is Found in some Form

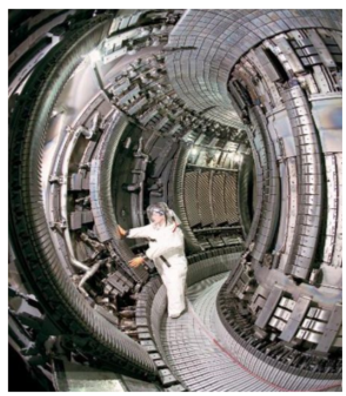
- Aerospace & Defense
- Nuclear & fusion energy
  - Beryllium metal components
  - FLiBe molten salt coolant
- Automotive
- Electronic
- Consumer goods
- Fabricators (welding)
- Telecommunications
- Plastics manufacturing
- Foundry/Casting/Smelting (Be metal, Be-containing alloys, BeO; Al, Ni, Mg alloys)
- Healthcare (x-ray & lasers)
- Audio speakers and drivers
- Non-destructive testing & inspection
- Scientific
- Semiconductor manufacturing
- Security
- Chemical
- Gas/Oil exploration & processing
- Jewelry
- Surgical/Medical/Dental device manufacturing
- Food processing
- Present as a naturally occurring constituent:
  - Sand- and grit-blasting (fly ash slag)
  - Fertilizer manufacturing
  - Cement manufacturing (fly ash)

bsi

Be4FUSION

Impact on Protection for Workers & Consumers

- Historical Exposure Assessments
  - France: dental industry survey questionnaire 2003-2004
  - France: surveys of other manufacturing industries in 2019 showed exposures over $0.05 \mu g/m^3$ in several fields
  - USA: OSHA and NIOSH identified industries with exposures over $0.1 \mu g/m^3$ in 2001, based on data collected from 1979-1996
- Needs for Current & Future Activities
  - Always work to ALARA / ALARP principles
  - Management commitment & priority in energy research
  - Education of and cooperation with regulatory agencies
  - Contractors taking responsibility for sub-contractors
  - Consumer information and awareness programs

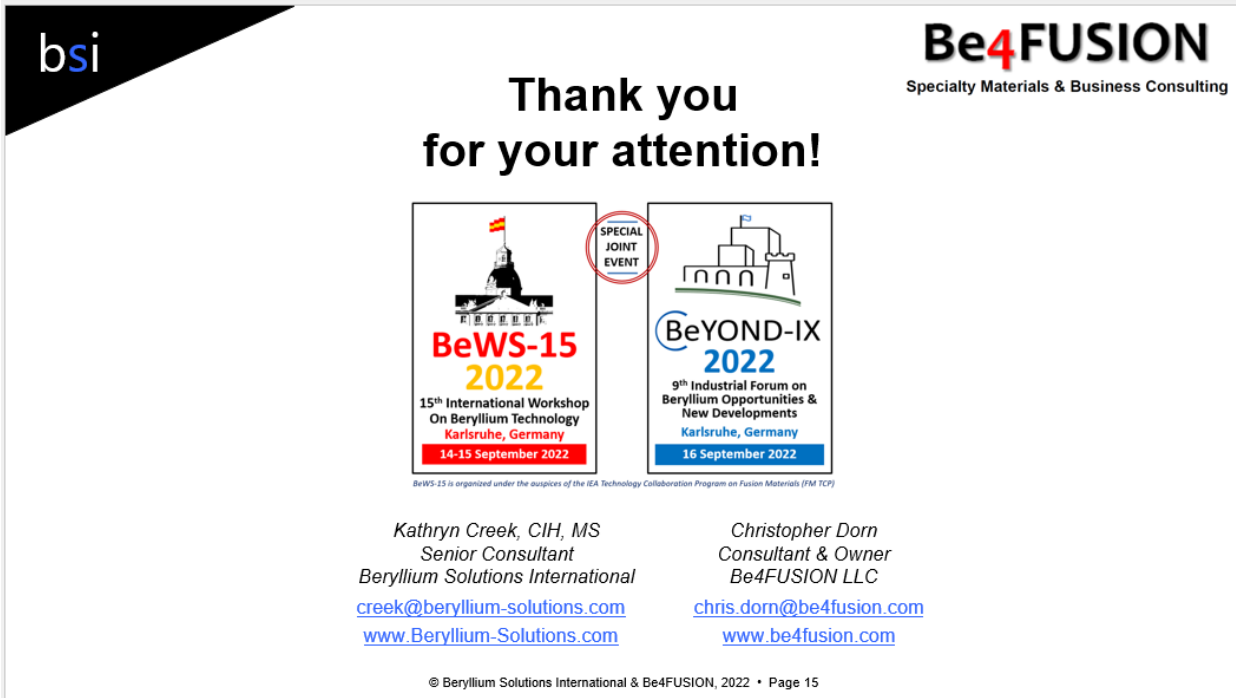


Beryllium worker wearing pressurized suit inside the Joint European Torus (JET) vessel

Image Source: Campling, D. *Be Safety Training at JET – PPE & RPE*, presented to the European Commission, 17-Sep-2018
https://slideplayer.com/slide/14016011/

bsi

Be4FUSION


bsi
Be4FUSION
Specialty Materials & Business Consulting
Thank you
for your attention!
BeWS-15
2022
15th International Workshop
On Beryllium Technology
Karlsruhe, Germany
14-15 September 2022
SPECIAL
JOINT
EVENT
BeYOND-IX
2022
9th Industrial Forum on
Beryllium Opportunities &
New Developments
Karlsruhe, Germany
16 September 2022
BeWS-15 is organized under the auspices of the IEA Technology Collaboration Program on Fusion Materials (FM TCP)
Kathryn Creek, CIH, MS
Senior Consultant
Beryllium Solutions International
creek@beryllium-solutions.com
www.Beryllium-Solutions.com
Christopher Dorn
Consultant & Owner
Be4FUSION LLC
chris.dorn@be4fusion.com
www.be4fusion.com
© Beryllium Solutions International & Be4FUSION, 2022 • Page 15

HLA-DPB1 E69 Genotype and Exposure in Beryllium Sensitization and Disease

Margaret M. Mroz MSPH[1], James Crooks PhD[1,2], Michael VanDyke PhD[1,2], Alison McGrath MS[1,2], Christine Schuler PhD[3], Erin McCanlies PhD[3], Abbas Virji ScD[3], Ken Rosenman MD[4], Milton Rossman MD[5], Carol Rice PhD[6], Dimitri Monos PhD[5], Tasha E. Fingerlin PhD[1,2], and Lisa A. Maier MD, MSPH[1,2]

[1]National Jewish Health, Denver, Colorado, U.S.A.
[2]University of Colorado, Denver, Colorado, U.S.A.
[3]CDC/National Institute for Occupational Safety and Health, Morgantown, West Virginia, U.S.A.
[4]Michigan State University, East Lansing, Michigan, U.S.A.
[5]University of Pennsylvania, Philadelphia, Pennsylvania, U.S.A.
[6]University of Cincinnati, Cincinnati, Ohio, U.S.A.

HLA-DPB1 E69 genotype and inhalational beryllium exposure individually contribute to risk of chronic beryllium disease (CBD) and beryllium sensitization (BeS) in exposed individuals. This retrospective nested case-control study assessed the contribution of genetics and exposure in the development of BeS and CBD.

Workers with BeS (n=444), CBD (n=449), and beryllium-exposed controls (n=890) were enrolled from studies conducted at nuclear weapons and primary beryllium manufacturing facilities. Lifetime-average beryllium exposure estimates were based on workers' job questionnaires and historical and industrial hygienist (IH) exposure estimates, blinded to genotype and case status. Genotyping was performed using sequence specific primer-polymerase chain reaction (SSP-PCR). Logistic regression models were developed allowing for over-dispersion, adjusting for workforce, race, sex, and ethnicity.

Having no E69 alleles was associated with lower odds of both CBD and BeS; every additional E69 allele increased odds for CBD and BeS. Increasing exposure was associated with lower odds of BeS. CBD was not associated with exposure as compared to controls, yet the percent of individuals with CBD versus BeS increased with increasing exposure. No evidence of a gene-by-exposure interaction was found for CBD or BeS.

Risk of CBD increases with E69 allele frequency and increasing exposure, although no gene by environment interaction was found. A decreased risk of BeS with increasing exposure and lack of exposure-response in CBD cases may be due to the limitations of reconstructed exposure estimates. Although reducing exposure may not prevent BeS, it may reduce CBD and the associated health effects, especially in those carrying E69 alleles.

Corresponding Author:
Margaret Mroz, MSPH
mrozp@NJHealth.org
National Jewish Health
1400 Jackson Street
Denver, Colorado 80206-2761
U.S.A.

National Jewish Health

HLA-DPB1 E69 Genotype and Exposure in Beryllium Sensitization and Disease

Lisa A Maier, MD MSPH
National Jewish Health, USA
September 16, 2022

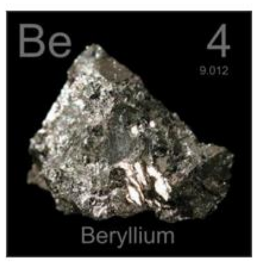
BeYOND-IX 2022

Beryllium

Brittle, grey metal found in coal, soil, volcanic dust, some rock minerals
4th lightest element, low density, stiff, corrosion resistant, high melting point

Forms:
- Metal
- Ceramic (beryllia)
- Alloys
  - Be copper (2-4%)
  - AlBeMet (40-60%)
- Salts
- Silicate
  - Naturally occurring
  - Very low concentration in air and soil

*All refined forms have been associated with health effects



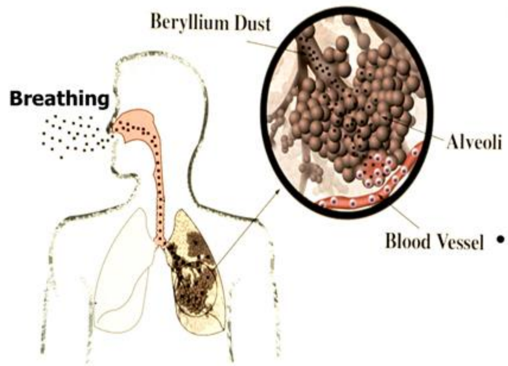
Applications:
- Aerospace
- Alloys
- Automotive parts
- Computers
- Dental prosthesis
- Electronics
- Manufacturing
- Non-sparking tools
- **Nuclear reactor components**
- Nuclear weapons
- Telecommunications

National Jewish Health

2

Health Effects of Beryllium

Routes of Exposure



Health Effects

- **Lungs**
  - Acute beryllium disease
  - Lung cancer
  - **Beryllium sensitization (BeS)**
  - **Chronic beryllium disease (CBD)**
- **Skin**
  - Several skin effects
  - BeS

National Jewish Health

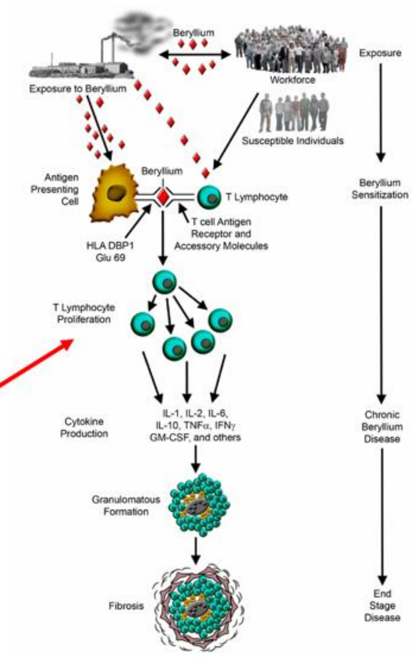
3

National Jewish Health

Immunology of CBD

Type IV, delayed hypersensitivity, cell-mediated immunity

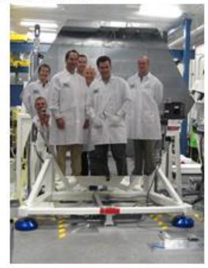
BeLPT assesses this response



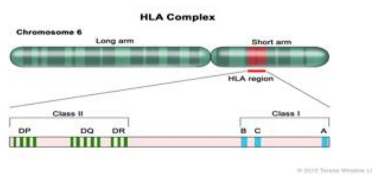
4

Background

Positive association between increasing beryllium exposure and CBD



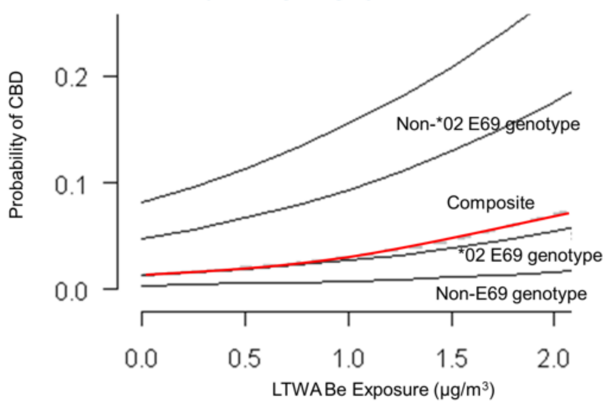
Association glutamic acid at position 69(E69) in the HLA-DPB1 gene and CBD or BeS



5

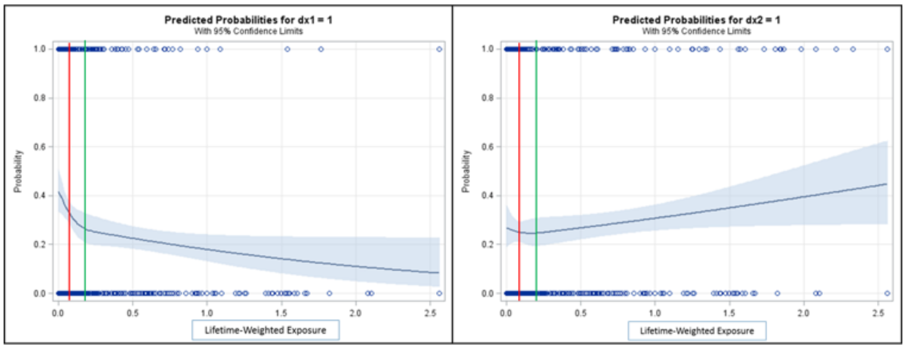
Differential risk by Glu69 status and exposure level

Increasing exposure increases risk in all workers



6

Risk of BeS and CBD related to Exposure



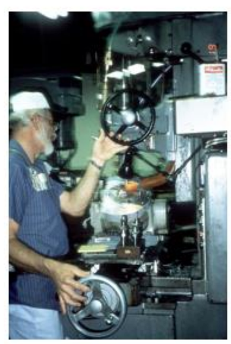
As exposures increase, the risk for developing BeS declines while the risk of developing CBD increases.

National Jewish Health

7

Specific Aims

To define the relationship between beryllium exposure estimates and HLA DPB1 E69 genotypes in a combined cohort of four different beryllium exposed workforces.



National Jewish Health

8

Methods

Retrospective nested case-control study – case definitions

CBD
2 positive beryllium lymphocyte proliferation tests (BeLPT)
+
granulomas on biopsy
or a
positive broncheoalveolar lavage lymphocyte proliferation test
with
lymphocyte >15%.

BeS only
2 positive BeLPTS
+
No evidence of CBD on bronchoscopy and biopsy

Control
Exposure to beryllium
+
2 or more negative BeLPTs

National Jewish Health

9

Cohorts

Study Cohorts

DOE current/former medical surveillance programs

Years of exposure: 1940 – 2013

Workers evaluated at NJH:
BeS: 335
CBD: 324
Non-sensitized: 1107

	Enrolled (n)	Tenure (mean, SD)
BeS	246	15.9 (11.0)
CBD	298	17.7 (10.5)
Control	442	16.8 (11.2)
P=0.20		

DOE Repository enrolled BeS, CBD, Be-exposed controls

Years of exposure: 1945 – 2009

Workers enrolled:
BeS: 93
CBD: 52
Non-sensitized: 104

	Enrolled (n)	Tenure (mean, SD)
BeS	86	17.9 (11.3)
CBD	27	15.8 (10.4)
Control	100	15.2 (11.8)
P=0.30		

Former Be-Processing Plants Medical surveillance screening studies

Years of Exposure: 1935-2000

Workers participating:

CBD/BeS cases: 161
Non-sensitized: 1299

	Enrolled (n)	Tenure (mean, SD)
BeS	73	5.7 (8.5)
CBD	67	8.4 (9.8)
Control	287	9.7 (10.8)
Controls significantly longer tenure than BeS, p = 0.02		

Beryllium Processing Medical surveillance/genetic research studies

Years of Exposure: 1953-2000

Workers participating:
BeS:64
CBD: 90
Non-sensitized: 727

	Enrolled (n)	Tenure (mean, SD)
BeS	39	---
CBD	57	---
Control	61	---
Tenure not provided due to confidentiality protections.		

Study Population

BeS = 444
CBD = 449
Control = 890

National Jewish Health

10

Genotyping

- HLA-DPB1 genotyping by sequence specific primer-polymerase chain reaction
  1) E69 positive, indicating carriage of at least one E96 allele
  2) E69 homozygous, specifying carriage of two copies of any E69-positive alleles;
  3) E69 negative, non-carriage of any E69-positive alleles.

Exposure

- Beryllium exposure estimates: individual worker detailed job exposures
- Historical industry data, published data and data collected for regulatory purposes → establish job exposure estimates
- Cumulative exposure (x Be proc), **Lifetime Average Exposure** and highest process exposure (x DOE repository) were calculated for cases and controls

Statistics

- Logistic regression models developed allowing for over-dispersion, adjusting for workforce, race, sex, and ethnicity.

11

National Jewish Health

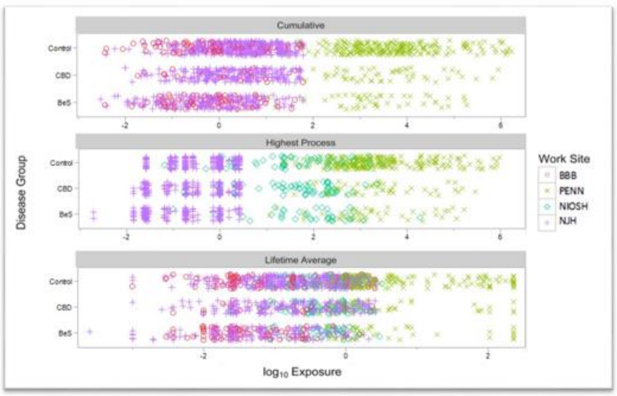
Number of E69 alleles by Diagnosis

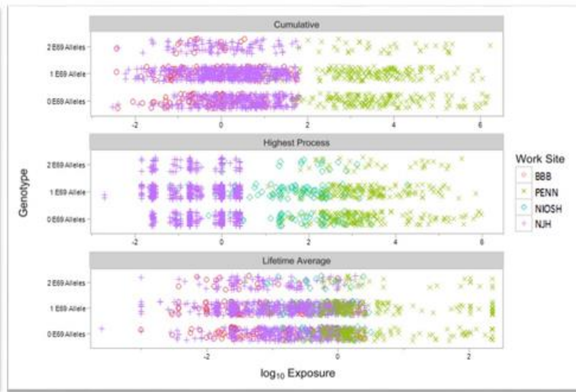
	Diagnosis N (%)				
	Number	Control	BeS	CBD	Chi-square p-value
E69 Alleles	0	549 (77.3)	93 (13.1)	56 (7.9)	5.59 E-87
	1	302 (32.3)	291 (31.1)	305 (32.6)	
	2	39 (19.4)	60 (29.9)	88 (43.7)	

12

National Jewish Health

Exposure by Diagnosis and E69 Genotype





National Jewish Health

13

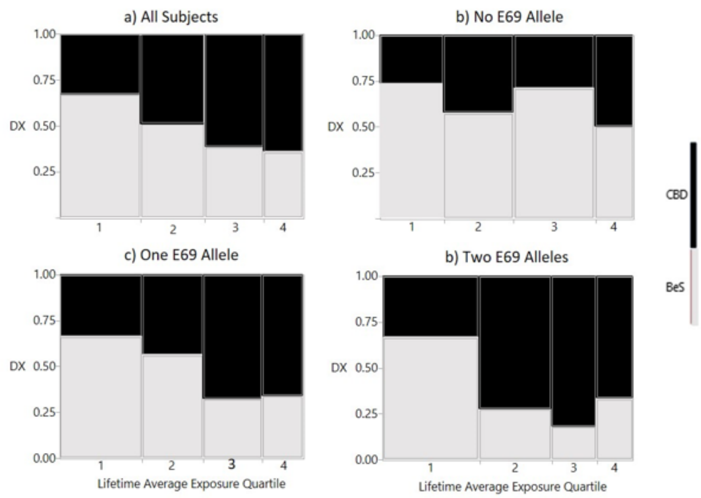
Results

- Having no E69 alleles = lower odds of both CBD and BeS
- Every additional E69 allele increased odds for CBD and BeS
- Increasing lifetime-average exposure = lower odds of BeS vs controls; CBD not significantly associated with increasing exposure
- No evidence of gene-by-exposure interaction for CBD or BeS
- The percent of individuals with CBD vs. BeS increased with increasing quartile of exposure

National Jewish Health

14

Subjects with CBD vs. BeS by Lifetime Average Exposure Quartile



15

National Jewish Health

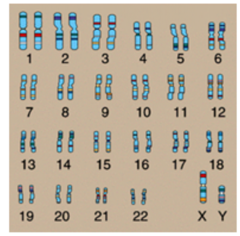
Conclusions

- Risk of CBD increases with E69 allele frequency and increasing exposure.
- No gene by environment interaction was found.
- Lack of exposure-response in CBD cases may be due to the limitations of reconstructed exposure estimates.
- Decreased risk of BeS with increasing exposure ? Censorship or development of CBD
- Reduced exposure may not prevent BeS: **it may reduce the development CBD** and the associated health effects, especially in those most susceptible.

16

National Jewish Health

Genetic Workplace Testing



- In US, legal and policy lagging behind science
- Genetic discrimination
- Shift of responsibility from employer to employee
- Double edged sword: prevent disease and threaten autonomy, loss of employment, etc
- Exposure may be ignored: shift of responsibility from employer to employee
- Other factors affect disease
- Others: privacy, psychological impact

National Jewish Health®

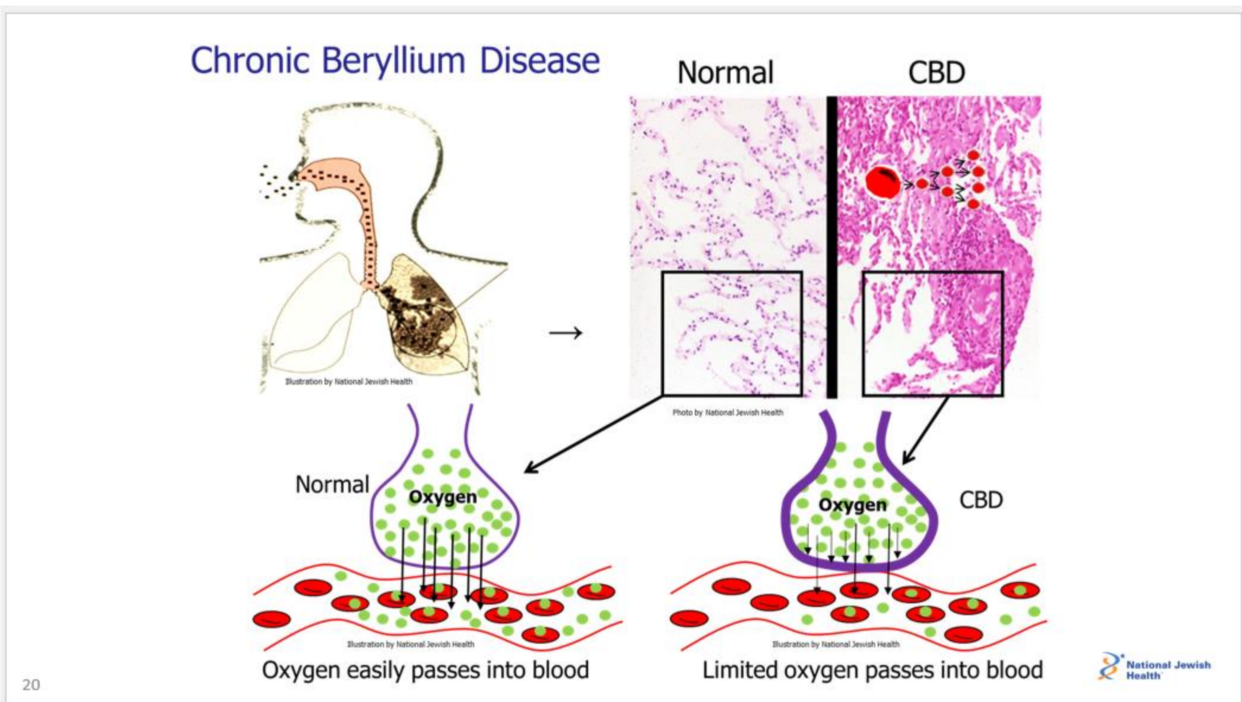
17

Summary

- HLA-DPB1 E69 genotype and beryllium exposure EACH contribute to chronic beryllium disease (CBD) and beryllium sensitization (BeS)
- Increasing exposure = higher risk of CBD
- Having no E69 alleles = lower odds of both CBD and BeS; every additional E69 allele increased odds for CBD and BeS.
- Increasing exposure = lower odds of BeS NOT CBD vs controls in this study; these findings were likely affected by differential exposure misclassification.
- The % with CBD vs BeS increased with increasing exposure, supporting impact of exposure with CBD.
- This study suggests that **although reducing exposure may not prevent BeS, it may reduce the development CBD and the associated health effects, especially in those most susceptible.**

18


National Jewish Health
Breathing Science is Life.
19


Chronic Beryllium Disease
Normal
CBD
Illustration by National Jewish Health
Photo by National Jewish Health
Normal
Oxygen
Oxygen
CBD
Illustration by National Jewish Health
Illustration by National Jewish Health
Oxygen easily passes into blood
Limited oxygen passes into blood
National Jewish Health
20

Occupational Safety in the Environment Containing Beryllium Dust at HELCZA Facility

Lukáš Toupal, Richard Jílek, and Tomáš Kubásek

Centrum Výzkumu Řež (CVR), Hlavní 130, 25068 Husinec-Řež, Czech Republic

The Full-Scale Prototypes (FSPs) currently undergoing High Heat Flux (HHF) tests at HELCZA (High Energy Load Czech Assembly) were manufactured with beryllium tiles, designed as plasma-facing material, on the surface. The HHF testing poses negative impact on the cohesion of the surface and throughout various processes, as they cause the formation of beryllium dust. This is the significant issue for safety of personnel and environment because airborne beryllium could be carcinogenic for humans. The inhalation of high amount of mentioned dust can result in severe lung disease, additionally long-term beryllium exposure may lead to beryllium sensitization or development of subclinical chronic beryllium disease (CBD).

To address the mentioned danger, measures were carried out with an aim to protect the workers against exposure to beryllium. This paper deals with personnel safety and protection against beryllium dust with the focus being on the beryllium spread monitoring at HELCZA facility.

Corresponding Author:
Mr. Lukáš Toupal
lukas.toupal@cvrez.cz
Research Centre Řež (CVR)
Postal address:
Morseova 1267/10
30100 Plzeň
CZECH REPUBLIC

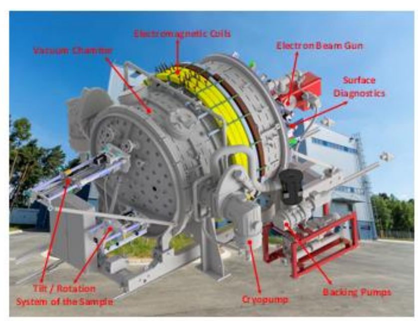
Occupational safety in the environment containing beryllium dust at HELCZA facility

Lukáš Toupal

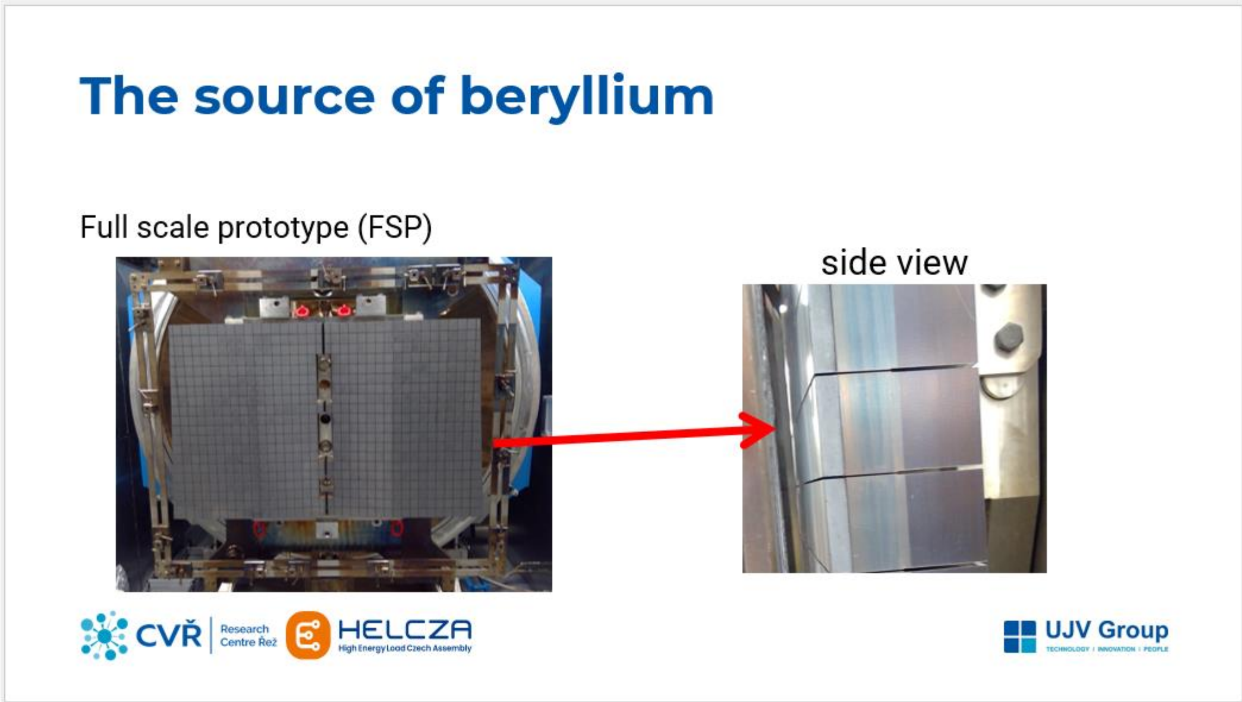
CVŘ Research Centre Řež | HELCZA High Energy Load Czech Assembly | UJV Group TECHNOLOGY | INNOVATION | PEOPLE

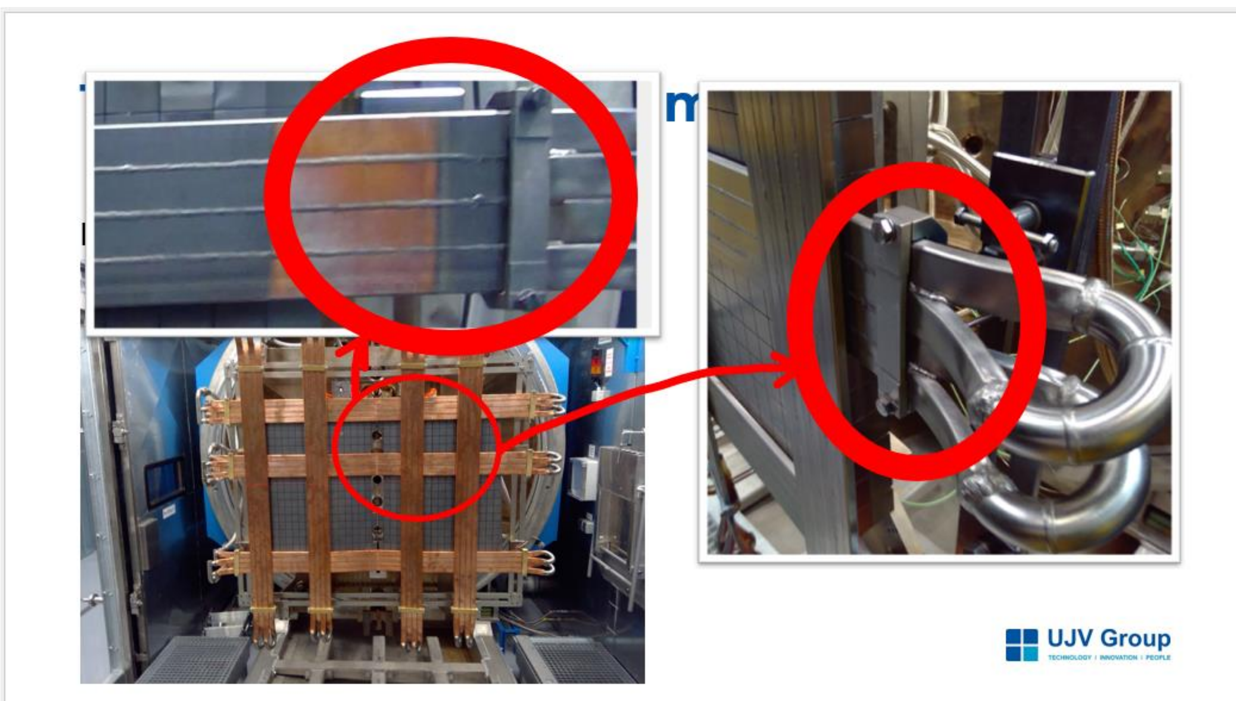
What is this presentation about?

source (FSPs)
cause (toxicity)
protection (personnel protective equipment PPE)
monitoring (smearing)
cleaning / response
analytical laboratory



CVŘ Research Centre Řež | HELCZA High Energy Load Czech Assembly | UJV Group TECHNOLOGY | INNOVATION | PEOPLE


The source of beryllium
Full scale prototype (FSP)
side view
CVŘ Research Centre Řež
HELCZA
High Energy Load Czech Assembly
UJV Group


UJV Group

Toxicity Cause

Acute effects (concentration >100 µg/m³)

- inflammation
- conjunctivitis (eyes)
- dermatitis

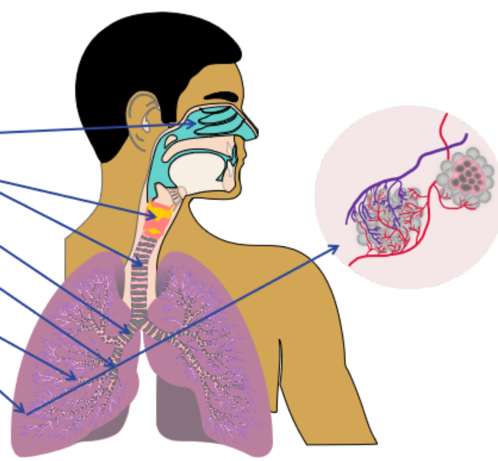
BeS (Beryllium Sensitization)

CBD (Chronic Beryllium Disease)

Lung cancer

Protect lungs from beryllium dust pollution

organ	size [µm] [1]
nasal cavity	(7.0-11.0)
larynx, trachea	(4.5-7.0)
primary bronchus	(3.5-4.7)
secondary bronchi	(2.3-3.3)
terminal bronchi	(1.1-2.3)
alveoli sacs	(0.4-1.1)

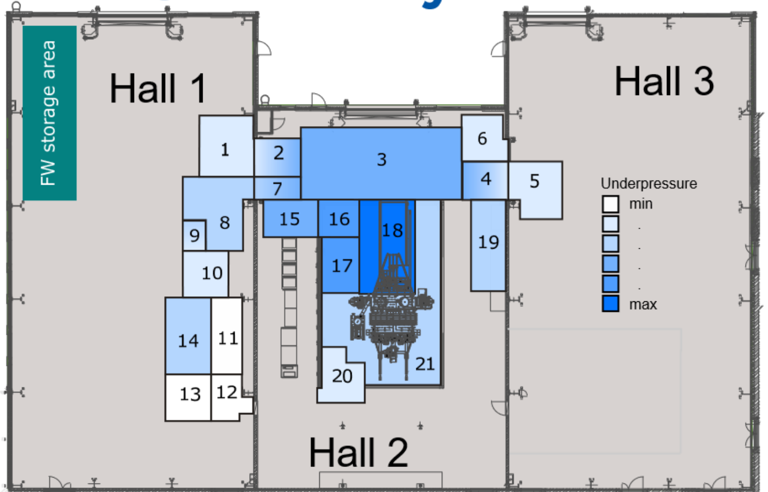


[1] https://www.acrd.bc.ca/particulate-matter (1/8/2022)


Protect lungs from beryllium dust pollution
respirator / half mask (FFP3)
filter ventilation unit
air fed suit
UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

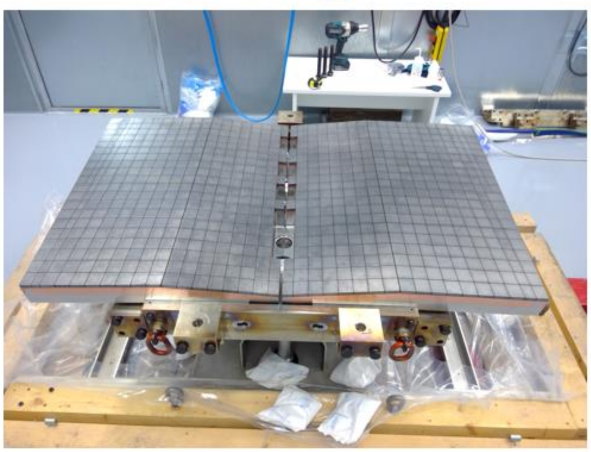

Protect skin and clothes from beryllium
CVŘ
Research Centre Řež
HELCZA
High Energy Load Czech Assembly
UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Layout HELCZA facility



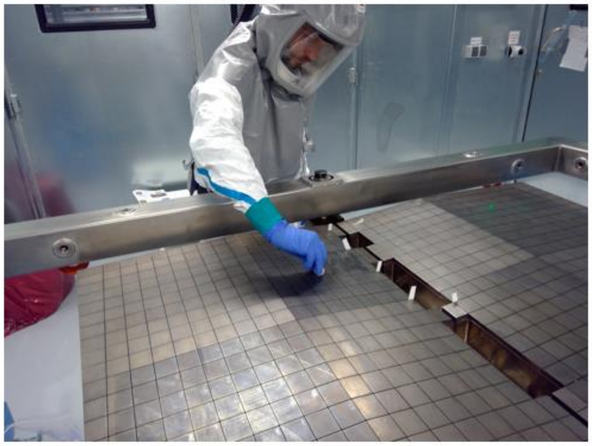
CVŘ Research Centre Řež | HELCZA High Energy Load Czech Assembly | UJV Group TECHNOLOGY | INNOVATION | PEOPLE

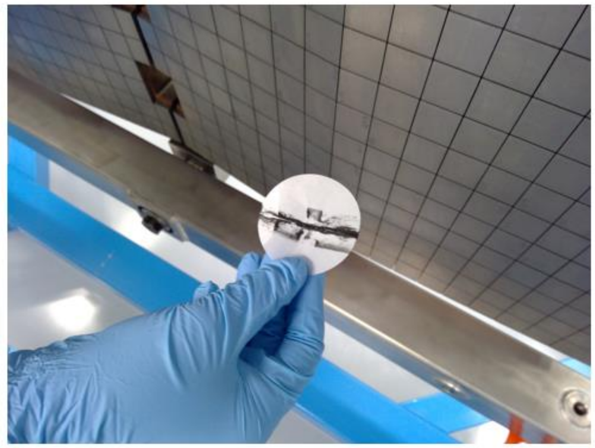
Monitoring - Be smearing



CVŘ Research Centre Řež | HELCZA High Energy Load Czech Assembly | UJV Group TECHNOLOGY | INNOVATION | PEOPLE

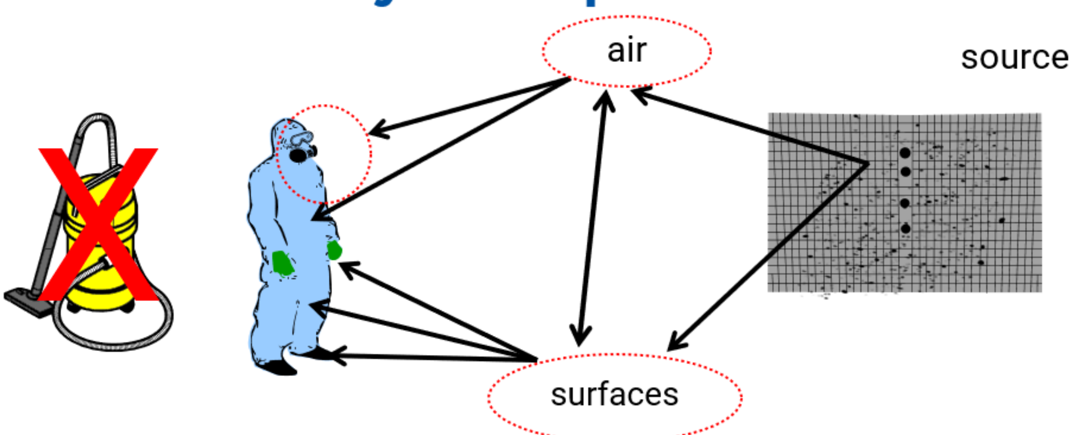
Monitoring - Be smearing





CVŘ Research Centre Řež | HELCZA High Energy Load Czech Assembly | UJV Group

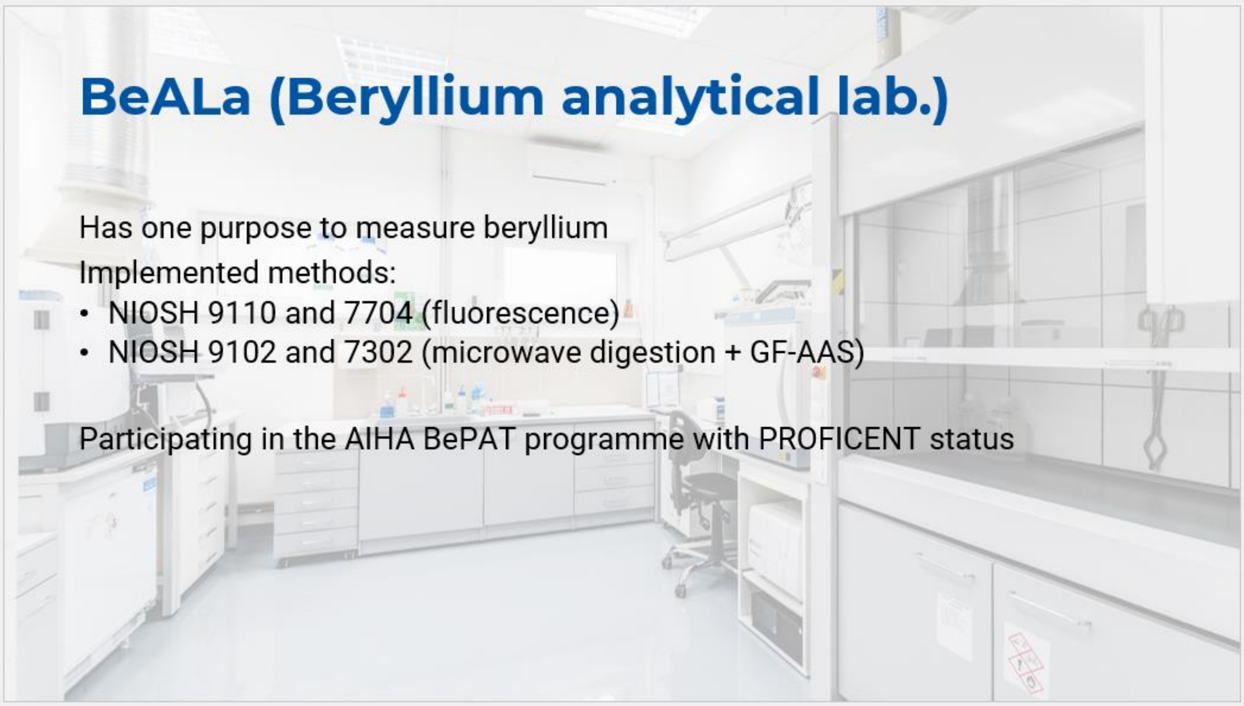
Keep the facility clean and eliminate beryllium spread



CVŘ Research Centre Řež | HELCZA High Energy Load Czech Assembly | UJV Group


Decontamination


BeALa (Beryllium analytical lab.)



Potential cooperation

- handling hazardous materials, which may release carcinogenic dust particles (e.g. beryllium) during handling or testing
- development of methodologies, procedures and their validation for such environment
- training of personnel to work in hazardous environments
- decontamination operations
- determining characteristics of materials and substances under investigation
- determining quantity and size of dust particles
- non-destructive testing of materials under investigation
- safe handling of hazardous substances

CVŘ Research Centre Řež HELCZA High Energy Load Czech Assembly UJV Group TECHNOLOGY | INNOVATION | PEOPLE 15

Space for questions

CVŘ Research Centre Řež HELCZA High Energy Load Czech Assembly

UJV Group TECHNOLOGY | INNOVATION | PEOPLE

Thank you for your attention

contact: lukas.toupal@cvrez.cz

web: https://www.helcza.cz

images: https://www.flickr.com/photos/192795109@N08/albums/72157719002120696

CVŘ Research Centre Řež HELCZA High Energy Load Czech Assembly

UJV Group TECHNOLOGY | INNOVATION | PEOPLE 17

Standardized Methods for Molecular Fluorescence Determination of Trace Beryllium

Kevin Ashley[1], John P. Cronin[2], Anoop Agrawal[2], and Lori Adams[2]

[1]Ashley Analytical Associates LLC, Amado, Arizona, U.S.A.
[2]Berylliant Inc., Tucson, Arizona, U.S.A.

Standardized protocols have been developed based on a molecular fluorescence method for the determination of trace beryllium (Be) in samples obtained in occupational and environmental settings. The methodology, which is field-portable, entails extraction of collected samples in dilute ammonium bifluoride (aqueous), followed by fluorescence measurement of the complex formed between Be and hydroxybenzoquinoline sulfonate (HBQS).

The technique has been optimized to achieve an estimated method detection limit (MDL) of ≤1ng Be/sample, with a dynamic range extending to >10µg Be/sample. Potentially interfering metals (in >400-fold excess concentration compared to that of Be) are negligible or minimal. Besides beryllium salts and other Be compounds, the procedure is effective for the dissolution and quantitative determination of Be extracted from refractory beryllium oxide (BeO) particles.

The method has also been successfully modified for measuring Be content in soils. The performance of the overall procedure compares favorably with methods employing sample digestion in acid mixtures that include hydrofluoric acid, followed by inductively coupled plasma-mass spectrometry (ICPMS). ASTM International voluntary consensus standards and U.S. National Institute for Occupational Safety and Health (NIOSH) methods based on the methodology have been promulgated.

The sampling and analytical protocol has been thoroughly evaluated and validated through intra- and inter-laboratory testing. These methods are recognized by laboratory accrediting organizations in the USA and in Europe. Application to the measurement of trace Be in occupational and environmental samples has been successfully extended to:

- Workplace air samples
- Surface wipe samples (media: cellulosic and polyvinyl alcohol)
- Cellulosic inserts for air & micro-vacuum samples
- High-fired (calcined) BeO
- Cotton gloves
- Nanoparticles (airborne)
- Soil samples

Corresponding Author:

Dr. Kevin Ashley
keadash4@live.com
Ashley Analytical Associates LLC
1921 West Eagle Way
Amado, Arizona 85645
U.S.A.

STANDARDIZED METHODS FOR MOLECULAR FLUORESCENCE DETERMINATION OF TRACE BERYLLIUM

Kevin Ashley, PhD
Ashley Analytical Associates LLC, Amado, AZ (USA)

John P Cronin, PhD
Anoop Agrawal, ScD
Lori Adams
Berylliant, Inc., Tucson, AZ (USA)

Beryllium Workshop, Karlsruhe, Germany, September 2022

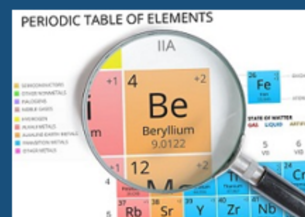
PRESENTATION OVERVIEW

- Brief background on Be sampling & trace analysis methods
- Re-cap method development, evaluation and validation of Be measurement: fitness for purpose
- Interlaboratory studies: supporting data
- Consensus standard protocols & government methods for trace Be in occupational environments
- Focus: Ultra-trace Be measurement in various media (occupational / environmental) by molecular fluorescence

APPLICATIONS / USES OF BERYLLIUM

Occupational environments where beryllium is used or may be present:

- Aerospace
- Nuclear power & weapons
- Automotive industry
- Sports equipment
- Communications (cell phones)
- Foundries (e.g., Cu-Be alloys)
- Recycling of electronic components (e.g., computers)
- Aluminum (Be in bauxite)
- Coal (Be in ore; sandblasting)
  (etc.)



BERYLLIUM – HEALTH RISKS

- Exposure pathways:
  - Inhalation (aerosols)
  - Dermal (surface contamination)
- Be health effects:
  - Immunological response (sensitization)
  - Chronic beryllium disease (CBD)
- ACGIH:
  - 0.05 $\mu g/m^3$: 8-hr TWA [I]
- US DOE – surface Be:
  - 0.2 $\mu g/100\ cm^2$

Be-in-Air Regulatory Limit Values

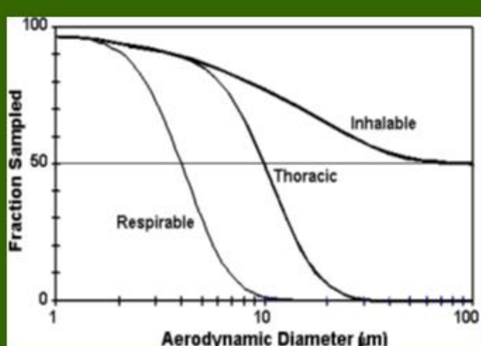
(GESTIS database 2020; IFA, Germany)

Country	8-hr TWA, µg/m³	STEL, µg/m³
United States (OSHA)	0.2	2
Germany	0.14 (I); 0.06 (R)	0.14 (I); 0.06 (R)
Australia, France, New Zealand, Singapore, Sweden, Switzerland, United Kingdom	2	–
Canada (Quebec)	0.15	–
Ireland, Poland, Spain	0.2	–
Czech Republic, Japan, Latvia, Norway	1	–
Finland	0.1	0.4
China	0.5	0.1
Austria	2	0.8
Denmark	1	2
Hungary	2	2
Belgium, Canada (Ontario), **Rep. of Korea**	2	10

SAMPLING ASPECTS: BERYLLIUM

Air Samples

Newer occupational exposure limits (OELs) often specify collecting inhalable fraction of aerosol



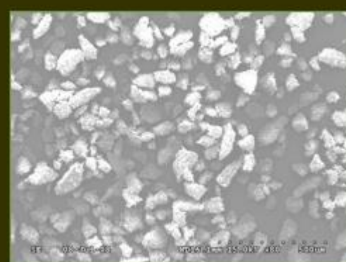
Surface Sampling

Wipe sampling media and techniques are now well standardized.

Also vacuum and bulk sampling protocols

ANALYTICAL CONSIDERATIONS

- **Dissolution:** Dissolve Be from refractory media, e.g., calcined BeO
- **Determination:** Quantitatively measure Be at sub-nanogram levels



"High-fired" (refractory) BeO particles

TRACE MEASUREMENT METHODS FOR BERYLLIUM IN AIR SAMPLES: ESTIMATED METHOD DETECTION LIMITS (MDLs)

Technique	Estimated MDL (ng/sample)
GFAAS (ETAAS)	5 (NIOSH Method 7102)
ICP-AES (ICP-OES)	9 (NIOSH Method 7300)
ICP-MS	<4.2 (Rousset et al., *J. Occup. Environ. Hyg.* 2016)
Molecular fluorescence	≈0.1 (Adams et al., *Int. J. Environ. Anal. Chem.* 2017)

→ Very low MDLs needed for lower limit values & short-term monitoring

INTERNATIONAL CONSENSUS STANDARDS: BERYLLIUM SAMPLING & ANALYSIS

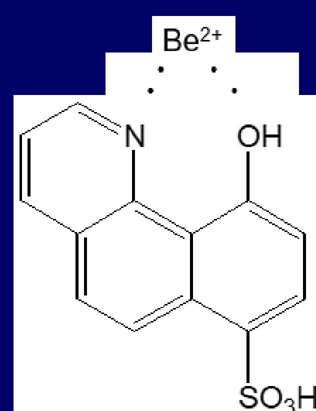
ASTM D7035: ICP-AES (workplace air samples)
ASTM D7202: Molecular fluorescence (air & surfaces)
ASTM D7439: ICP-MS (workplace air samples)
ASTM D7458: Molecular fluorescence (soils / sediments)

ISO 15202: ICP-AES (workplace air samples)
ISO 30011: ICP-MS (workplace air samples)

→Standards describe sample collection, preparation & analysis

BERYLLIUM FLUORESCENCE: HIGH QUANTUM-YIELD FLUOROPHORE FOR TRACE DETECTION

- Beryllium binds phenolate groups strongly
- Six-member chelate ring provides ideal Be-O / Be-N stereochemistry



Hydroxybenzoquinoline sulfonic acid (HBQS)

H. Matsumiya et al., *Analyst* (2002)

Beryllium fluorescence with HBQS (3× dilution; pH ≈13; λ_f = 480 nm)

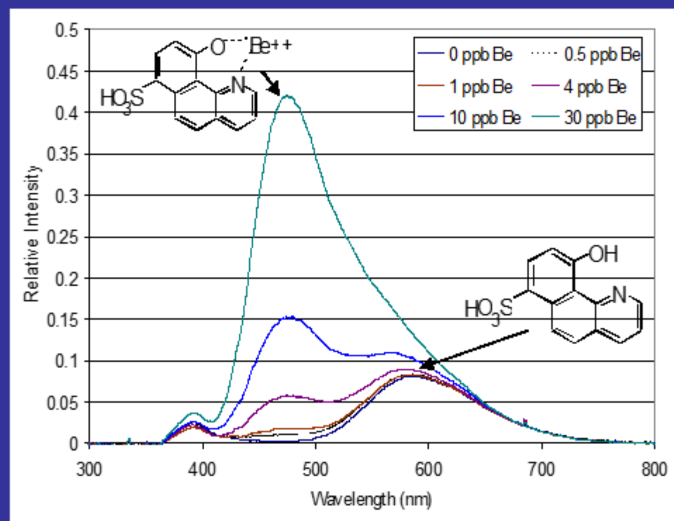
For λ_i = 384 nm:

MDL ≈0.06 ppb/0.1 ng

LOQ ≈0.2 ppb/0.3 ng

Linear response, wide dynamic range (5x)

Lack of interference from most metals in high excess (except Fe, Ti)



E. Minogue et al., *J. ASTM Int.* (2005)

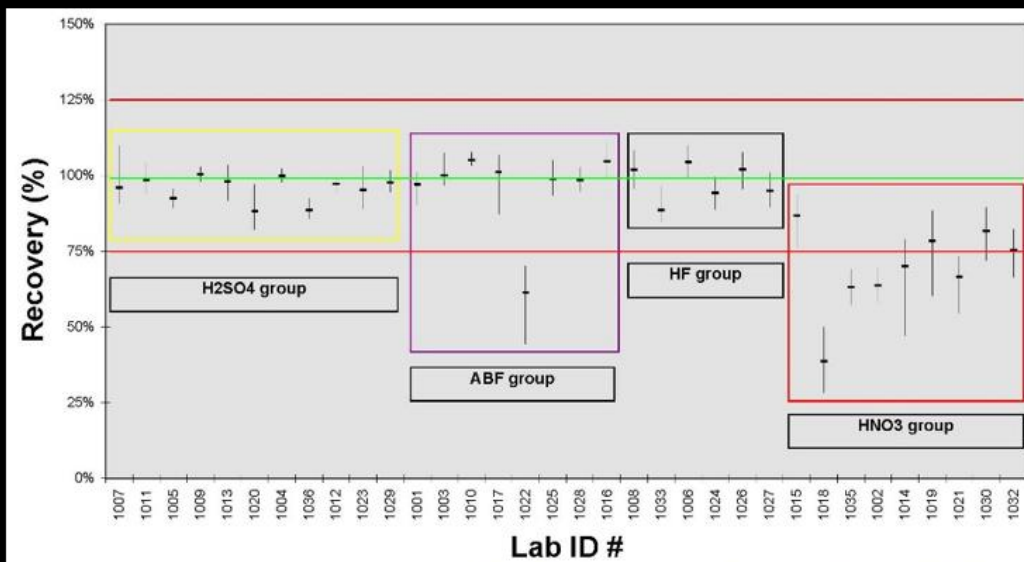
Alternative dissolution to HF, H_2SO_4: Dilute ammonium bifluoride (NH_4HF_2)

$$SiO_2 + 4NH_4HF_2 \rightarrow (NH_4)_2SiF_6 + 2NH_4HF + 2H_2O$$

- Dissolution of silicate materials; apply to refractories such as ceramic BeO:

$$BeO + 2NH_4HF_2 \rightarrow (NH_4)_2BeF_4 + H_2O$$

MULTI-LAB BERYLLIUM OXIDE DISSOLUTION STUDY



T. J. Oatts et al., *J. Environ. Monit.* (2012)

NH_4HF_2 (1%) DISSOLUTION: BERYLLIUM METAL & BERYLLIUM OXIDE ON SAMPLING MEDIA

Sample / media	Extraction temp (°C)	Mean % recovery	RSD (%)
Be/MCE filter (n=3)	23°	93	7.3
Be/cellulosic wipe (n=3)	23°	95	4.2
BeO/MCE filter (n=15)	23°	86	5.9
BeO/MCE filter (n=6)	85°	99	7.7
BeO/cellulosic wipe (n=15)	23°	82	5.6
BeO/cellulosic wipe (n=6)	85°	96	6.2
BeO/PVA wipe (n=5)	90°	99	2.5

K. Ashley et al., *Anal. Chim. Acta* (2007)

Trace BeO measurement: $(NH_4)HF_2$ extraction – HBQS fluorescence method (cellulosic filters & wipes)

Spike level, µg Be (as BeO; 4 labs)	Mean, µg Be (MCE; Wipe)	RSD (%) (MCE; Wipe)
Blank media	0.0001; 0.0004	---
0.002 (<< PEL)	0.0023; 0.0025	13; 19
0.005 (< 15-min STEL)	0.0052; 0.0056	2.3; 6.3
0.020 (≈ STEL)	0.0210; 0.0209	2.6; 2.3
0.050 (< 8-hr TWA)	0.0504; 0.0507	2.8; 2.6

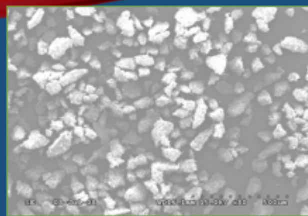
K. Ashley et al., *Anal. Chim. Acta* (2007)

Interlab trace BeO measurement in alcohol (PVA) wipes (8 labs): 1% aq. $(NH_4)HF_2$ extraction – HBQS fluorescence method (ASTM D7202)

Certified Be level, µg (as BeO) ± SD	Interlab Mean (µg Be) ± SD: Dry; Wetted*	Mean Recovery ± RSD (%): Dry; Wetted
<**0.01** (media blank)	0.0025; 0.0085*	– (blank) –
0.030 ± 0.005	**0.0291** ± 0.0046; **0.0270*** ± 0.0039	**97.0** ± 15.8; **90.0** ± 14.4
0.16 ± 0.02	**0.144** ± 0.016; **0.139*** ± 0.012	**90.0** ± 11.4; **86.9** ± 8.4
0.32 ± 0.02	**0.295** ± 0.017; **0.287*** ± 0.013	**92.2** ± 5.7; **89.1** ± 4.6
1.8 ± 0.1	**1.71** ± 0.08; **1.64*** ± 0.13	**95.0** ± 4.6; **91.1** ± 8.1
2.8 ± 0.1	**2.76** ± 0.28; **2.61*** ± 0.37	**98.6** ± 10.3; **93.3** ± 14.1
5.6 ± 0.1	**5.29** ± 0.54; **4.91*** ± 0.24	**94.5** ± 10.2; **87.7** ± 4.8

*(Corrected for H_2O content)

K. Ashley et al., *Anal. Methods* (2011)



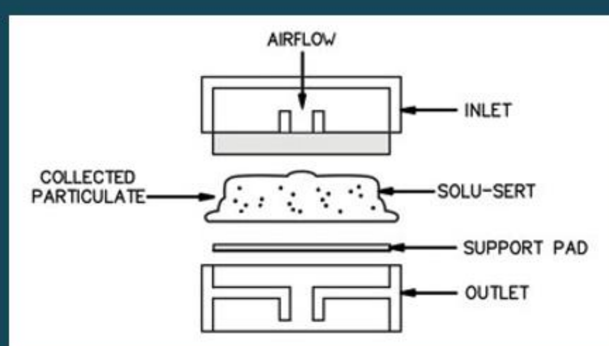
Dissolution of larger BeO particles:
3% $(NH_4)HF_2$ extraction (90˚C, 4-5 h)
HBQS fluorescence Be measurement

BeO particle size fraction (µm)	No sampling media (% Rec. ±SD)	MCE air filters (% Rec. ±SD)	Cellulosic wipes (% Rec. ±SD)	Cotton gloves (% Rec. ±SD)
<32	95 ± 5	92 ± 6	91 ± 5	111 ± 17
90-106	102 ± 12	100 ± 7	97 ± 4	98 ± 12
180-212	97 ± 5	92 ± 1	97 ± 4	90 ± 5

M. J. Goldcamp et al., *J. Occup. Environ. Hyg.* (2009)

CELLULOSIC CAPSULE INSERTS* – "SOLU-SERTS™"

*Mixed cellulose ester (MCE) filter with cellulose acetate dome *[CFC sampler]*



(Courtesy of Antylia / Zefon International)

Analysis of beryllium spiked cellulosic filter cassettes using 3x dilution

(ASTM D7202 protocol)

µg Be; ppb Be (n=3)	µg Be measured (RSD)	ppb Be measured (±Std Dev)	Avg % Recovery
0.0000; 0.000	-0.0001 (25)	-0.004 (±0.0025)	---
0.0005; 0.033	0.0005 (7.2)	0.033 (±0.0024)	100
0.001; 0.067	0.0009 (2.8)	0.061 (±0.0017)	91.0
0.002; 0.133	0.0020 (5.4)	0.133 (±0.0071)	100
0.005; 0.333	0.0045 (1.4)	0.301 (±0.0042)	90.3
0.050; 3.334	0.0456 (2.2)	3.043 (±0.0675)	91.3
0.480; 32.00	0.448 (0.87)	29.87 (±0.26)	93.3

L. Adams et al., *Int. J. Environ. Anal. Chem.* (2017)

Addressing interference of Fe (10,000x excess) using filtration through hydrophilic polypropylene filters

% NH_4HF_2 (aqueous, w/w):	**1%**		**3%**	
Dilution factor (HBQS dye):	20×	5×	20×	5×
Relative fluorescence intensity, no Fe	100.0	100.0	100.0	100.0
Relative fluorescence intensity (Fe present), filtered immediately	99.9	100.1	97.1	100.9
Relative fluorescence intensity (Fe present), filtered after 2 hr	99.9	102.2	100.7	99.8

L. Adams et al., *Int. J. Environ. Anal. Chem.* (2017)

DISPOSABLE INHALABLE SAMPLER (DIS)

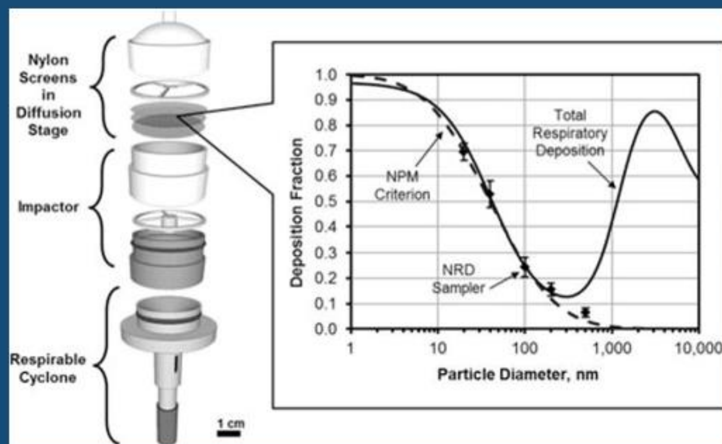
- Based on IOM design, but incorporates many improvements
- ENTIRE UNIT disposable
- Pre-weighed PVC filter + PVC capsule for gravimetric analysis,

  OR
- Digestible MCE filter + cellulose capsule for metals analysis
- Also, modification available for within-cassette dissolution
- And foams for multi-fraction (Respirable & Inhalable) sampling

[Courtesy of Antylia / Zefon Int'l]

DISPOSABLE INHALABLE SAMPLER [DIS]
(U. UTAH / ZEFON STUDY: D. SLEETH / M. HARPER)

ASTM D8208: STANDARD PRACTICE FOR COLLECTION OF NON-FIBROUS NANOPARTICLES USING A NANOPARTICLE RESPIRATORY DEPOSITION (NRD) SAMPLER

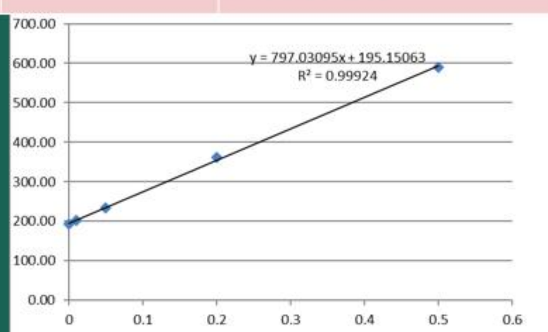


L. G. Cena et al., *J. Occup. Environ. Hyg.* (2014)

TRACE BERYLLIUM BY $(NH_4)HF_2$ EXTRACTION & HBQS FLUORESCENCE MEASUREMENT: NANOPARTICLE SAMPLER (NYLON FILTERS)

Be mass, µg	[Be], ppb	Mean recovery (± Std dev; n=3)
0.001	0.01	97.3 (± 0.4)
0.002	0.02	99.4 (± 0.3)
0.005	0.05	99.3 (± 0.3)
0.02	0.2	99.8 (± 0.2)
0.05	0.5	100.2 (± 0.1)

Raw fluorescence signal vs. [Be], ppb



FLUORESCENCE MEASUREMENT OF BERYLLIUM IN GEOLOGIC MEDIA*

Reference material / source country	Reference [Be], µg/g	Measured [Be], µg/g
Basalt (Japan)	0.27 (± 0.04)	0.31 (± 0.02)
Sediment (USA)	1.6 (± 0.3)	2.37 (± 0.05)
Andesite (Japan)	2.05 (± 0.44)	2.11 (± 0.02)
Soil (Canada)	2.4	2.53 (± 0.03)
Soil (USA)	2.5 (± 0.07)	3.35 (± 0.10)
Sediment (USA)	3	3.50 (± 0.06)
Rhyolite (Japan)	7.6 (± 0.83)	7.1 (± 0.18)
Coal fly ash (USA)	12.1	12.85 (± 0.36)
Syenite (Canada)	22	21.35 (± 0.60)

*0.5 g samples; 50 mL 3% $(NH_4)HF_2$ extraction solution (90 °C, 40 h)

A. Agrawal et al., *Environ. Sci. Technol.* (2008)

FLUORESCENCE MEASUREMENT OF BERYLLIUM IN SOIL – INTERLAB STUDY (N=6) (ASTM D7458)

[Be] ref. value, µg/g	Mean reported [Be] (±SD), µg/g	Interlaboratory RSD (%)	Estimated bias
2.4 (unspiked)	2.43 (± 0.22)	8.9	+0.01
4.36*	5.13 (± 0.53)	10	+0.18
11.5*	12.4 (± 0.6)	4.8	+0.08
124*	126 (± 9)	7.1	+0.02
246*	234 (± 16)	6.9	-0.05

*Canadian CRM soil spiked with high-fired BeO
(Values in red → anthropogenic contamination)

J. P. Cronin et al., *J. Environ. Monit.* (2008)

U.S. NIOSH methods for determining ultra-trace beryllium in air & wipes

NIOSH Manual of Analytical Methods *5th ed.*:

www.cdc.gov/niosh/nmam

- Method No. 7704, Be in Workplace Air by Fluorescence
- Method No. 9110, Be in Surface Wipes by Fluorescence
  - ► Both entail NH_4HF_2 extraction / HBQS fluorescence detection

NMAM

International consensus standards – Be ultra-trace fluorescence analysis

ASTM International (**www.astm.org**)

ASTM D7202: Beryllium in workplace samples by NH_4HF_2 extraction and fluorescence detection

→ **Covers both air & surface wipe samples**

Also:

ASTM D7458: Beryllium in soil samples by NH_4HF_2 extraction & fluorescence detection

Summary: Trace Be fluorescence analysis with HBQS after NH_4HF_2 extraction – Sample types validated

Occupational air samples

→ Cellulosic inserts & DIS for air sampling

Surface wipe samples

Microvacuum samples

Cotton gloves

Soil samples

High-fired (calcined) BeO

Nanoparticles

COMMERCIAL USE OF BE-HBQS FLUORESCENCE METHOD

US DOE Laboratories: CA, IA, ID, NM, NV, SC, TN, WA

US Army Corp of Engineers, NY/OH

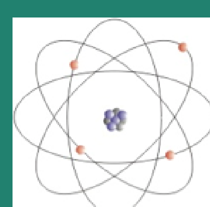
Materion, USA

INRS, France

JET, United Kingdom

Max Planck Institute, Germany

EPS, Spain



- Recognized by AIHA-LAP as accredited method; AIHA-PAT: beryllium proficiency testing program

ACKNOWLEDGMENTS

ASTM International

ASTM Committee D22 on Air Quality

ASTM Interlaboratory Studies program

High-Purity Standards – Charleston, SC (USA)

Materion – Tucson, AZ (USA) (formerly Brush Wellman Ceramics)

Dr Martin Harper – *University of Florida* (formerly with Antylia / Zefon)

Prof Darrah Sleeth – *University of Utah*

Gary Griffin, Linda Youmans, Mike Brisson, Roland Chretien – *Beryllium Health & Safety Committee (BHSC)*

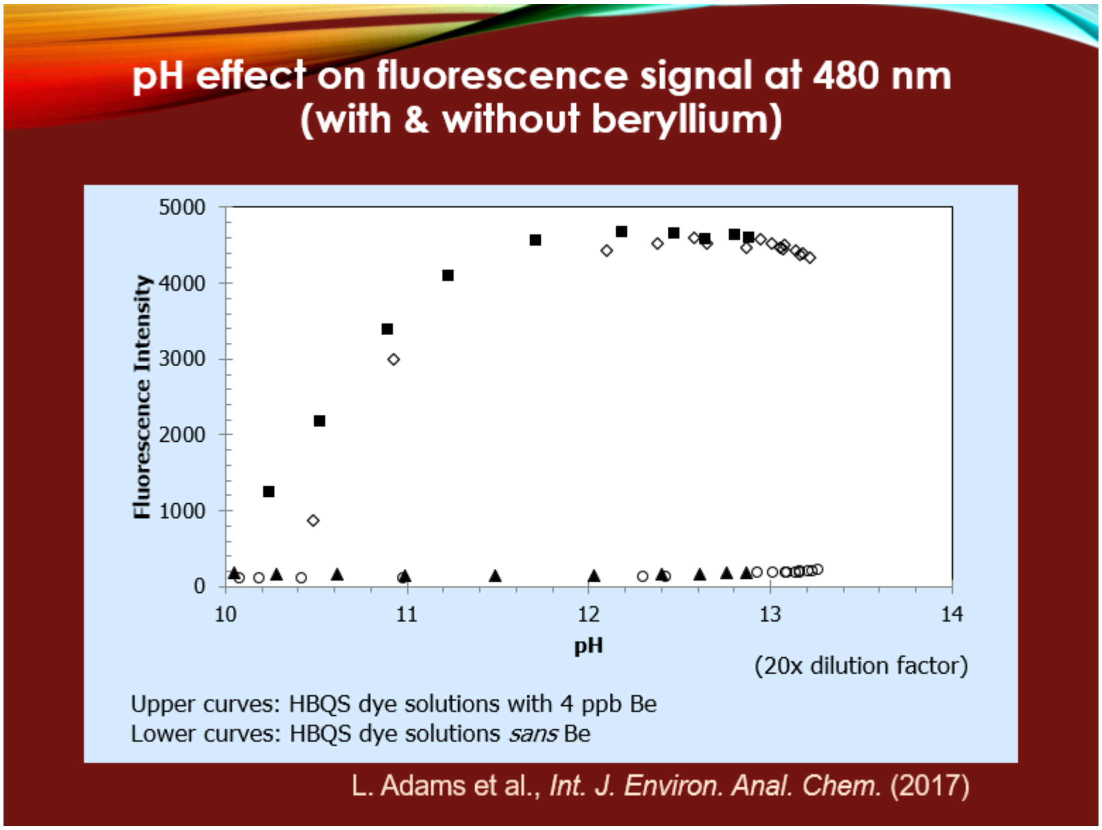
CONTACT INFORMATION

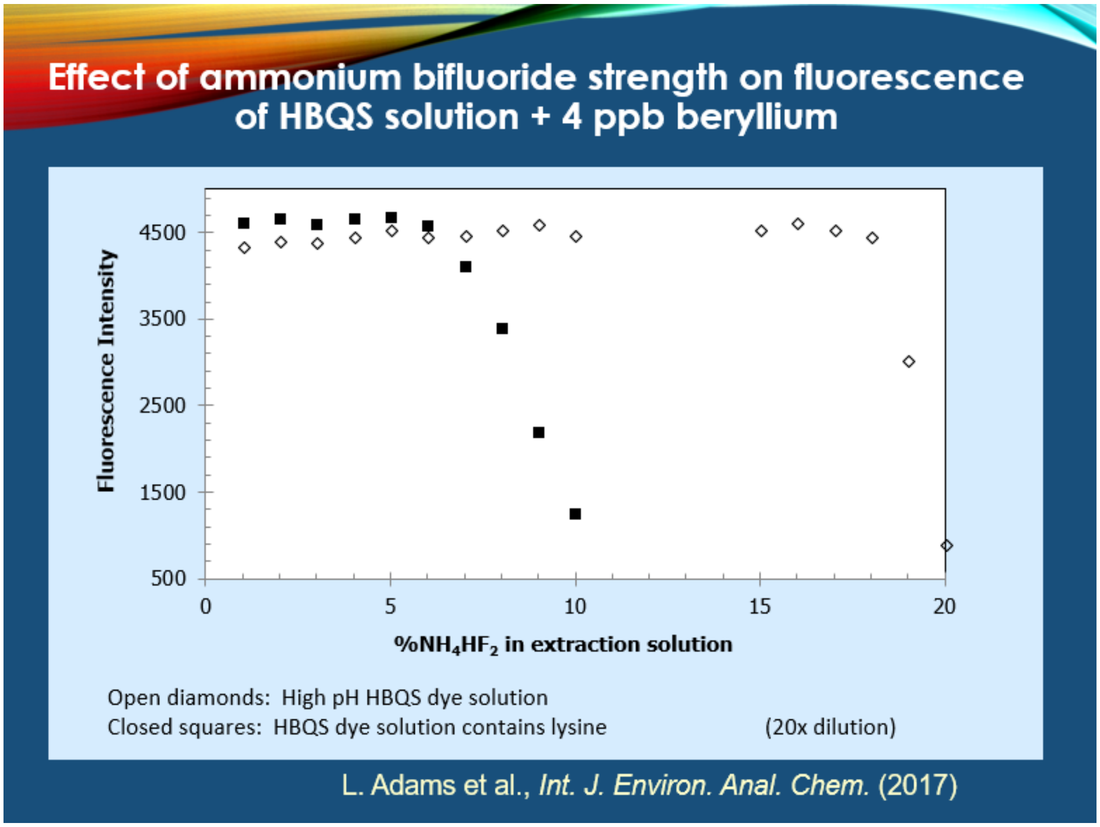
Kevin Ashley, PhD, FASTM
Ashley Analytical Associates, LLC
1921 W Eagle Way
Amado, AZ 85645 (USA)
+1(513)708-0253
keadash4@live.com
se habla español

Drs John Cronin & Anoop Agrawal
Beryllliant, Inc.
6595 N Oracle Road, Suite 153A
Tucson, AZ 85704 (USA)
+1(520)665-9229
info@berylliant.com

4
Berylliant
Beryllium
9.01218

32


pH effect on fluorescence signal at 480 nm
(with & without beryllium)
Fluorescence Intensity
5000
4000
3000
2000
1000
0
10
11
12
13
14
pH
(20x dilution factor)
Upper curves: HBQS dye solutions with 4 ppb Be
Lower curves: HBQS dye solutions *sans* Be
L. Adams et al., *Int. J. Environ. Anal. Chem.* (2017)


Effect of ammonium bifluoride strength on fluorescence of HBQS solution + 4 ppb beryllium
Fluorescence Intensity
4500
3500
2500
1500
500
0
5
10
15
20
$\%NH_4HF_2$ in extraction solution
Open diamonds: High pH HBQS dye solution
Closed squares: HBQS dye solution contains lysine
(20x dilution)
L. Adams et al., *Int. J. Environ. Anal. Chem.* (2017)

Session 3: Beryllium in Molten Salts and More Health & Safety

New Beryllium-Contamination Testing Method

A. Goraieb (KBHF, Germany) et al.

New Beryllium-Contamination Testing Method

Aniceto Goraieb[1], Benjamin Fretz[1], Engin Cilinger[1], Ramil Gaisin[2], and Pavel Vladimirov[2]

[1]*Karlsruhe Beryllium Handling Facility (KBHF), Eggenstein-Leopoldshafen, Germany*
[2]*Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany*

Beryllium is one of the poisonous metals, the concentration of which in air and dust is strictly limited. When working with beryllium, a planned air intake through the filter and wiping tests are usually carried out. The disadvantages of these methods are the insufficient frequency of control and the danger to personnel in case of contamination. In addition, these methods cannot determine exactly where the beryllium contamination has occurred in order to close and clean the particular facility.

This work proposes an automated method for the continuous monitoring of the beryllium content without danger to personnel. The method consists in the analysis of air and surface along a given route by a specially designed robot in facilities where work with beryllium is carried out.

After each analysis of the surface around the potentially beryllium-contaminated area, the robot returns to the base to transmit the analyzed test. After collecting the material, the beryllium content is determined for each test. In case of detection of contamination, personnel are not allowed to work, and the facility is cleaned automatically. The possibilities of implementing such an analysis using various methods for the detection of beryllium are discussed.

Corresponding Author:
Mr. Benjamin Fretz
fretz@versuchstechnik.de
Karlsruhe Beryllium Handling Facility (KBHF GmbH)
Hermann-von-Helmholtz-Platz 1
D-76344 Eggenstein-Leopoldshafen
GERMANY

Karlsruhe Institute of Technology

BeYOND-IX 2022
9th Industrial Forum on Beryllium Opportunities & New Developments, Karlsruhe

KBHF

New Be-contamination testing method

Aniceto Goraieb, Benjamin Fretz, Engin Cilinger
Karlsruhe Beryllium Handling Facility
Ramil Gaisin, Pavel Vladimirov
Institute for Applied Materials - Applied Materials Physics, Karlsruhe Institute of Technology

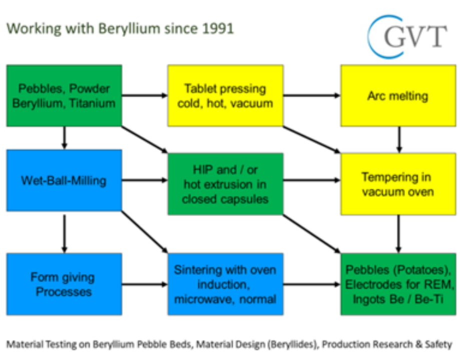
KIT – The Research University in the Helmholtz Association

www.kit.edu

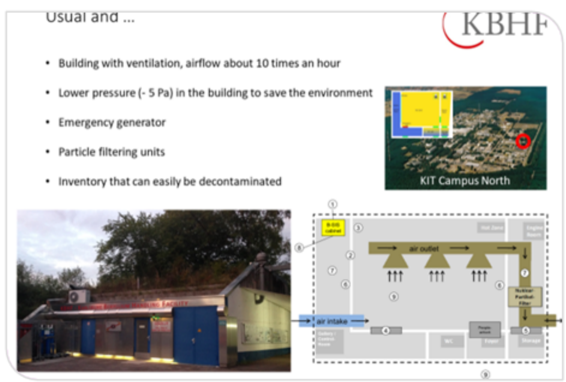
Necessary Beryllium handling safety

Karlsruhe Institute of Technology

Beryllium processing usually starts from powder



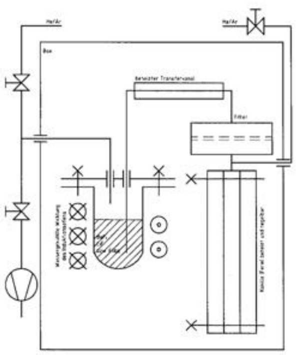
Therefore, contamination is a common risk



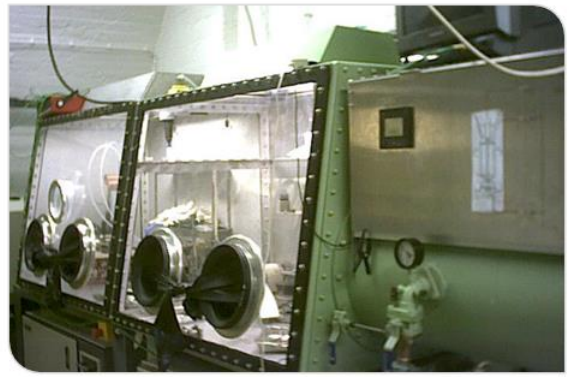
FLiBe: Breeder for Fusion & Fission, candidate for melt-based x-ray lenses & high-term solar systems

KIT Karlsruhe Institute of Technology

Letters of intent from UC Berkeley and SSLS brought us to FLiBe



20 years ago, building up FLiBe experimental sample production



3 16.09.2022 Aniceto Goraieb GVT/KBHF

FLiBe: Some unique properties, advantages & disadvantages for Fusion applications

KIT Karlsruhe Institute of Technology

- ⬇ Molten salts are very hygroscopic and therefore FLiBe forms hydrofluoric acid
- ⬆ In case of an accident, it freezes in contrast to liquid metal breeder like Li-Pb
- ⬇ During remelting it shrinks and can cause damage of the containment
- ➡ It has a very high surface tension and covers a surface even against gravity
- ⬆ This effect *plus no MHD* can be useful for liquid walls in compact Fusion device
- ➡ Graphite or maybe SiC (to be tested) could work as containment (Ni not Fusion)
- ⬆ Nearly no vapor pressure at 900 °C under vacuum conditions (LW & HT-Fission)
- ⬆ For Fission application it can be mixed with other fluorides like UF, ThF, PuF
- ⬆ Fluorides can be used in recycling processes or for enrichment

4 16.09.2022 Aniceto Goraieb GVT/KBHF

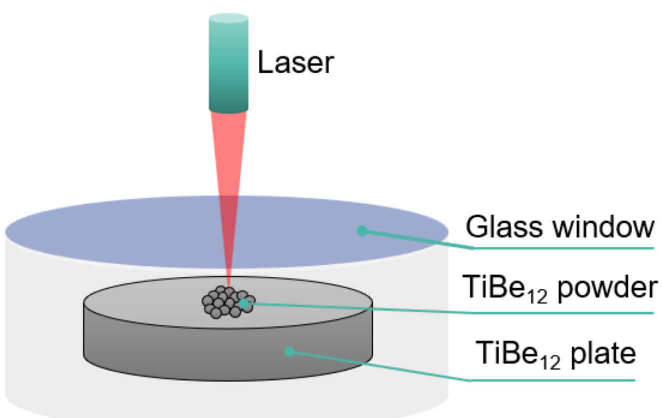
Looking for a simple way for Beryllide (small scale) sample production Be-Ti; Be-Zr; Be-V; Be-Cr; Be-W

Hot extrusion wastes a lot of material because of the canning

HIP would be an option but only for near to endshape samples

5 16.09.2022 Aniceto Goraieb GVT/KBHF

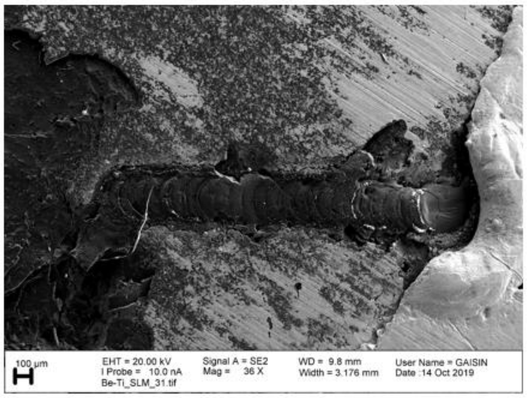
Selective laser melting of $TiBe_{12}$

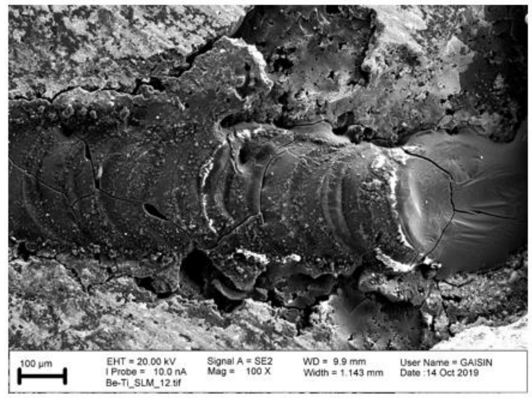


6 16.09.2022 Aniceto Goraieb GVT/KBHF

Selective laser melting of $TiBe_{12}$

Karlsruhe Institute of Technology





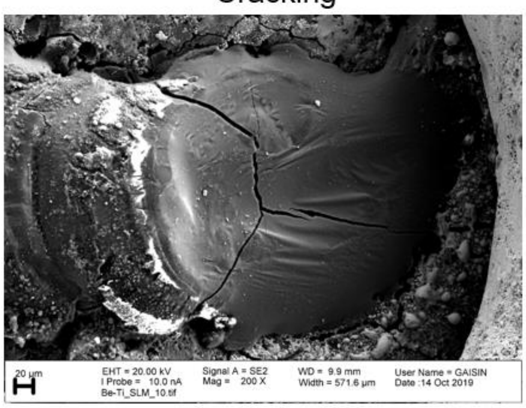
Melting of titanium beryllide powder on the surface of titanium beryllide

7 16.09.2022 Aniceto Goraieb GVT/KBHF

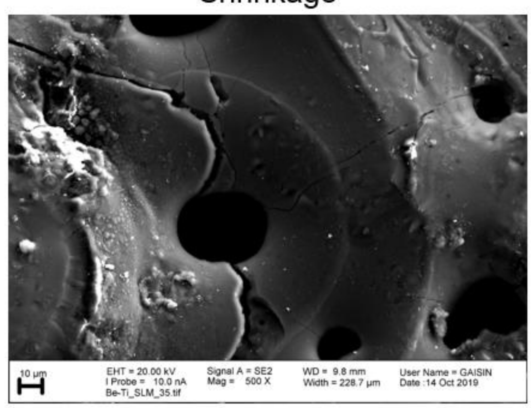
Selective laser melting of $TiBe_{12}$

Karlsruhe Institute of Technology

Cracking

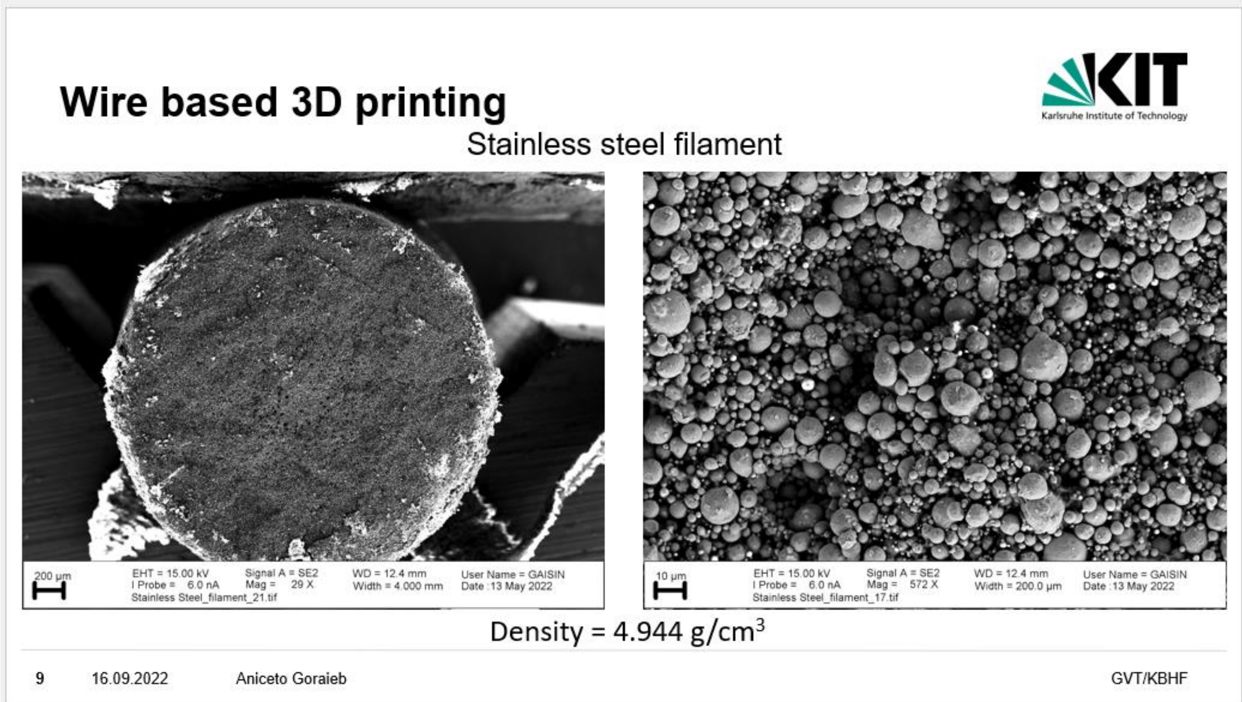


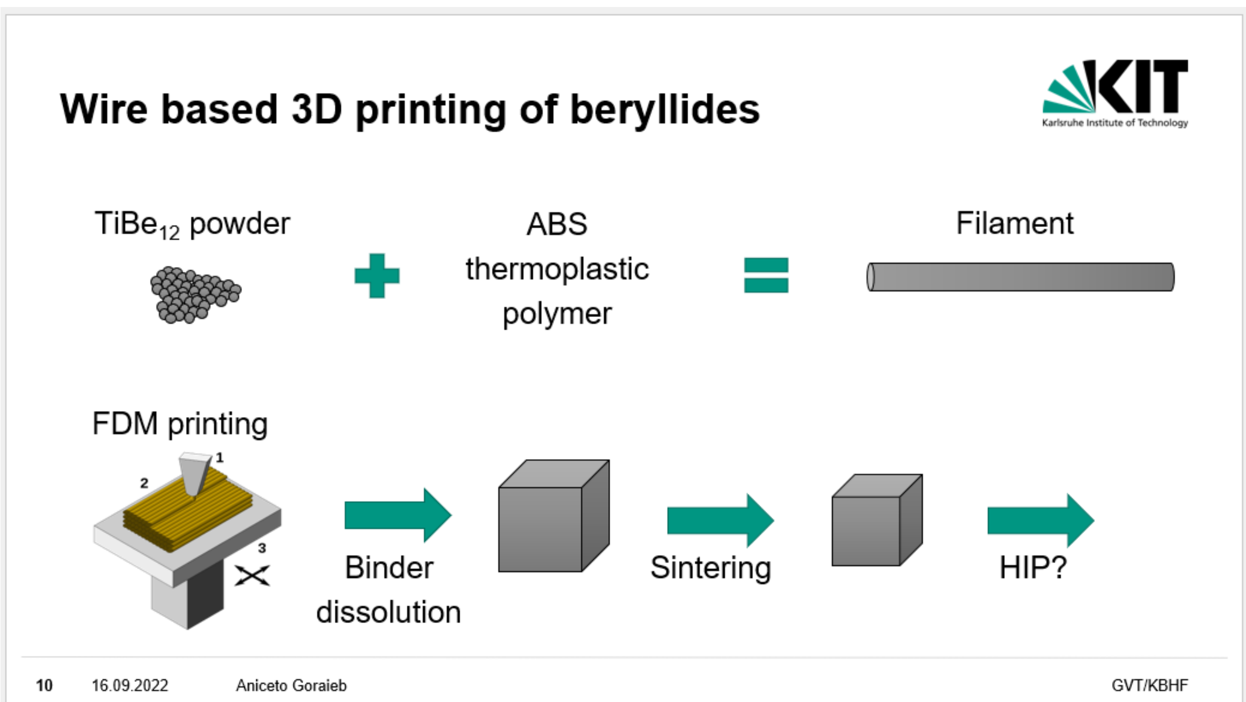
Shrinkage



Melting of titanium beryllide during SLM leads to the formation of casting defects

8 16.09.2022 Aniceto Goraieb GVT/KBHF


Wire based 3D printing
Karlsruhe Institute of Technology
Stainless steel filament
200 µm
EHT = 15.00 kV
I Probe = 6.0 nA
Stainless Steel_filament_21.tif
Signal A = SE2
Mag = 29 X
WD = 12.4 mm
Width = 4.000 mm
User Name = GAISIN
Date :13 May 2022
10 µm
EHT = 15.00 kV
I Probe = 6.0 nA
Stainless Steel_filament_17.tif
Signal A = SE2
Mag = 572 X
WD = 12.4 mm
Width = 200.0 µm
User Name = GAISIN
Date :13 May 2022
Density = 4.944 g/cm3
9
16.09.2022
Aniceto Goraieb
GVT/KBHF


Wire based 3D printing of beryllides
Karlsruhe Institute of Technology
TiBe12 powder
ABS thermoplastic polymer
Filament
FDM printing
1
2
3
Binder dissolution
Sintering
HIP?
10
16.09.2022
Aniceto Goraieb
GVT/KBHF

FDM-Printing could take place even outside of the Beryllium safety area

KIT Karlsruhe Institute of Technology

Powder handling and Filament production under wet conditions

Binder dissolution and sintering takes place in Be-safety area, again

11 16.09.2022 Aniceto Goraieb GVT/KBHF

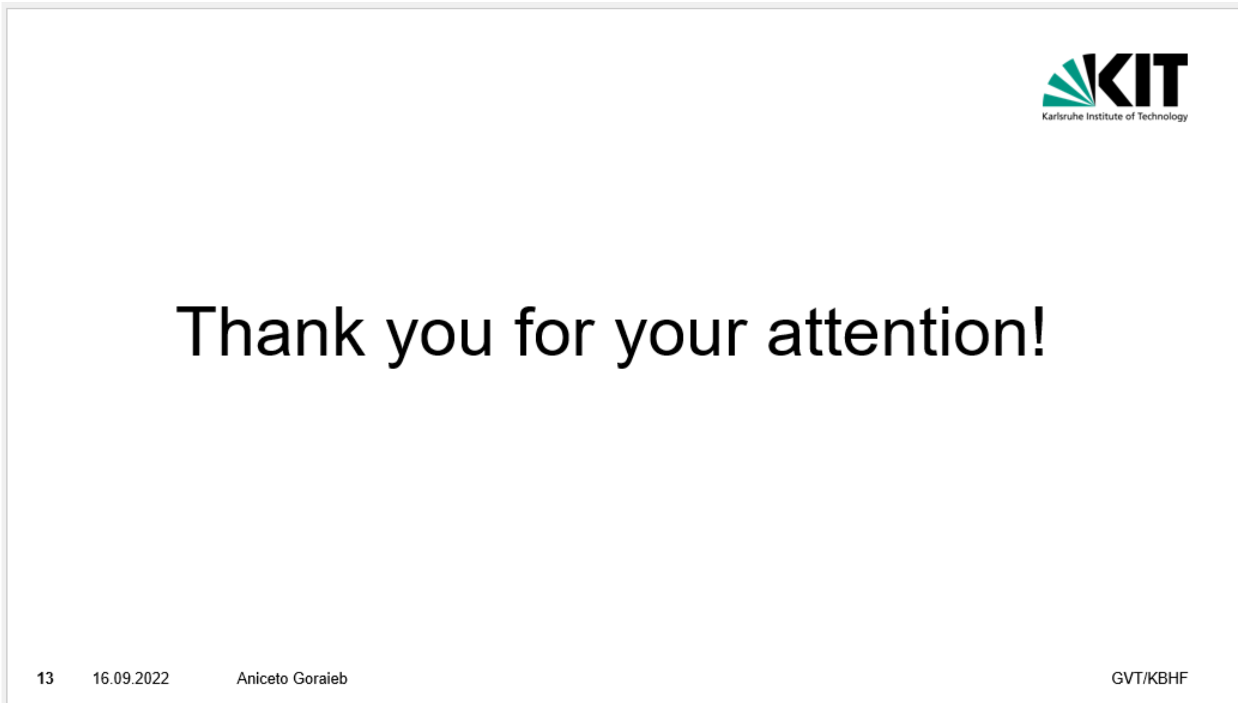
New Be-contamination testing method

KIT Karlsruhe Institute of Technology

- Real-time measurement is not simple; Beryllium is just metal, no radiation
- The next step down would be frequently but fully automated systems
- Robotic wiping tests and air sampling could be an option but are expensive
- How could an existing, available and cheap system help to find a solution?
- Cleaning robots are common these days, even with self-cleaning function
- We have used a simple version of these machines already for a longer time
- Our intention is to combine it with the right Beryllium (Metal) detection method

We can offer the test area and are looking for partnerships, now!

12 16.09.2022 Aniceto Goraieb GVT/KBHF


Karlsruhe Institute of Technology
Thank you for your attention!
13
16.09.2022
Aniceto Goraieb
GVT/KBHF

Commercial Challenges Associated with FLiBe for Fusion Energy

Richard Pearson[1,2], Keisuke Mukai[2,3], Colin Baus[2,3], Andrew Wilson[1], Andrea D'Angio[1], Shutaro Takeda[2], Satoshi Konishi[2,3], and Juro Yagi[3]

[1]*Kyoto Fusioneering UK, Reading, United Kingdom*
[2]*Kyoto Fusioneering, Uji-City, Kyoto, Japan*
[3]*Institute of Advanced Energy, Kyoto University, Kyoto, Japan*

FLiBe is a low-TRL material that is of interest for use as a coolant and breeding material for use in blanket designs for future commercial fusion reactors. FLiBe is potentially highly attractive, due to features including low pressure operation, avoidance of MHD effects (as is experienced in liquid metal coolants in the presence of high magnetic fields), and due to relatively high TBR at low lithium enrichment.

However, FLiBe is expensive to manufacture, in part due to the fact that beryllium is expensive, and the resource has limited availability. In this study, the supply chain and manufacturability of FLiBe are analysed. Other challenges such as tritium extraction, purification, and material compatibility will be addressed, with reference to ongoing research using a new FLiBe loop developed by Kyoto Fusioneering through collaboration with Kyoto University.

Use of FLiBe in private industry for breeding blankets and other areas is discussed in regard to a necessary scaling of the supply chain for commercial applications in the near-term. Finally, the potential of FLiBe for power applications, including for high-efficiency electricity generation via Brayton cycles as well as non-electricity applications (such as energy storage) are considered and analysed.

Corresponding Author:
Dr. Richard Pearson
r.pearson@kyotofusioneering.com
Kyoto Fusioneering UK
200 Brook Drive
Reading, Berkshire RG2 6UB
UNITED KINGDOM

KYOTO FUSIONEERING

Commercial Challenges and Opportunities Associated with FLiBe for Fusion Energy

Joint 15th IEA International Workshop on Beryllium Technology (BeWS-15) and BeYOND-IX

R. Pearson, J. Mund, C. Baus, A. Wilson, A. D'Angio', S. Takeda, S. Konishi, J. Yagi, P. Barron, K. Mukai.

Karlsruhe, Germany | 16 September 2022

FUSION for the FUTURE.

1

Contents

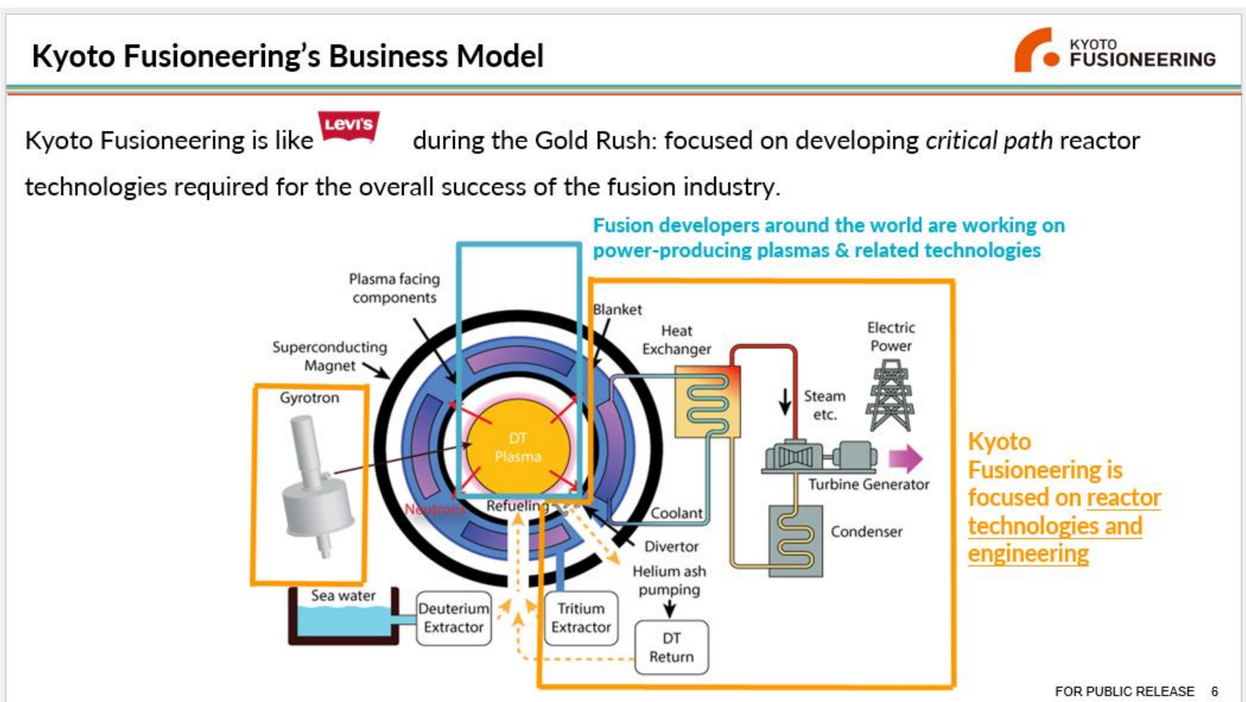
- **About Kyoto Fusioneering**
- **Introduction to FLiBe for fusion**
- **Challenges & opportunities for use of FLiBe in fusion**
  - Materials compatibility
  - Tritium breeding performance
  - Tritium extraction
  - FLiBe chemistry (purification)
  - Availability & supply of Be for FLiBe
  - FLiBe as a heat transfer fluid (power cycles & commercial applications)
- **Current FLiBe activity at KF**
- **Summary**

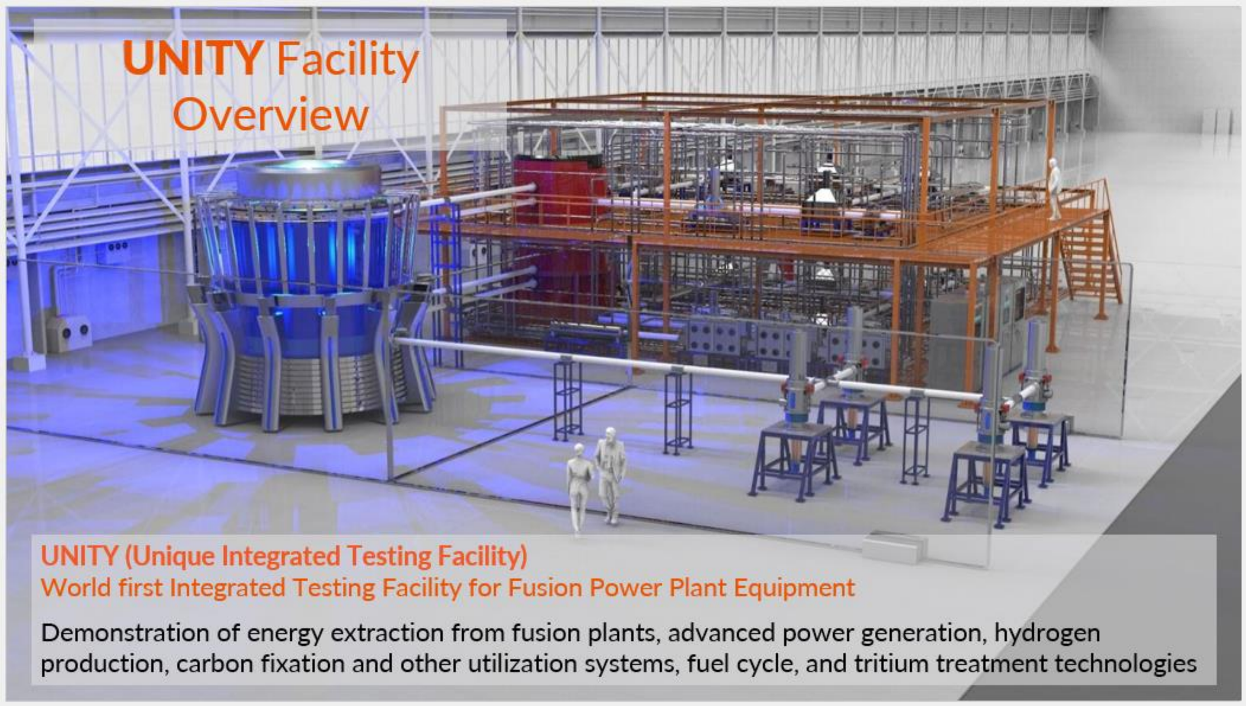
2


KYOTO
FUSIONEERING
FUSION for the FUTURE


Mission Statement:
To accelerate the development of high performance, commercially viable reactor technologies associated with power generation and the fuel cycle to support the rapid expansion of the budding fusion industry


Company Profile
KYOTO FUSIONEERING
Established: October 2019
Funding (VC): ¥2.1B JPY (~$17M USD)
Inv
DBJ
VENTURE GROWTH INVESTMENTS
CORAL CAPITAL
KYOTO-iCAP
大和企業投資
Daiwa Corporate Investment
JAFCO
JGC
global brain
Locations: Kyoto (laboratory)
Tokyo (business HQ)
Reading (UK HQ)
US location by end 2022 (TBD)
Company size: 55+ staff (incl. part-time)
Currently hiring in JP & UK


Kyoto Fusioneering's Business Model
KYOTO FUSIONEERING
Kyoto Fusioneering is like Levi's during the Gold Rush: focused on developing critical path reactor technologies required for the overall success of the fusion industry.
Fusion developers around the world are working on power-producing plasmas & related technologies
Plasma facing components
Superconducting Magnet
Gyrotron
Blanket
Heat Exchanger
Electric Power
Steam etc.
Turbine Generator
DT Plasma
Neutrons
Refueling
Coolant
Condenser
Divertor
Helium ash pumping
Sea water
Deuterium Extractor
Tritium Extractor
DT Return
Kyoto Fusioneering is focused on reactor technologies and engineering
FOR PUBLIC RELEASE 6


UNITY Facility
Overview
UNITY (Unique Integrated Testing Facility)
World first Integrated Testing Facility for Fusion Power Plant Equipment
Demonstration of energy extraction from fusion plants, advanced power generation, hydrogen production, carbon fixation and other utilization systems, fuel cycle, and tritium treatment technologies


Introduction: FLiBe for fusion
KYOTO
FUSIONEERING

Introduction: a brief history of FLiBe

Who first made/discovered FLiBe?

- FLiBe is a molten salt, with a 2:1 mixture (**2LiF-BeF$_2$**) and a melting point 457°C.
- FLiBe was first used in a **Molten Salt Reactor Experiment (MSRE)** at the Oak Ridge National Laboratory which ran from 1965-1969, but the first use of molten salts in general was 10 years earlier in the **Aircraft Reactor Experiment (ARE)** also run by ORNL (now stationed at INL).
- HYLIFE - One of the earliest applications of FLiBe in fusion design developed by LLNL supported by the US Department for Energy (Moir et al., 1993)

What are the applications/use of FLiBe to date? (see: Cadwallader et al., 1999)

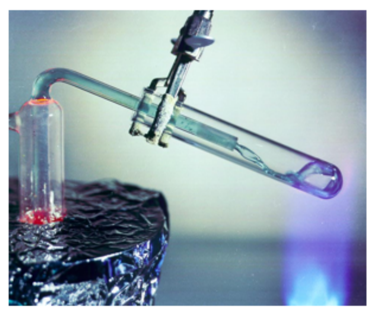
1. In **advanced fission reactor** (LFTRs and MSRs) where FLiBe is expected to act as a moderator, coolant and solvent for fissile material.
2. Molten salts have generally been used as **heat transfer fluids** and as a **thermal storage medium**. However, FLiBe is not currently used industrially for this.
3. In **fusion power plant concepts** as an advanced tritium breeder-coolant, or as a renewable surface for interfacing with plasma in high plasma-flux regions in MFE designs, and as a shield from neutrons and hydrodynamic blast in IFE designs.

Heat Transfer Reactor Experiment (HTRE-2 and HTRE-3) at Idaho National Lab. Credit: Richard Pearson. Photos taken October 2017.

 9

Why is FLiBe being considered for fusion?

- **Strong tritium breeding performance:** good neutronics properties for breeding, as FLiBe has both a high lithium and beryllium content.
- **Thermal performance:** Good thermal-hydraulic properties and high thermal efficiency (very high specific heat).
- **Liquid form:** can be circulated for simultaneous tritium breeding and heat extraction (self-cooled concepts), and does not get damaged as with solid breeders (general benefit of liquid breeders).
- **Passive/inherent safety:** unpressurised media, low reactivity with air and water, and turns into salt on freezing.
- **Low chemical reactivity from safety perspective:** chemical reactivity with air and water, whilst low tritium solubility/retention may allow easy tritium extraction (but also increases permeation).
- **High temperature for efficient power cycle:** relatively low melting point, high boiling point and low vapor pressures at relatively high operating temperatures (650-700°C); high temperature increases thermal efficiency.
- **Potential to avoid MHD effects:** low electrical conductivity and low magnetohydrodynamic resistance which is compatible with high magnetic fields in MCF reactors.
- **Neutron shielding:** A liquid blanket is needed for highly efficient neutron shielding with high plasma fusion power densities (beneficial as they improve long-term economic viability).

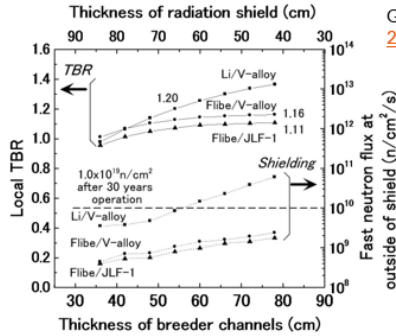


Source: Oak Ridge National Laboratory

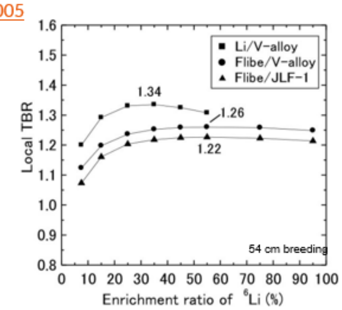
(Abdou et al., 2015; Ferry et al., 2022; Sorbom et al, 2015; Forsberg et al, 2019) 10

Comparison with other liquid breeders for fusion

- **High lithium content** allows **high tritium breeding ratio (TBR)**
- **Li-6 enrichment not necessary to achieve TBR>1**; if needed, Li-6 enrichment increases TBR by ~0.1
- Sufficiently **low melting point**
- **Excellent heat transfer** properties



Graphs: Tanaka, Muroga & Sagara, 2005

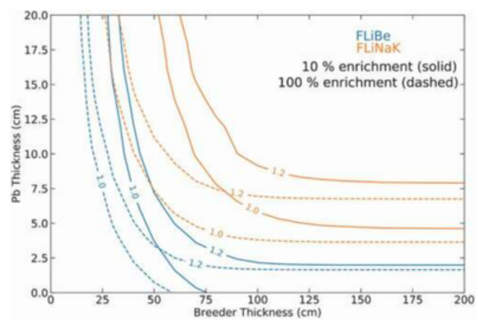


Coolant	Supply	Melting point (°C)	Density (g/cm³)	Li content (g/cm³)	Specific heat (kJ/m³K)	Tritium solubility (mol% at 1 Pa)
Li (400°C)	ok	181	0.5	0.5	2120	$3x10^{-2}$
LiPb (400°C)	ok	235	9.5	0.065	1796	$2x10^{-8}$
FLiBe (650°C)	supply and resource constraint	459	1.92	0.269	4670	$2x10^{-11}$

11

Notable projects & concepts that use FLiBe in fusion

- **LIBRA (MIT)**
  - ARPA-E supported experiment to study **T breeding potential in a large volume of FLiBe** & improve T accountancy.
  - **Be neutron multiplier in FLiBe** allows the reactor to be much **smaller than if an alternative such as FLiNaK or LiPb** were to be used (see graph on RHS) (Ferry et al., 2022).
- **JUPITER-II project (JP-US)**
  - Started 2001 to explore key feasibility issues related to the use of FLiBe such as corrosion of structural materials, tritium control and safe handling of FLiBe (Petti et al., 2005).
- **ARC reactor (MIT & Commonwealth Fusion Systems)**
  - Liquid immersion concept developed by MIT and envisioned to be built by Commonwealth Fusion Systems (Bocci et al., 2020; Sorbom et al., 2015).
- **FFHR reactor (Japanese Fusion-Fission Hybrid Reactor)**
  - Stellarator concept developed by JP research group (Fukada, 2013; Sagara et al., 2000; Farmer, 2007).



Study on FliBe TBR performance on the LIBRA concept. Ferry et al., 2022

12

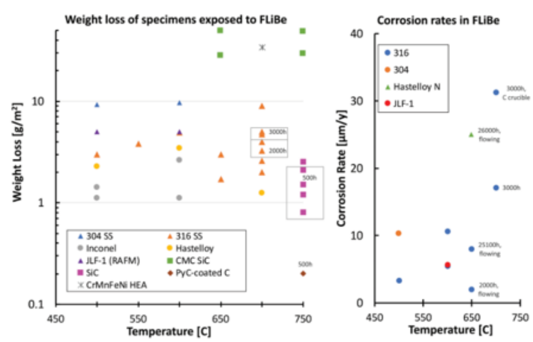
FLiBe compatible materials

- A major challenge in using FLiBe is the **compatibility of structural materials** with molten fluorides.
- Salt impurities and metallic fluorides dispersed in the FLiBe determines which compound will ultimately form (thermodynamics) (Forsberg et al., 2017):

Free energy of formation

High(er) corrosion $TiF_4 < VF_3 < CrF_2 < FeF_2 < NiF_2 < WF_6 < MoF_6$ ***Low(er) corrosion***

- Trade-off on manufacturability if using pure Ni, Mo, W, so candidate structural materials are commercially available **Ni-Mo-based alloys** (i.e. Hastelloy, Inconel) with low Cr content.
- Chromium is leached from the structural material, making SS a less attractive option (Zheng et al., 2015).
- Non-metallic solutions may be plausible, e.g. **SiCf/SiC**, but effect of oxygen, metallic impurities from the matrix or other segment of the blanket/loops and fluorides that can be silicised require attention.



Weight loss and corrosion rate of structural materials in FLiBe Ferry et al., 2022.

14

FLiBe compatible materials: areas of development and prospects

Material development

- Structural material composition: **novel Ni-Mo alloys incorporating additives** (e.g. Y), and **computationally-guided alloy design** has generated novel Ni-based alloys with improved mechanical properties and FLiBe corrosion resistance (Muralidharan et al., 2022).
- SiCf/SiC and CVD-SiC are different materials: **effects of matrix composition for NITE SiCf/SiC and manufacturing approach** (pores in CVI SiCf/SiC) (Wang et al. 2017).
- REDOX agents: **Adding Be metal to FLiBe inhibits corrosion in SS316** by lowering oxidation potential, at the expense of introducing intermetallic compounds which may reduce mechanical performance (Keiser et al, 2022).
- **Use of dissimilar materials interacting with FLiBe affects corrosion resistance** from upstream to downstream.
- **Transmutation and long-lived radionuclides.**
- **Variable experimental setup and conditions** (material crucibles, flow conditions etc.).

Representative environment

- Effect of **molten salt flow rate on the corrosion rate.**
- Effect of **thermal gradient**: mass gain in some areas with potential obstruction of pipelines.
- **Corrosion performance post-irradiation.**

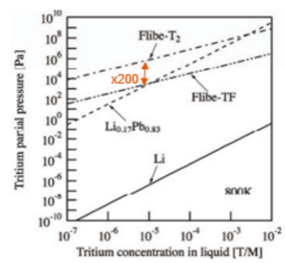
Equipment

- Online and offline purification of FLiBe or redox controller to prevent corrosion.
- Diagnostic tools to monitor FLiBe composition and corrosion.

15

Tritium Extraction

- Tritium partial pressure *higher* than LiPb and *much higher* than Li due to low solubility of T.
- Challenge lies in redox. Be can be added as redox agent:
  - TF → T_2 ⇒ increase equilibrium pressure above FLiBe by about 200 times ⇒ easy gas purge
- Key methods for tritium extraction:



Tritium partial pressure in several candidate liquid breeders
Fukada, 2012

  - *NB: Rate of extraction for all options is typically determined by surface area and turbulence of fluid*
  - Vacuum Sieve Tray and Vacuum Disengager - hot FLiBe salt is sent to a vacuum tower where spray nozzles create small droplets. Tritium diffuses out of the droplets as they fall and is removed by vacuum pumps (Dolan 1992).
  - Gas Sparging - inert gas is bubbled through the salt combined with sonochemistry (Rubio et al., 2016).
  - Counter-current He Tower - inert metal packing, desorption at surface (Fukada et al., 2012).
  - Solid Adsorbers - a particle bed of a solid adsorber removes tritium from FLiBe and then desorbed via heating (Forsberg et al., 2019).
  - Permeation membranes - wall with high permeability to tritium (e.g. vanadium) (Reiter et al., 1989).

16

FLiBe Purification

- Impurities in FLiBe come from **initial ingots, metal pipes, and transmutation.**
- Purification is necessary to **control corrosion and reactivity.**
- Several impurities contained, even after filtering (see table).
  - *For FHR, 53 impurities have been identified (Seifried et al., 2019).*
  - *H_2O limit is at 1000 ppm for MSRE (as water is a strong moderator).*

Impurity	ppm
O	560
Fe	260
N	32
Cr	16
Ni	15
C	10
H_2O	high?

Typical impurities in FLiBe Petti 2006 (also see Bocci et al., 2020).

- **Methods of purification** (several needed to remove all types) (Forsberg 2019; Seifried 2019)
  - **Fluorination with HF to remove fluoride impurities** - *proven in production of FLiBe.*
  - **Control redox by the ratio of hydrogen to HF to precipitate most remaining impurities** - *proven in production of FLiBe.*
  - **Filter out any metal particulates** - proven in production of FLiBe.
  - **High-performance, high-temperature distillation columns of molybdenum or other materials** (high-capacity, low-cost, no-additive).
  - **Exposure of the salt to an active metal to consume oxidizing impurities.**

17

FLiBe as a heat transfer fluid

- Molten salts - particularly FLiBe - were **proposed and used as a coolant** (*and as a fuel medium*) for fission reactors in the 1960s:
  - They are able to **operate at atmospheric pressure** (*unlike water and gases*)
  - They are **transparent** and **do not react with air and water** (*unlike some liquid metal coolants*)
  - They have a **considerable operating temperature range** (*FLiBe: ~460-1400°C*)
  - They are **capable of dissolving nuclear fuel** in the form of uranium or thorium fluorides; remains far from commercialisation (*see: Kairos Power*)
- Molten salts have also been **suggested as an energy storage medium** (particularly for solar thermal) due to their substantial volumetric heat capacity:
  - Intended use as part of a **sensible heat thermal storage system**, where the **storage medium** is used to **store heat without a phase change**.
  - They have lower energy density than latent heat (phase change) and thermochemical (chemical conversion) energy storage options, although these options are more complex and further from commercialisation
  - FLiBe has **exceptionally high volumetric heat capacity**, which sets it apart from other molten salts.
  - Energy storage will play an important role to convert the pulsed heat generation of a fusion plant into more continuous or dispatchable electricity generation. Molten salt is unlikely to be the sole energy storage medium, but its operating temperature range makes it highly compatible with other media.

Romatoski & Hu, 2017; Barqi et al., 2022; Forsberg et al., 2019
18

FLiBe as a heat transfer fluid

- Both applications (*as either a coolant or energy storage medium*) **require that FLiBe be coupled to a power conversion cycle**.
- Compatibility and performance **depends on temperature** of the molten salt.
- Some indicative data on candidate molten salts:

Salt	Melting point (°C)	Boiling point (°C)	Volumetric heat capacity (kJ/m^{3}°C)
Li_2BeF_4 (FLiBe)	459	1,430	4,540
LiF-NaF-KF (FLiNaK)	454	1,570	3,700
0.58NaF-0.42ZrF_4	500	1,290	3,670
0.42LiF-0.29NaF0.29ZrF_4	460	1,350	3,978

- Whilst all of these molten salts are *potentially compatible* with a Brayton cycle, **FLiBe's high boiling point will allow for the greatest cycle efficiency** (alongside FLiNaK).
  - **Molten salt heat transfer capabilities are well suited to very high temperature applications** (exceeding 1000°C), so their thermal capabilities are not fully used by most fusion designs. FLiBe's breeding capabilities is its more important characteristic for fusion.

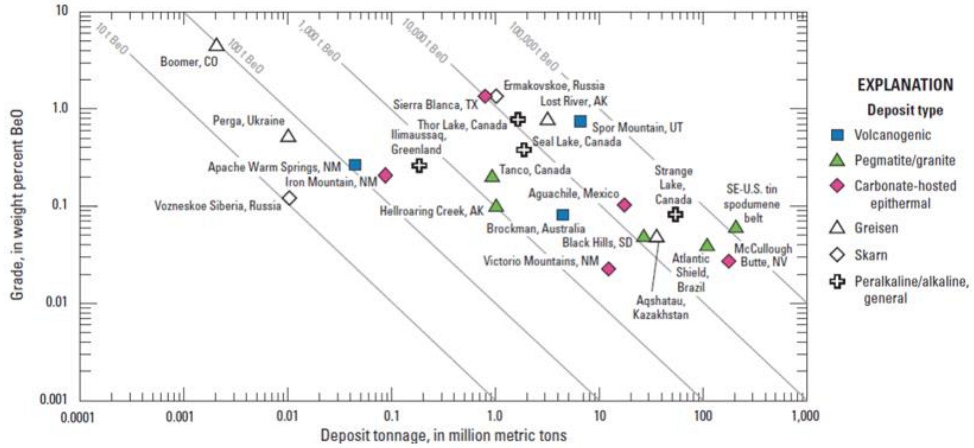
Serrano-Lopez et al., 2013; Bahri et al., 2017; Peterson et al., 2003; Romatoski & Hu, 2017

Beryllium: Resources, reserves, and production

- **Geology**
  - Due to complex geological processes and very specific conditions, beryllium containing ores in any mineable concentration (beryl or bertrandite) are formed in very specific geographical regions.
- **Abundance**
  - **2.1 ppm** on Earth (Trueman & Sabey, 2014)
  - Economically mineable deposits are the issue: Be occurs in low concentrations (e.g. world's largest mine in Utah has **0.7% BeO content**).
  - *Not* economically extractable from seawater (0.00006 ppm)
- **Resources & Reserves**
  - Global resources estimated at **100,000t** (USGS, 2022)
    - *Real quantity may be several times higher: possibly as high as **485,000t** (Dombrowski, 1996).*
  - Utah mine world's largest (Materion Corp.) contains an estimated: **20,000t** contained Be.
- **Global Production of Primary Beryllium (260t in 2021)**
  - USA: 170t (65% - Materion Corp.)
  - China: 70t (27% - Ningxia & others)
  - Others: 20t (8% - Ulba in Kazakhstan)

Surface mining of bertrandite ore in Utah.

Global Beryllium Deposits (Grade/Concentration vs. Size/Tonnage)

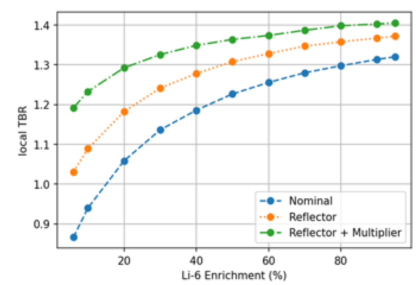


Estimates of grade and tonnage for a variety of beryllium deposits, districts, and belts in the United States and worldwide that have potential for minable beryllium resources. Diagonal lines show equal value of contained metal in metric tons. Available data for deposits of these types are sparse; some deposit information was compiled using incompletely documented past-production, reserve, and resource information. For additional information, see Trueman & Sabey, 2014.

21

Comparison of solid Be vs. FLiBe in fusion (1): solid Be

- **Cost & required quantities:**
  - Cost of manufacturing solid Be compounds is **very high**.
  - High cost suggests use of small quantities of solid Be.
  - Small quantities of Be can be used as a "TBR booster" (Pearson et al., 2022 [in press]; Wong et al., 2013; Sagara et al., 2000).
- **Supply & production capacity:**
  - For use of Be metal or high Be-content intermetallic compounds, **fusion will be the only customer**, and Be demand will skyrocket:
    - *Current forms of material (e.g. 1mm-diameter pebbles) are not produced in quantities that can be considered as a standard commercial product.*
  - Large increase in production capacity needed.
- **Using solid Be compounds for fusion:**
  - Recent internal KF study asked: ***how much is an "acceptable" amount of beryllium per fusion reactor, from the perspective of availability, supply, cost and market complexity?***
  - Modelling indicated **in the order of 10t solid Be compounds per reactor** would be an acceptable quantity.



Green line shows impact of a Be "booster" layer to increase TBR in a self-cooled blanket (Pearson et al., 2022 [in press])

22

Comparison of solid Be vs. FLiBe in fusion (2): FLiBe

- **FLiBe cost & required quantities:**
  - **Manufacturing FLiBe has potential to be substantially lower cost** than the process for solid Be compounds.
  - But if FLiBe is used as a breeder for fusion, larger quantities will be needed as it is **not a viable choice as a "booster"**.
  - In the order of **~hundreds of tons contained Be** (*~thousands of tons of FLiBe*) will be required per fusion reactor.
    - *ARC concept requires ~350t contained Be per GWe reactor if used in the blanket (Sorbom et al., 2015).*

Commissioning of the FLiBe production facility by Materion, Ohio, USA. Source: Power Mag.

- **Supply & production capacity:**
  - **Limited existing supply chain for FLiBe.**
  - There is **potential synergy with fission & energy storage technology industries.**
    - *Actively being considered as a fluid useful for GenIV fission power, as illustrated by the strategic partnership between Materion and Kairos Power to build a dedicated FLiBe production plant on Materion's site in Ohio (now operational - refer to Keith Smith's talk).*

23

Modelling commercial rollout of fusion against *Be resource availability*

Availability of beryllium resource could be a major issue for the commercial rollout of fusion, as it could limit the maximum capacity of fusion reactors to be installed on the grid.

Assuming approximately 350t Be (contained in FLiBe*) per GWe (~170t Be/GWth in ARC concept using FLiBe Sorbom et al., 2015):

**Be is 9.11% of total mass of FLiBe, formula: 2LiF-BeF_2*

Scenario	No. fusion plants installed on grid (GWe)	Quantity of Beryllium required (t)	Percentage of known Be resources (2022: 100,000 t)	Comments
FOAK power plant	1	350	0.35%	Uses one year's worth of annual Be supply, but unproblematic from a resource perspective.
First 100 power plants	100	35,000	35%	Exhausts current stated economical reserves at Spor Mountain, UT, almost two times over. First 100 fusion plants using FLiBe likely to be viable if supply capacity scaled (notwithstanding other issues)
Fusion matches current fission installed capacity	400	140,000	140%	Uses up entirety of known total resource base.
Fusion is transformative	5000	1,750,000	1,750%	17.5 times known total resource base. Exhausts beryllium supply many times over; even if the higher resource base estimate of 475,000t is true.

24

Modelling commercial rollout of fusion against *Be supply capacity*

Production (supply capacity) of FLiBe is a bottleneck for fusion commercial rollout.

Again assuming approximately 350t Be (contained in FLiBe) per GWe (Sorbom et al. 2015):

Scenario	Approximate build rate of fusion plants installed on grid (GWe/yr)	Beryllium required per year (tpy)	Proportion of current annual beryllium supply capacity: to 350 tpy	Comments
Fusion has a minor impact on society (single or small no. of nations, or for niche applications only)	10	3,500	10 x	If Beryllium supply capacity is expanded 10-fold, then it will be sufficient for fusion have a minor impact on society
Rollout of fusion sufficient to be transformative for electricity generation. globally.	50	17,500	50 x	50-fold capacity increase in supply capacity is needed, but even then is insufficient for fusion to be transformative for electricity generation. Note that 17,500 tpy is equivalent to mining almost all known reserve at Spor Mountain deposit, but every year.
Rollout of fusion sufficient to be transformative for primary energy, globally.	200	70,000	200 x	Capacity would need to be increased 200-fold, and an amount of beryllium equivalent to 70% of current known resources would need to be mined per year.

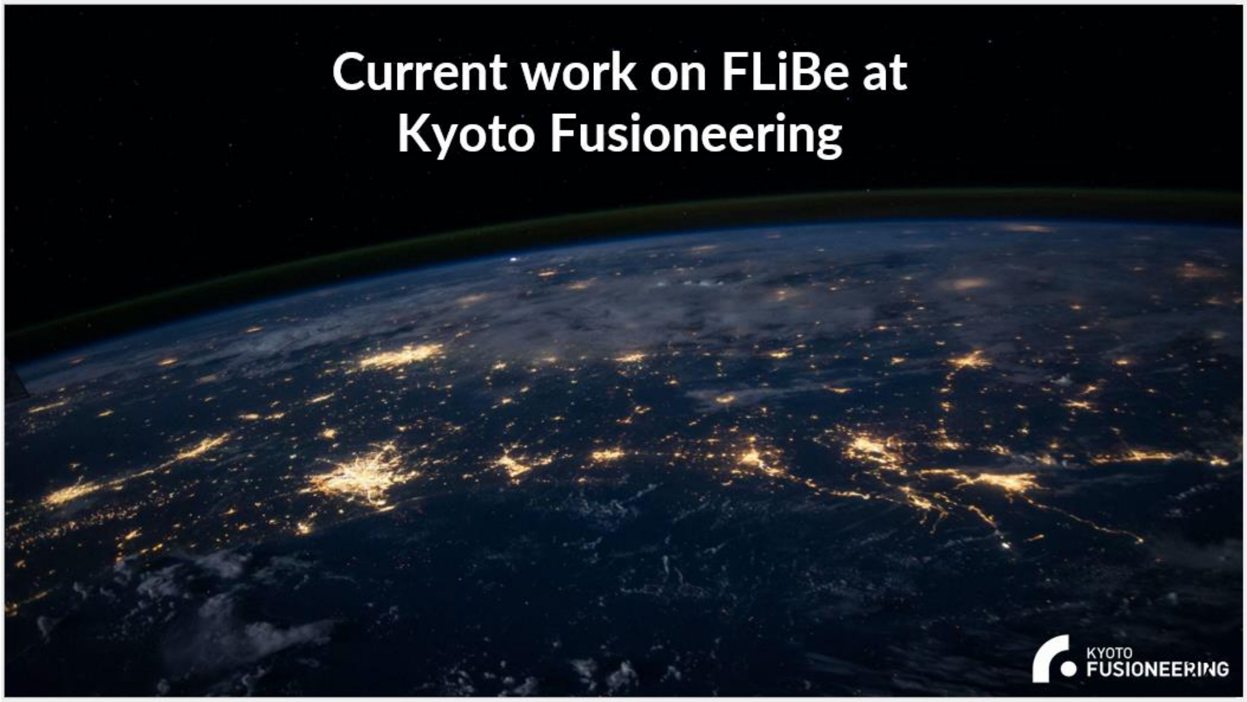
 25

Beryllium availability & supply: Future market aspects

If fusion developers require beryllium for fusion, then the following must be considered:

- **Beryllium industry risk appetite**
  - **Be industry must scale for what is effectively one customer:** a monopsony. This situation will be "high risk" for the Be industry.
  - There is also a potential cliff-edge, in the case that there is a shift away from using FLiBe or Be products after a first generation of fusion reactors.
- **Who pays for it?**
  - **The capital investments needed to scale Be supply will have to be justified to the industry, or it likely** won't happen.
    - *Unless government help can be found... the US military cost shared with Materion for a new facility to produce military-grade Be metal (Materion, 2010).*
- **Geopolitical aspects**
  - Several nations supply primary Be in the world (USA, China and Kazakhstan). Be is a strategic material, and increasing supply drastically may not be straightforward from a strategic perspective. High concentration grades of beryllium are export controlled.
- **Fusion end-users must make a business decision on the form of beryllium: solid or FLiBe (or no beryllium at all?)**
  - *FLiBe is less complex from a manufacturability point of view, but grand scale-up of beryllium mining and supply will be needed.*
  - *Solid Be is more complex and costly from a manufacturability point of view, but if used in small quantities looks better from a beryllium mining and supply perspective.*
  - *Other breeders may offer similar performance with fewer commercial (and technical) challenges.*

 26



KF ongoing and future R&D

Purification (metal oxides): Conventional FLiBe purification process via Be addition

- HF bubbling: metal oxide ⇒ metal fluoride
- H_2 addition, reduces: metal fluoride ⇒ metal + HF
- Strong disadvantages:
  - Be concentration gradually increases.
  - Higher T_2 equilibrium pressure ⇒ higher permeation.
  - Additional LiF feeding is necessary.
  - Continuous O removal is necessary.
- Proposed method (studied at KU): electrochemical purification using Li under potential control so it reacts only with TF.

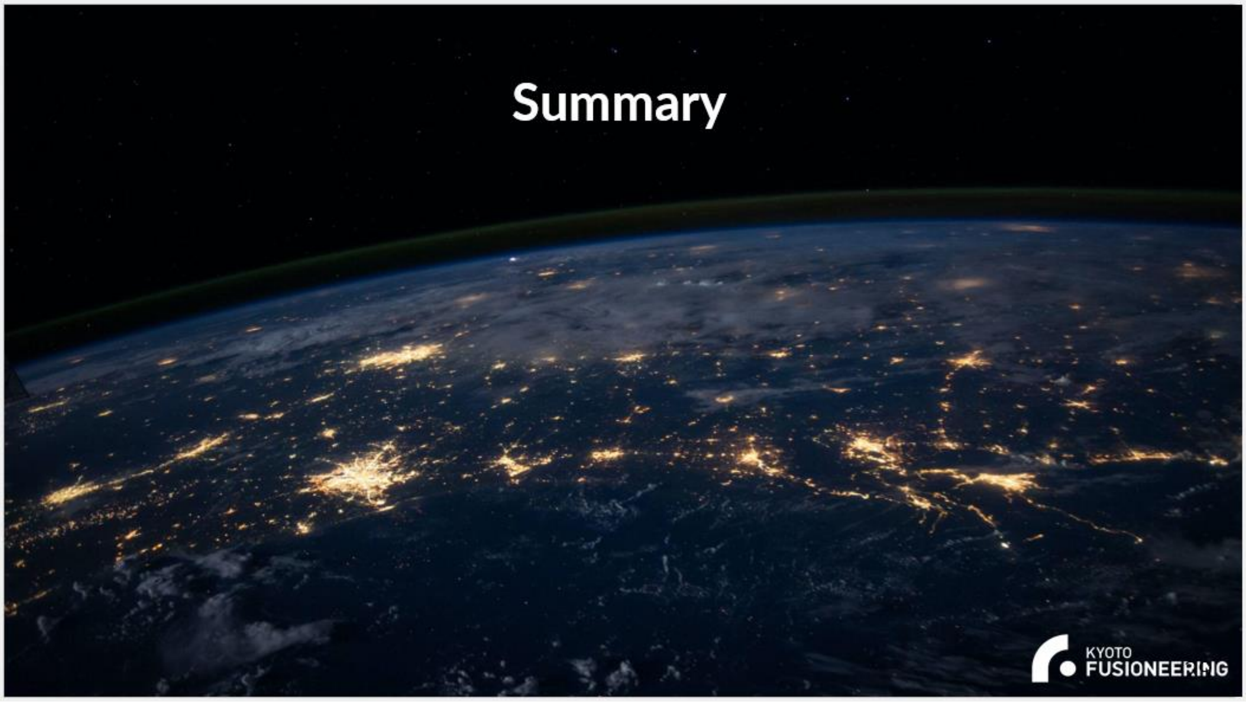
Corrosion experiments

- SiCf/SiC in flow conditions.
- Low-nickel materials for high neutron flux environment.
- High-nickel materials for heat exchanger.

Above: FLiBe test loop benchtop experiment sited at Kyoto University (Inconel 600).

Below: melted FLiBe in a pot before purification.

28



Summary

<u>Some aspects of FLiBe look very attractive:</u> In particular, as a breeder, FLiBe looks good from a **TBR performance**, **safety** and **thermal performance** perspective. There are **synergies with advanced fission**. It is potentially **cost effective** (*especially compared with solid beryllium blankets, but probably not LiPb or Li*), has a good temperature range to be coupled with a power cycle, and strong safety characteristics.

<u>But, there are significant challenges and trade-offs:</u>

- There are **limited options for FLiBe compatible materials**. Steels, silicon carbide and Ni-based alloys are among materials under exploration, but **compatibility is a significant challenge for FLiBe** (e.g. primary candidate Ni-based alloy not ideal for fusion due to waste concerns, high Ni content).
- **Lack of knowledge or experimental data on tritium retention, extraction and handling**. Experimental research needed to resolve, as well as **purification and redox control**.
- Using **FLiBe as a heat transfer fluid** for fusion **requires experimentation;** largely theoretical at this stage.
- **Beryllium resource is scarce**, and **supply capacity is limited**. For fusion use, FLiBe requires on the order of ~hundreds of tonnes per reactor. Issues with scale-up of supply associated with commercial risk, cost and geopolitics.

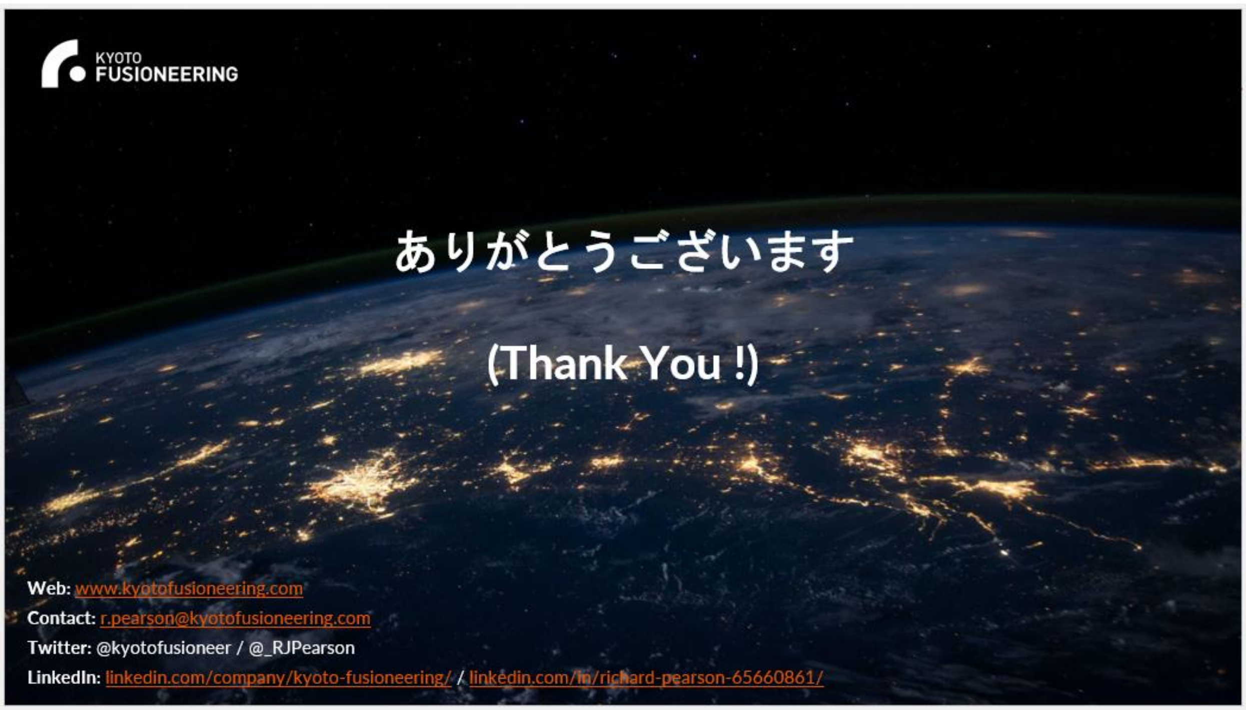
If FLiBe is to be considered as a realistic and useful breeder-coolant for fusion, we need to explore this interesting salt now. Alongside others, this is what Kyoto Fusioneering is doing.

 30

Concluding remark...

The 2020s needs to be seen as the **age of fusion industrialisation**, and the investment of time, effort and capital in this decade is the foundation for **fusion commercialisation in the 2030s**

31



The Possible Toxicity of Beryllium Salts

Michael McCawley[1] and Kathryn Creek[2]

[1]West Virginia University, School of Public Health, Morgantown, West Virginia, U.S.A.
[2]Beryllium Solutions International LLC, Lourinha, Portugal

Li_2BeF_4 (also known as "FLiBe") is a primary candidate as a coolant for fluoride-salt-cooled, high-temperature reactors. As a beryllium salt, there is concern about exposure that might result in chronic beryllium disease, either from skin exposure or inhalation exposure of the FLiBe. Beryllium, in many of its various forms is predominantly insoluble, especially oxidized, or alloyed with other metals such as copper, nickel and aluminum. FLiBe, however, is soluble.

Past work on exposure to soluble forms of beryllium, such as beryllium hydroxide and beryllium fluoride in the mining of ore and the production of aluminum from beryllium-containing bauxite, respectively, seems to indicate, at most, very low rates of disease in exposed individuals. Exposures to beryllium in the form of soluble beryllium salts, while often in excess of those found in workplaces where soluble beryllium forms dominate, nevertheless have rates of new cases of chronic beryllium disease well below the rate of five percent seen for workforces exposed to insoluble forms.

A review of the epidemiologic literature is presented taking into account both dermal and inhalation routes of exposure. These two exposure routes appear to account for the observed rates of disease for insoluble species of beryllium and explain why the persistence of insoluble beryllium deposited in the lung may offer the best explanation for the observed rates of disease and the relative lack of disease for soluble beryllium. However, sensitization, the first step in the disease process, occurring dermally, may not be as diminished by the quick dissolution and elimination of the soluble compounds. This could present a hazard for workers whose jobs might eventually lead to exposure of the insoluble forms of beryllium.

Corresponding Author:

Dr. Michael McCawley
mamccawley@hsc.wvu.edu
West Virginia University
School of Public Health
P.O. Box 9190
Morgantown, West Virginia 26506
U.S.A.

The Possible Toxicity of Beryllium Salts

M. McCawley, West Virginia University
K. Creek, Beryllium Solutions International
BeYOND-IX Industrial Forum
16 September 2022

RATIONALE

- Beryllium (Be) health research has mostly centered around Be metal (oxides and alloys) exposure.
- Standards of under 0.2µg/m^3 have been suggested and adopted in the US as potentially protective.
- Be must be at least partially soluble to elicit a cellular response from the immune system.
- Despite this, highly soluble forms of Be should be expected to have less of an effect if their dissolution and excretion rate is sufficiently fast.
- Aluminum smelting operations are known to use beryllium containing bauxite in smelting operations.
- Workers in those operations have measurable exposure to beryllium fluoride salt produced from the contaminated bauxite from those limited sources.
- The solubility of Be has been recognized as a potential factor that may lessen risk.
- The US OSHA extracts water soluble Be from air sample filters and discards it before analysis.

2

EVIDENCE

3

Beryllium (Be) health research has mostly centered around Be metal (oxides and alloys) exposure.

4

	Beryllium Extraction Mine and Mill	Copper-Beryllium Alloy Finishing	Beryllium Ceramics Manufacturing
BeS + CBD			
Round 1	5/120 (4.2%)	10/144 (6.9%)	8/136 (5.9%)
Round 2	1/47 (2.3%)		8/77 (10.4%)
Cumulative	6.3%		15.7%
CBD			
Year opened	1969	1951	1980
Year summed	2009	2001	1999
CBD diagnoses	2	7	25
Person-years	11,513	13,129	10,698
CBD/10,000 person years	1.7	5.3	23.4
Relative rate	1	3.1	13.5

5

Source: Deubner et al., 2011

Standards of under 0.2µg/m³ have been suggested and adopted in the US as potentially protective.

6

Caution on the Airborne Exposure Limits for Beryllium from US DOE Data

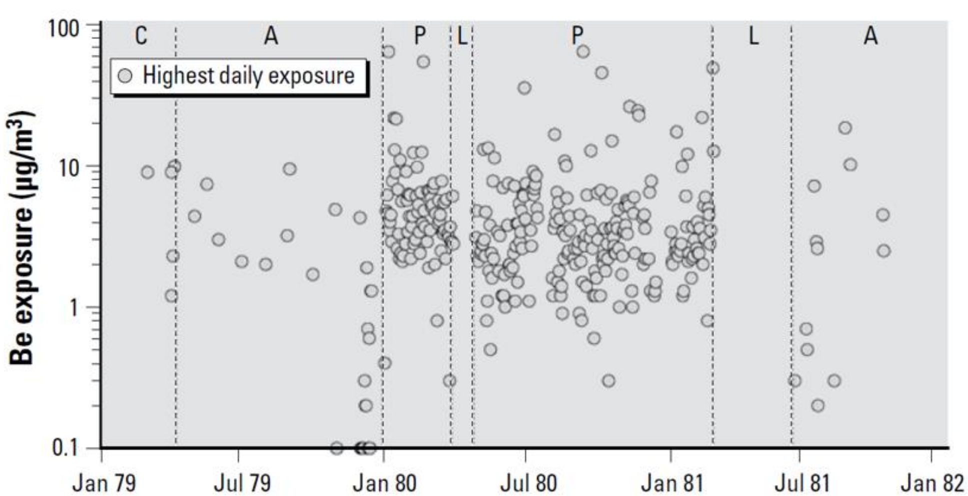
"... we now believe that our 2µg/m^3 PEL does not adequately protect beryllium-exposed workers from developing chronic beryllium disease, and there are adequate exposure and health effects data to support this [DOE's] rulemaking."

The letter continues by citing existing data:
"... **cases of chronic beryllium disease have occurred in machinists where 90 percent of the personal exposure samples found levels of beryllium to be below the detection limit of 0.01µg/m^3**. ... Viewed from OSHA's regulatory perspective, these DOE study results document **risk of sensitization to beryllium of 35-40 per 1,000 workers** and **risk of chronic beryllium disease to machinists of 94 per 1,000**."

Source: Michaels and Monforton, 2008

7

CBD Case Historical Exposure Measurements



Source: Cummings et al., 2009

8

Beryllium must be at least partially soluble to elicit a cellular response from the immune system. Despite this, highly soluble forms of Be should be expected to have less of an effect if their dissolution and excretion rate is sufficiently fast.

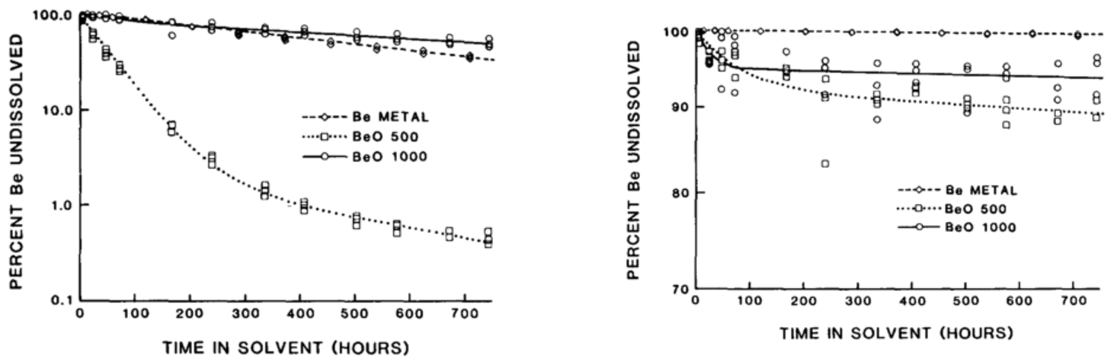
9

Aerosol†	Dissolution solvent	Dissolution components (± S.E.)‡ I A_1 (%)	I $t_{1/2}$ (days)	II A_2 (%)	II $t_{1/2}$ (days)
Be metal	HCl	100	20 ± 0.2		
	SUF	100	5800 ± 300		
BeO—500°C	HCl	97 ± 1	1.6 ± 0.1	3 ± 1	12 ± 1
	SUF	8 ± 2	2.3 ± 1.1	92 ± 2	640 ± 550
BeO—1000°C	HCl	15 ± 5	2.0 ± 1.4	85 ± 5	40 ± 6
	SUF	5 ± 1	0.7 ± 0.3	95 ± 1	2100 ± 3100

Source: Finch et al., 1988

10

Dissolution Rates of Low Temperature- and High Temperature-Fired Be Particles in Lung

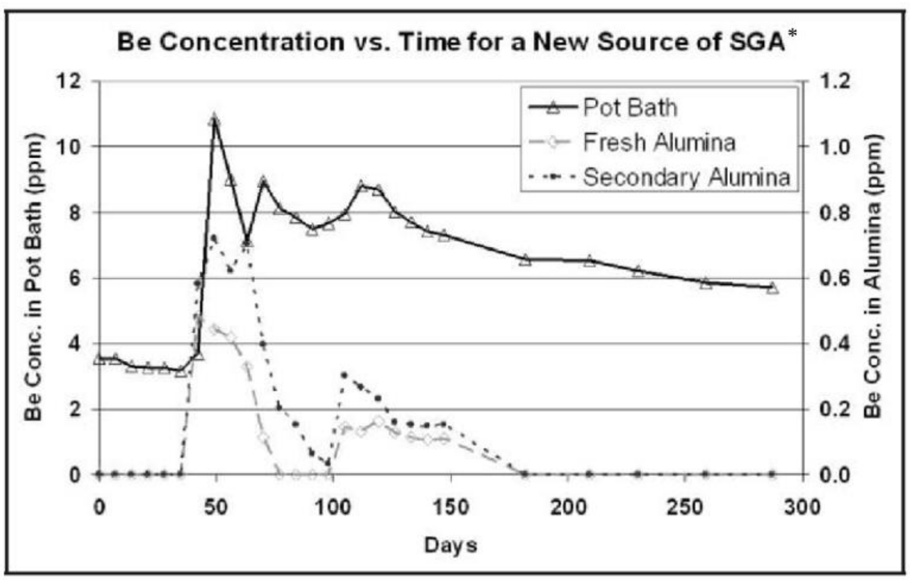


Source: Finch et al., 1988

11

Aluminum smelting operations are known to sometimes use beryllium-containing bauxite in smelting operations. Workers in those operations can have measurable exposure to beryllium fluoride salt produced from the contaminated bauxite from those limited sources.

12

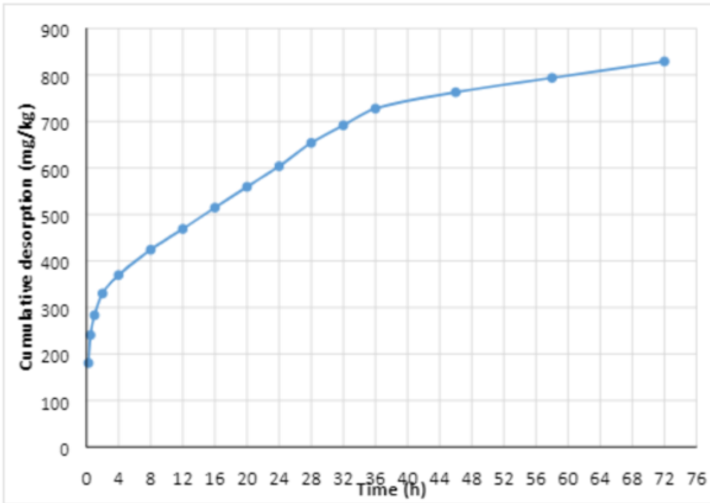


* Smelting Grade Alumina

Source: Lindsay & Dobbs, 2006

14

Desorption of Beryllium from Soils



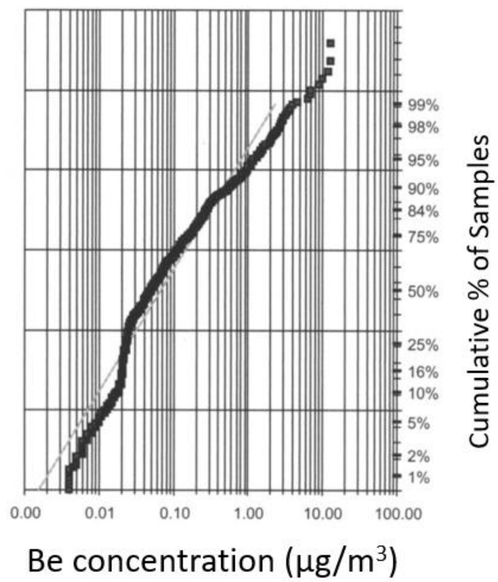
Source: Islam et al., ACS Omega 2021, 6, 30686–30697

15

The solubility of beryllium has been recognized as a potential factor that may lessen risk. The US OSHA extracts water-soluble Be from air sample filters and discards it before analysis.

16

Beryllium Exposure to Aluminum Smelter Workers



Source: Taiwo et al., 2008

17

Risk of Sensitization (BeS) Among Aluminum Smelter Workers

Company	Number of Smelters	At-risk Workers	Workers Tested	BeS	% BeS
A	4	1278	734	4	**0.5**
B	3	423	328	0	**0**
C	1	1100	508	4	**0.8**
D	1	384	362	1	**0.3**
Total	9	3185	1932	9	**0.5**

Taiwo et al., 2010

18

CAVEATS

Be sensitization appears to occur through cut or abraded skin exposure as well as inhalation.

Frequent and repeated exposures, even of soluble Be salts, may initiate sensitization.

Skin exposures offer the ability for frequent exposures if not recognized and addressed.

A directed study of beryllium salt exposure in aluminum potrooms measuring routes of exposure and body burden does not seem to be unwarranted.

19

CONCLUSIONS

- Beryllium salts (in particular - fluorides) have high solubility making them candidates for low potential toxicity if straightforward safeguards are followed.
- Directed studies may be possible in the aluminum industry spurred by a vested interest in less expensive electrical power production resulting from the use of beryllium salts.
- Much of the information to guide this work is already in the published literature and startup of the research should proceed swiftly including fostering renewed awareness of the known caveats.

20

REFERENCES

- Cummings, K. J., Stefaniak, A. B., Virji, M. A., & Kreiss, K. (2009). A reconsideration of acute beryllium disease. *Environmental health perspectives*, *117*(8), 1250-1256.
- Deubner, D., Kelsh, M., Shum, M., Maier, L., Kent, M., & Lau, E. (2001). Beryllium sensitization, chronic beryllium disease, and exposures at a beryllium mining and extraction facility. *Applied Occupational and Environmental Hygiene*, *16*(5), 579-592.
- Finch, G. L., Mewhinney, J. A., Eidson, A. F., Hoover, M. D., & Rothenberg, S. J. (1988). In vitro dissolution characteristics of beryllium oxide and beryllium metal aerosols. *Journal of aerosol science*, *19*(3), 333-342.
- Islam, M. R., Sanderson, P., Payne, T. E., Johansen, M. P., & Naidu, R. (2021). Desorption and Migration Behavior of Beryllium from Contaminated Soils: Insights for Risk-Based Management. *ACS omega*, *6*(45), 30686-30697.
- Lindsay, S. J., & Dobbs, C. L. (2016). Beryllium in pot room bath. In *Essential Readings in Light Metals* (pp. 596-601). Springer, Cham.
- Michaels, D., & Monforton, C. (2008). Beryllium's public relations problem: protecting workers when there is no safe exposure level. Public Health Reports, 123(1), 79-88.
- Taiwo, O. A., Slade, M. D., Cantley, L. F., Fiellin, M. G., Wesdock, J. C., Bayer, F. J., & Cullen, M. R. (2008). Beryllium sensitization in aluminum smelter workers. *Journal of occupational and environmental medicine*, 157-162.
- Taiwo, O. A., Slade, M. D., Cantley, L. F., Kirsche, S. R., Wesdock, J. C., & Cullen, M. R. (2010). Prevalence of beryllium sensitization among aluminium smelter workers. *Occupational medicine*, *60*(7), 569-571.

21

THANK YOU

mamccawley@hsc.wvu.edu

22

Why Standardise Training in the Beryllium Industry: The Argument for a Global Training Standard

Beth Walker

Safer Environment Ltd., Burtle, Somerset, United Kingdom

The Beryllium industry seems to have a lack of uniform knowledge on the dangers and safety measures surrounding beryllium.

Beryllium knowledge is updated regularly as we complete more research. Due to the lack of widespread use of the product, organisations do not have a standard training to fall back on, and there seems to be no best practice update database or comprehensive facility design that can be adopted, updated, or delivered. There is widespread use of beryllium in the alloy forms.

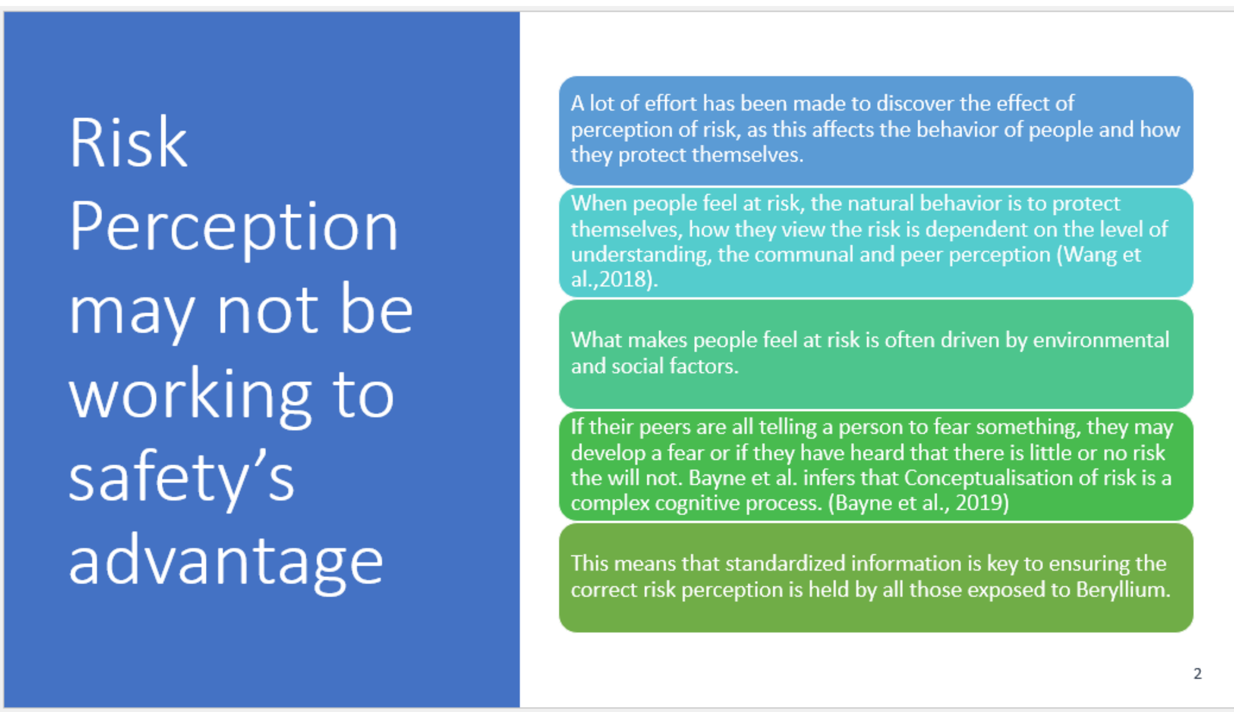
Part of the issue around training may be a lack of understanding or awareness of regulators to establish better requirements (like is the case with lead and asbestos). Examples of similar risks that have ratified training in the UK are lead and asbestos. Most countries have a standard for the training delivered in both of these.

One organization, Cambridge Technology Ltd., produces several different types of training even within its own organization. These differ between exposure levels, but there is a standard convention for the training design and certain 'base level' knowledge is given to all employees and visitors.

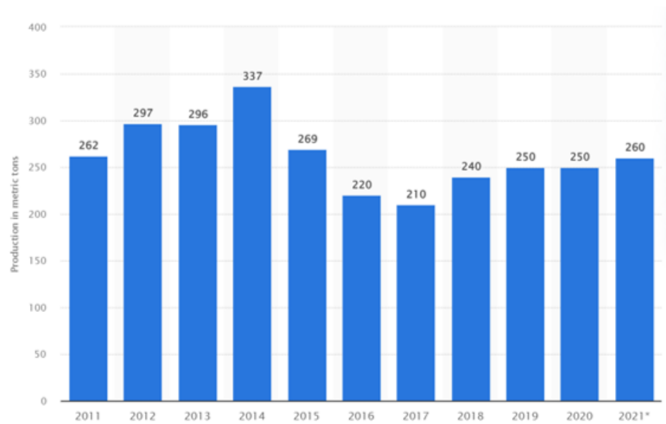
The difference of knowledge levels between experts and shop-floor staff is noticeable, and it is important to ensure that the people who are using beryllium-containing materials to make product on a daily basis are given the most up-to-date information. The easiest way to do this is have a standardized, accredited training program.

Corresponding Author:
Ms. Beth Walker
rbwalker39@gmail.com
Safer Environment Ltd.
Robins Cottage
Robins Lane
Burtle, Somerset TA7 8NT
UNITED KINGDOM


Why Standardise Training in the Beryllium Industry
The argument for a global training standard
Beth Walker
Safer Environment Ltd.
Presented at the 9th BeYOND Industrial Forum
16 September 2022


Risk Perception may not be working to safety's advantage
A lot of effort has been made to discover the effect of perception of risk, as this affects the behavior of people and how they protect themselves.
When people feel at risk, the natural behavior is to protect themselves, how they view the risk is dependent on the level of understanding, the communal and peer perception (Wang et al.,2018).
What makes people feel at risk is often driven by environmental and social factors.
If their peers are all telling a person to fear something, they may develop a fear or if they have heard that there is little or no risk the will not. Bayne et al. infers that Conceptualisation of risk is a complex cognitive process. (Bayne et al., 2019)
This means that standardized information is key to ensuring the correct risk perception is held by all those exposed to Beryllium.
2

Worldwide production of Beryllium



Beryllium production is on the increase again and with a similar latency to Asbestos, Is it worth waiting to find out if unregulated training is effective?

3

Asbestos: A comparison

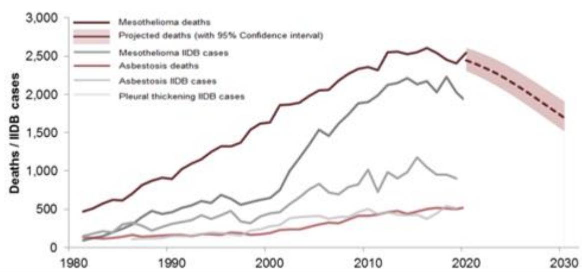
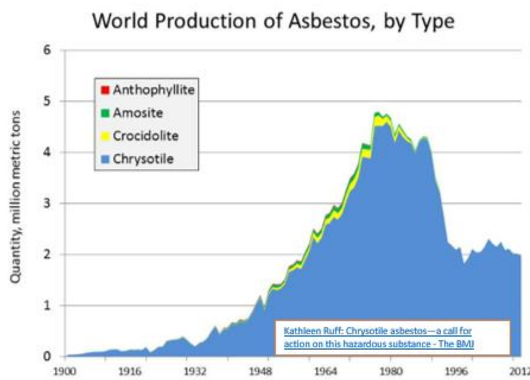


Figure 1 - Mesothelioma, asbestosis, and pleural thickening: time trends in annual deaths and Industrial Injuries Benefit Disablement (IIDB) cases*



These graphs show a 20-40 year latency between the height in production of Asbestos and illness peaks.
This number continues to rise due to the lack of awareness when Asbestos was in situ and/or being removed, taking into account latency.

4

The risk of not training at all

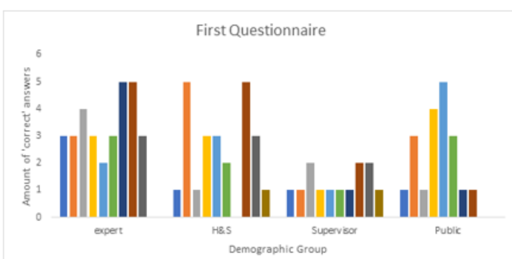
Most journal articles agree that there is often a difference between a quantifiable risk and the perception of the risk.

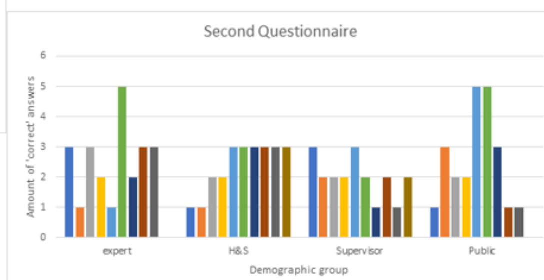
We know something is dangerous, but without direct evidence we often assume the exact level of danger.

This usually errs more to side of a situation being less dangerous than it actually is if the situation is often encountered and more dangerous when encountered less often (Yoshidaa, 2019)

5

Impact of basic training study around Beryllium risk





6

Research into training standards

- I reviewed 8 sets of training in my research
- All of which were broadly very similar.
- There were some striking differences and even some contradictions between training materials.
- No one is moderating training content.

- If there was an agreed training subcommittee consisting of inductsry experts and medical experts, these differences would be resolved prior to publishing.

7

Why create a training program

As the advances in knowledge around Beryllium risk become more frequent and widely recognized, we are in danger of leaving our workforce behind.

An authorized training program would assist organisations in keeping up to date on ensuring their workers have access to the best practice and are aware of the risks around Beryllium.

Current Beryllium knowledge is difficult to obtain and there are still many experts who hold outdated beliefs, particularly around BeLPT. A training program would allow an easily accessible conduit for the most up to date common knowledge to be distributed.

8

Beryllium Sensitization Testing—Where We Are and Where We Need to Go

Kathryn Creek

Beryllium Solutions International LLC, Lourinha, Portugal

As we learned in the early days of the Covid pandemic, the number of Covid cases appeared to be initially small, but this was only because widespread testing was not readily available. Similarly, in the EU and the UK, very limited testing for Chronic Beryllium Disease (CBD) is performed resulting in very few reported cases. France has conducted worker exposure studies showing high airborne concentrations of beryllium, yet there are no documented CBD cases because testing is not available.

From the U.S. Department of Energy's (DOE) experience, the Beryllium Lymphocyte Proliferation Test (BeLPT) is required for Beryllium Sensitization (BeS) and CBD to be diagnosed. The DOE discovered that CBD can be easily misdiagnosed, resulting in prolonged worker exposure and subsequent poorer health outcomes. Based on their worker population disease outcomes, DOE promulgated an expanded occupational health standard, "Chronic Beryllium Disease Prevention Program" which requires the use of annual BeLPT testing on all current workers potentially exposed to beryllium.

In the late 1990s, DOE addressed their problems with beryllium exposure and CBD, and the U.S. Department of Labor/Occupational Safety and Health Administration also passed expanded beryllium standards in general industry, construction and maritime in the 2017. Currently, the two biological laboratories in the U.S., National Jewish Health and Oak Ridge Associated Universities, conduct approximately 18,000 BeLPT tests per year. Further, the American Thoracic Society has stated, "the reduction of exposure alone is probably insufficient to prevent all cases of BeS and CBD, thereby providing an additional need for medical surveillance. The BeLPT is the cornerstone for both medical surveillance and the diagnosis of BeS and CBD."

In stark contrast, the EU and UK have avoided their responsibility for over 30 years. They have not developed occupational beryllium expanded standards, nor conducted studies on their worker populations using the BeLPT. They hide behind statements that the BeLPT is an unreliable test, that there are limited worker exposures to beryllium, and that they don't have any cases of CBD. They say, "we don't have a problem". How is it the EU and UK don't have a problem when the US does?

Clearly, the respective country's health organizations inside the EU and UK have no data to support their conclusions, given that they have not conducted any worker studies that use the BeLPT. The facts are that there are some countries that do not have biological laboratories (e.g., France, Turkey) that can conduct the BeLPT. For the countries that do have a lab that can conduct the BeLPT, they do not have the capability to conduct the test for even small worker populations like a facility that has less than 100 workers (e.g., UK, Germany, Spain, Italy).

Currently, there are no occupational health standards within the EU or UK that require using the BeLPT for worker testing. The concern remains unaddressed. A discussion on the situation in the EU and UK will be given with potential steps to address this concern that regulatory and health research organizations can take.

Corresponding Author:

Ms. Kathryn Creek, CIH, MS
creek@beryllium-solutions.com
Beryllium Solutions International LLC
Estrada dos Cassaqueiros, 14b
Santa Barbara
2530-732 Lourinha
PORTUGAL

bsi

Beryllium Sensitization Testing

Where we are and where we need to go

Kathryn Creek, CIH, MS
Senior Consultant
Beryllium Solutions International, LLC

bsi

"Absence of Evidence IS NOT Evidence of Absence."

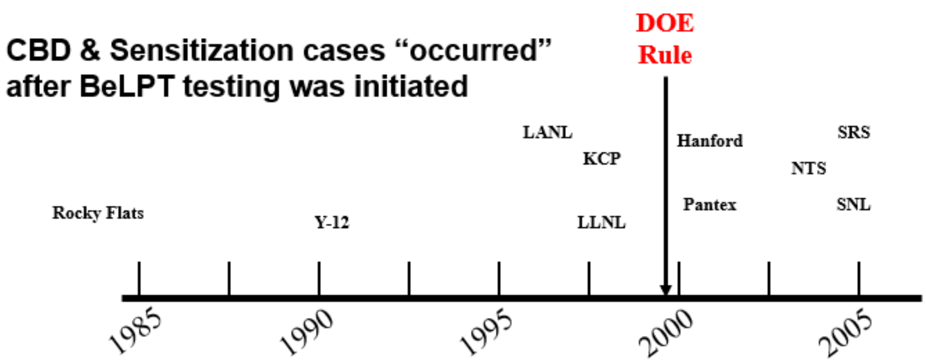
David Michaels, Epidemiologist and Public Health Professor, George Washington University

"Beryllium's Public Relations Problem: Protecting Workers When There is No Safety Exposure Level," *Public Health Reports,* vol. 123, no. 1, pp. 79-88, 2008.

Chronology of Cases in DOE

Use of BeLPT is key for diagnosing CBD

CBD & Sensitization cases "occurred" after BeLPT testing was initiated



CBD can easily be misdiagnosed as Sarcoidosis, Chronic Obstructive Pulmonary Disease, and Hypersensitivity Pneumonitis

bsi

BeLPT © 2022 Beryllium Solutions International

Page 3

DOE Study Data in 1998

The problem was discovered.
The extent of the problem was yet to be discovered.

Facility	LPT Positive	Confirmed CBD*
RFETS	180	73
Y-12	70	24

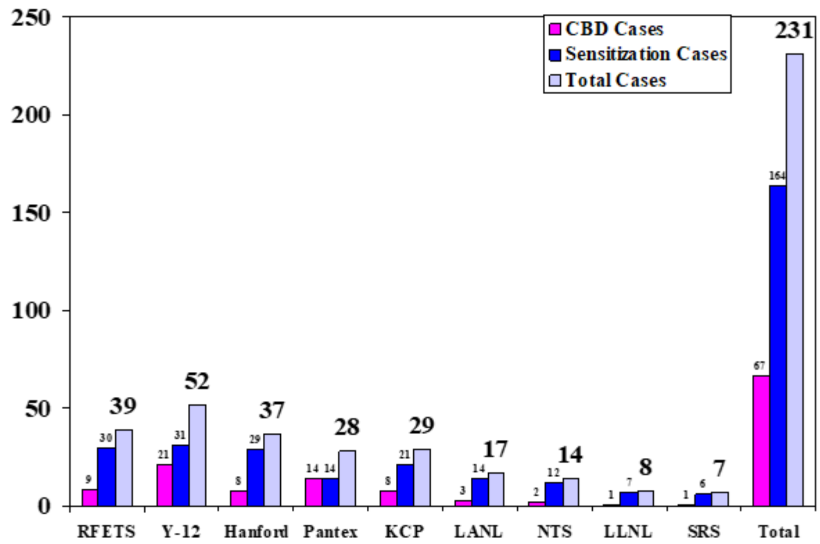
* DOE statistics include "CBD probable" and gold standard CBD cases

bsi

BeLPT © 2022 Beryllium Solutions International

Page 4

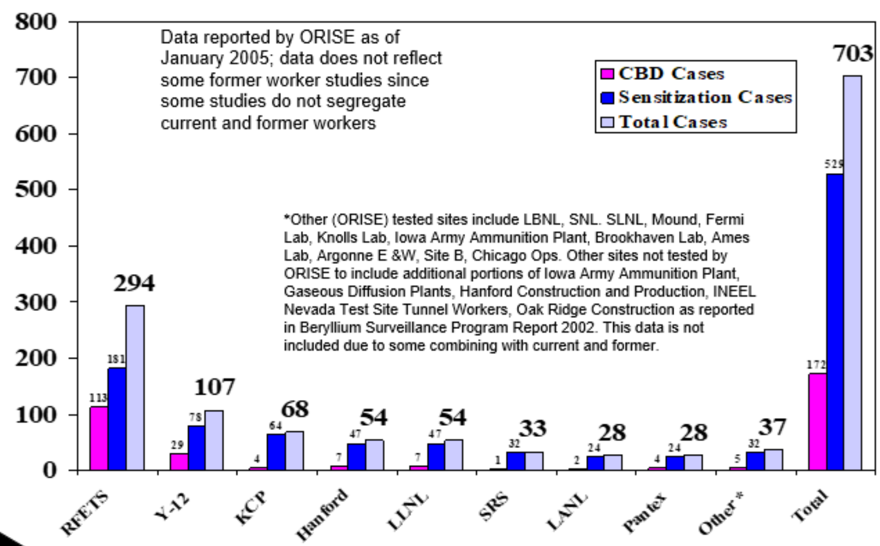
Current Worker Cases in 2005



BeLPT © 2022 Beryllium Solutions International

Page 5

Former Workers Cases in 2005



BeLPT © 2022 Beryllium Solutions International

Page 6

Initial DOE take home messages

- The BeLPT must be used to identify BeS and CBD.
- Standard IH programs are not effective.
- The past exposure limit of 2 μg/m^3 was not protective.

bsi

BeLPT © 2022 Beryllium Solutions International

Page 7

bsi

Prior to NIOSH studies, BeS and CBD rates at the facilities were unknown.

Manufacturers routinely stated that exposure from CuBe machining operations was not a risk because exposure levels were so low.

BeLPT © 2022 Beryllium Solutions International

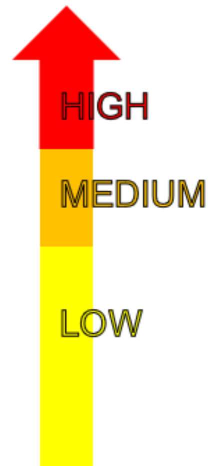
McCawley

Page 8

NIOSH Be Metal/Alloy/Oxide Processing Study

	Beryllium Particles / cc	Average Be Mass µg / m³
Fluoride Furnace	20,500	0.02
Oxide Furnace	18,500	0.25
Casting Operations	5,500	0.07
Reduction Furnace	4,800	0.06
Solution Preparation	2,200	0.06
Bulk Pickle	150	0.08
Ball Mill	100	0.07
Light Gauge Foil Room	70	0.004
Beryl ore mine	9	0.24
Ore crusher	5	0.08
4-HI Mill	3	0.004
Administration and shipping	1	0.004

CBD Risk



M.McCawley, "Ultrafine "Beryllium Number Concentration as a Possible Metric for Chronic Beryllium Disease Risk", App. Occ. & Env. Hygiene, 2001

bsi

BeLPT © 2022 Beryllium Solutions International

Page 9

CuBe Study CBD Rate vs Exposure Levels

Job Title	Sensitized (%)	CBD (%)	Median Exposure (µg/m³)	95th Percentile [1] (UTL) (µg/m3)
Point and Chamfer	21	21	0.03	0.2
Wire annealing/pickling	13	10	0.12	2.32
Wire drawing	14	10	0.06	0.32
Rod and wire packing	10	9	0.03	0.11
Straightening	8	8	0.03	0.17
Strip Annealing	11	8	0.02	0.21
Strip rolling	11	7	0.02	0.09
Administration (plant)	10	7	0.02	0.05
Slitting	8	6	0.02	0.16
Strip pickling	7	6	0.03	0.14
Inspection	6	6	0.02	0.05
Maintenance mechanics	6	6	0.02	0.07
Metallurgy lab	4	4	0.06	----
Shipping Receiving	4	2	0.02	0.04
Die grinding	0	0	0.02	----
Wastewater treatment	0	0	0.11	----
Administration (office)	0	0	0.01	0.09

C. Schuler, et, al,, "Process-related risk of beryllium sensitization and disease in a copper-beryllium alloy facility", Am. J. Ind Med, 2005, 47:195-205

bsi

BeLPT © 2022 Beryllium Solutions International

Page 10

Take home messages from NIOSH studies

- Skin exposure is the primary exposure route for establishing the initial sensitization response.
- Average mass-based airborne beryllium particulate exposures that were well below the now current exposure limit of 0.2 µg/m^3 resulted in sensitization and disease including copper beryllium machining operations.
- Particle-based metric may be a better indicator of risk.
- Reaffirmed that the use of the BeLPT is necessary for medical surveillance. If the BeLPT is not used, sensitization and CBD will most likely not be identified.

bsi

Page 11

Key Elements of a Comprehensive Program Start with Expanded Standards

US DOL/OSHA

(a) Scope and Application
(b) Definitions
(c) Permissible Exposure Limits (PELs)
(d) Exposure Assessment
(e) Beryllium Work Areas and Regulated Areas (General Industry); Regulated Areas (Maritime); and Competent Person (Construction)
(f) Methods of Compliance
(g) Respiratory Protection
(h) Personal Protective Clothing and Equipment
(i) Hygiene Areas and Practices
(j) Housekeeping
(k) Medical Surveillance
(l) Medical Removal
(m) Communication of Hazards
(n) Recordkeeping

US DOE

Subpart A—General Provisions

Sec.
850.1 Scope.
850.2 Applicability.
850.3 Definitions.
850.4 Enforcement.
850.5 Dispute resolution.

Subpart B—Administrative Requirements

850.10 Development and approval of the CBDPP.
850.11 General CBDPP requirements.
850.12 Implementation.
850.13 Compliance.

Subpart C—Specific Program Requirements

850.20 Baseline beryllium inventory.
850.21 Hazard assessment.
850.22 Permissible exposure limit.
850.23 Action level.
850.24 Exposure monitoring.
850.25 Exposure reduction and minimization.
850.26 Regulated areas.
850.27 Hygiene facilities and practices.
850.28 Respiratory protection.
850.29 Protective clothing and equipment.
850.30 Housekeeping.
850.31 Release criteria.
850.32 Waste disposal.
850.33 Beryllium emergencies.
850.34 Medical surveillance.
850.35 Medical removal.
850.36 Medical consent.
850.37 Training and counseling.
850.38 Warning signs and labels.
850.39 Recordkeeping and use of information.
850.40 Performance feedback.

US regulations require use of BeLPT

bsi

Page 12

European Commission Directive on Carcinogens and Mutagens

- June 2019 directive established the OEL of 0.6 μg/m^3 inhalable fraction 8-hour TWA for 5 years then lowering to 0.2 μg/m^3.
- Skin notation "The substance can cause sensitization of the skin and the respiratory tract."

20.6.2019 | EN | Official Journal of the European Union | L 164/23

DIRECTIVES

DIRECTIVE (EU) 2019/983 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 5 June 2019

amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work

EU directive does not require a program and does not mention BeLPT

BeLPT © 2022 Beryllium Solutions International

Page 13

Identifying CBD in Early Stages

Routine diagnostic tests

such as low dose computed tomography scan and pulmonary function tests

will NOT detect CBD

except for very advanced cases.

BeLPT © 2022 Beryllium Solutions International

Page 14

BeLPT Approved by the American Thoracic Society

"…the reduction of exposure alone is probably insufficient to prevent all cases of BeS and CBD, thereby providing an additional need for medical surveillance"

" The BeLPT is the cornerstone for both medical surveillance and the diagnosis of BeS and CBD."

An Official American Thoracic Society Statement: Diagnosis and Management of Beryllium Sensitivity and Chronic Beryllium Disease

John R. Balmes, Jerrold L. Abraham, Raed A. Dweik, Elizabeth Fireman, Andrew P. Fontenot, Lisa A. Maier, Joachim Muller-Quernheim, Gaston Ostiguy, Lewis D. Pepper, Cesare Saltini, Christine R. Schuler, Tim K. Takaro, and Paul F. Wambach; on behalf of the ATS *Ad Hoc* Committee on Beryllium Sensitivity and Chronic Beryllium Disease

This official statement of the American Thoracic Society (ATS) was approved by the ATS Board of Directors, June 2014

bsi

BeLPT © 2022 Beryllium Solutions International

Page 15

Comparison of BeLPT to Standard Medical Screening Tests

Disease	Test	Sensitivity	Specificity	Follow-up test
Breast Cancer	Mammography	75-88%	83-99%	Biopsy
Colon Cancer	Fecal Occult Blood	26-92%	90-99%	Colonoscopy
Neural Tube Defects	AFP	56-91%	5-10%	Amniocentesis
Prostate Cancer	PSA	29-80%	75%	Biopsy
BeS/CBD	BeLPT	69-91%	96-91%	Bronchoalveolar lavage/biopsy

bsi

BeLPT © 2022 Beryllium Solutions International

Page 16

BeLPT in the US

- Oak Ridge Associated University (DOE workers) can conduct 10,000 to 12,000 BeLPT tests annually
- National Jewish Health (private sector) can conduct 8,000 BeLPT tests annually

US labs can conduct up to
20,000
BeLPT tests a year

bsi

BeLPT © 2022 Beryllium Solutions International

Page 17

Biomarker limitations

- Beryllium Urinalysis—a dose metric
- Exhaled Breath
  - Beryllium—a dose metric
  - TNFα—a nonspecific indicator of inflammation

The biomarker limits of concern for beryllium are not well established. They are NOT medical surveillance screening tests

A high level of beryllium in urine would not result in a worker being referred for a medical evaluation that included a bronchoalveolar lavage or lung biopsy.

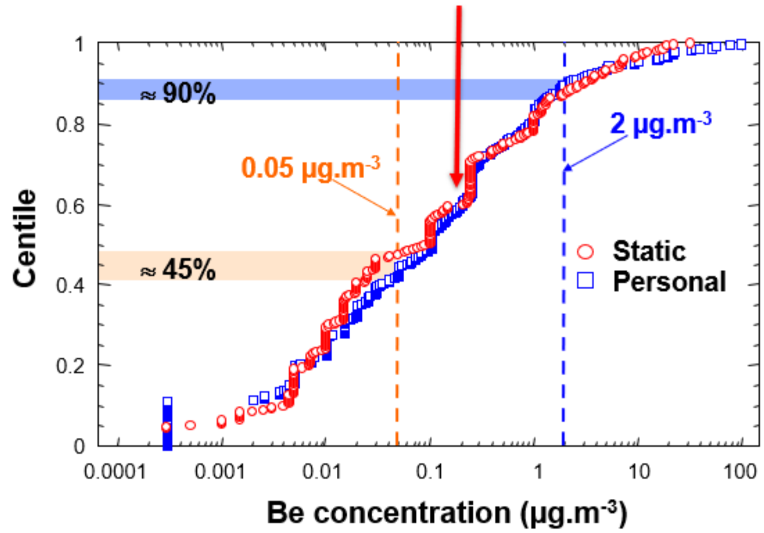
bsi

BeLPT © 2022 Beryllium Solutions International

Page 18

Workplace Studies in France by INRS

~60% of exposures were above 0.2 μg/m³



bsi

BeLPT © 2022 Beryllium Solutions International

Page 19

Beryllium and Europe

- It is very likely that France could have many cases of CBD based on exposure studies.
- Europe has has conducted small scale workplace studies using the BeLPT on dental technicians (Italy and Israel).
- France does not have BeLPT capabilities.
- UK cannot conduct 80 BeLPT per year.
- Germany conducts small numbers of BeLPT on workers who are very ill but not for routine testing.
- Spain conducts the MELISA test for only a few worksites who are working on Fusion energy projects.

The CBD rate in Europe is unknown as was the condition for the US in the early 1990's.

bsi

BeLPT © 2022 Beryllium Solutions International

Page 20

Let's compare

- COVID cases where underreported due to limited availability of testing in the early days of the pandemic
- CBD cases are underreported due to limited availability of testing

How would you like to have a disease that is not diagnosed?

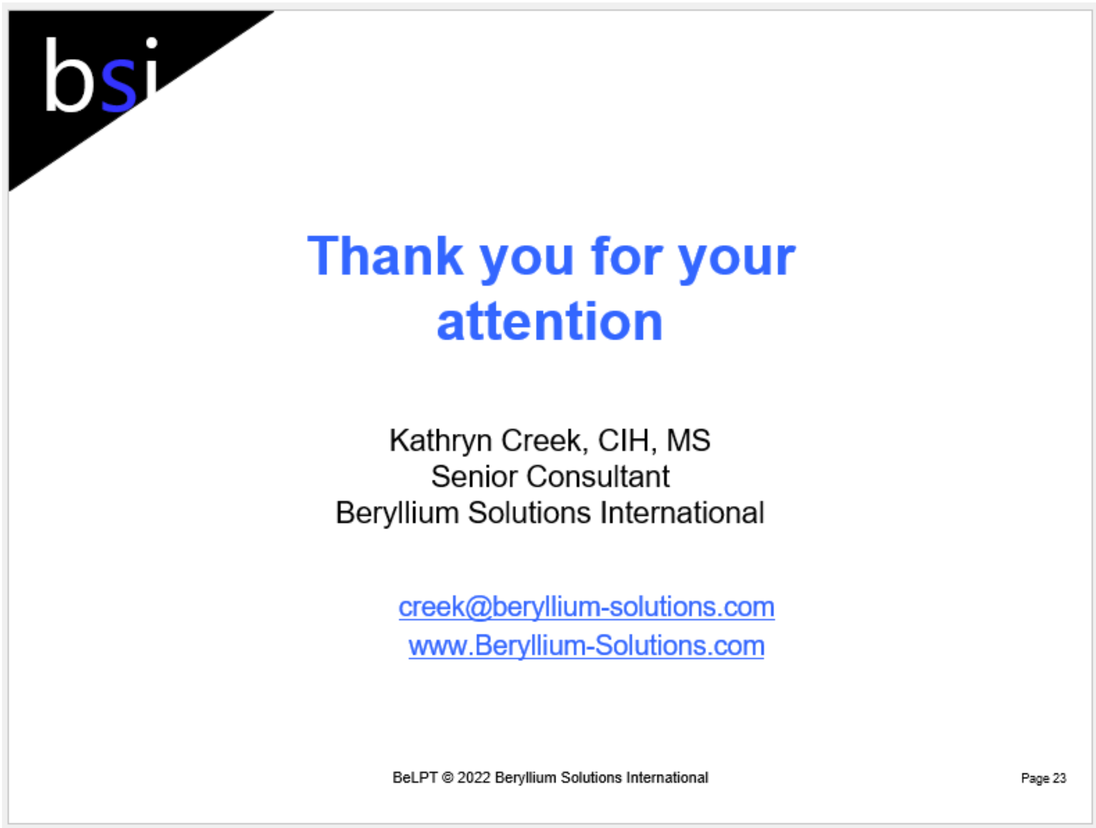
bsi

A recommended path forward

- Government agencies should
  - Establish large scale BeLPT testing capabilities
  - Conduct worker studies using the BeLPT
  - Develop and pass expanded health standards for beryllium risk which include the requirement for BeLPT testing.

Without data you are blind to the concern.

bsi


bsi
Thank you for your attention
Kathryn Creek, CIH, MS
Senior Consultant
Beryllium Solutions International
creek@beryllium-solutions.com
www.Beryllium-Solutions.com
BeLPT © 2022 Beryllium Solutions International
Page 23

Poster Session: Principles of Facility Design

Beryllium Facility Design: A Step Above Standard Industrial Controls

K. Creek (Beryllium Solutions International, Portugal)

Beryllium Facility Design: A Step Above Standard Industrial Controls

Kathryn Creek

Beryllium Solutions International LLC, Lourinha, Portugal

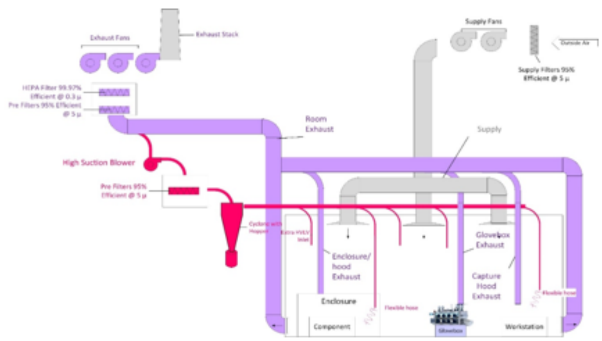
One of the key principles in any beryllium management system or worker protection program is the idea of preventing migration and keeping beryllium particulate at its source. This poster presentation describes:

- Beryllium controls are a step above the norm
- Basic logic for facility design
- Zone pressure controls
- Basic facility layout
- Need for a robust exhaust system
- Design features

Corresponding Author:
Ms. Kathryn Creek, CIH, MS
creek@beryllium-solutions.com
Beryllium Solutions International LLC
Estrada dos Cassaqueiros, 14b
Santa Barbara
2530-732 Lourinha
PORTUGAL

Beryllium Facility Design

A step above standard industrial controls



Kathryn Creek, CIH, MS
Senior Consultant
Beryllium Solutions International

 Page 1

Beryllium controls are a step above

- Standard industrial controls are insufficient for controlling the risk of beryllium exposure to energetic operations.
- Clean room type technology with high quality components is a good approach.

 Page 2

Basic Logic for Facility Design

- Hospital Operating Room Level of Cleanliness
  - Class 10,000 clean room
  - Once-through filtered supply air
  - 10-20 air changes per hour
- Clean-room design considerations such as recessed lighting

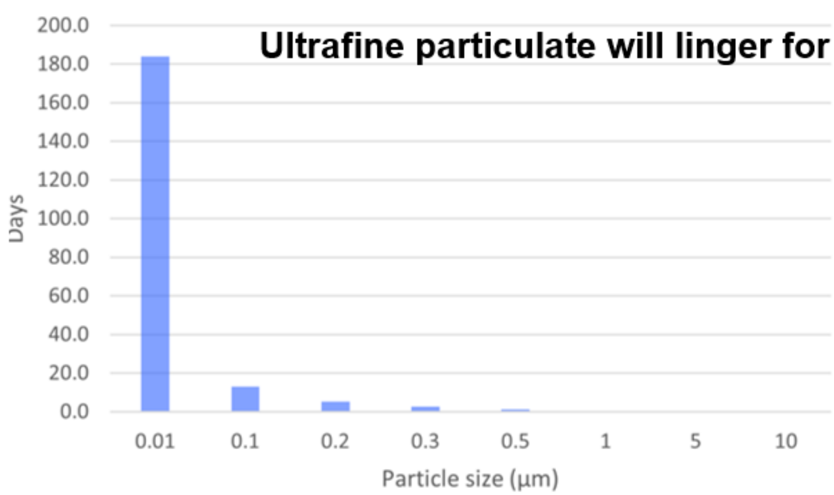
Beryllium Facility Design © Beryllium Solutions International 2022

Page 3

Settling Time of Particulate by Size

Days to Settle 1 meter

Ultrafine particulate will linger for days



Beryllium Facility Design © Beryllium Solutions International 2022

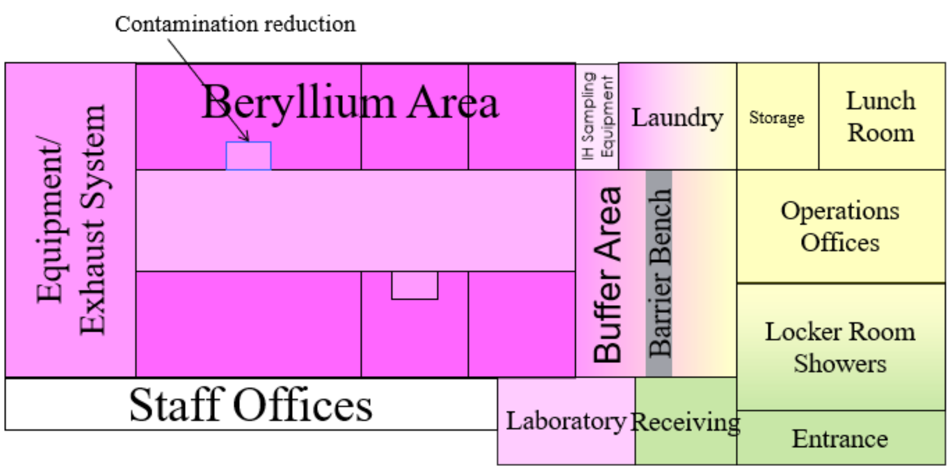
Page 4

Zone Pressure Control

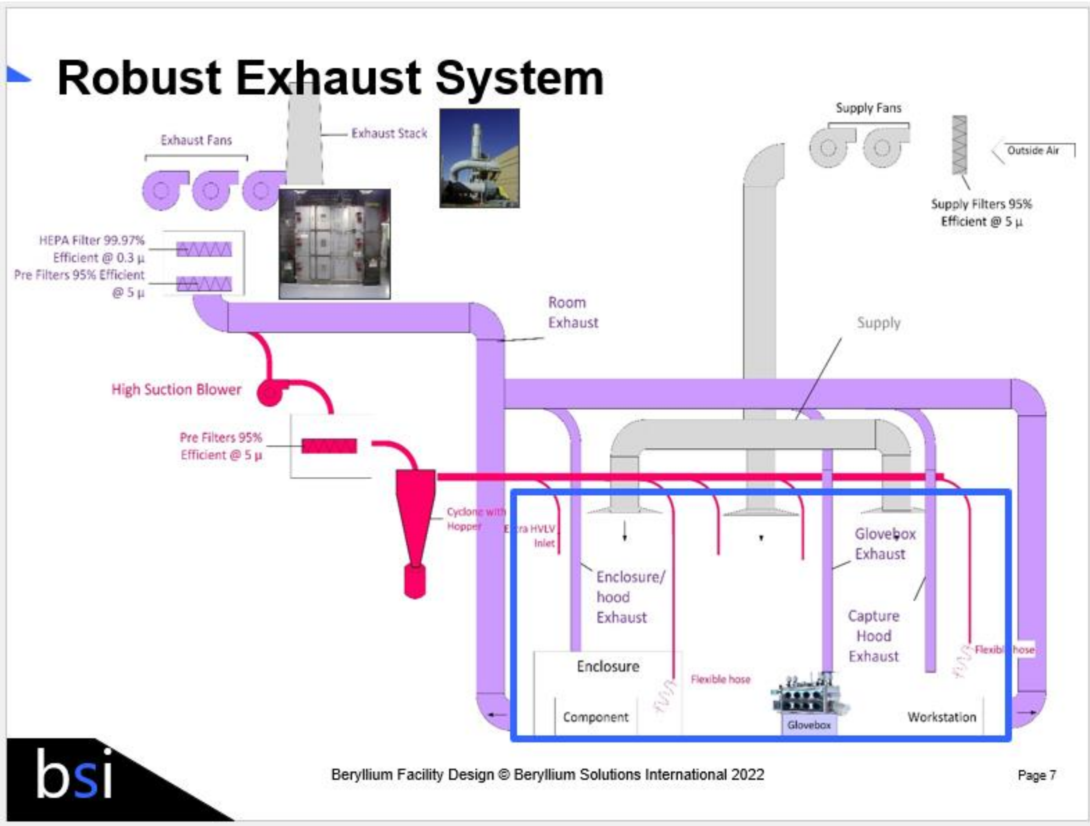
- Relatively leak tight building
- Air leak paths into beryllium areas should be eliminated to be able to maintain pressure cascades.
  - ~ -20 to 40 Pa per zone
- Seal all electrical system conduits (control system wiring, fire protection, communications wiring) that penetrate the beryllium areas.

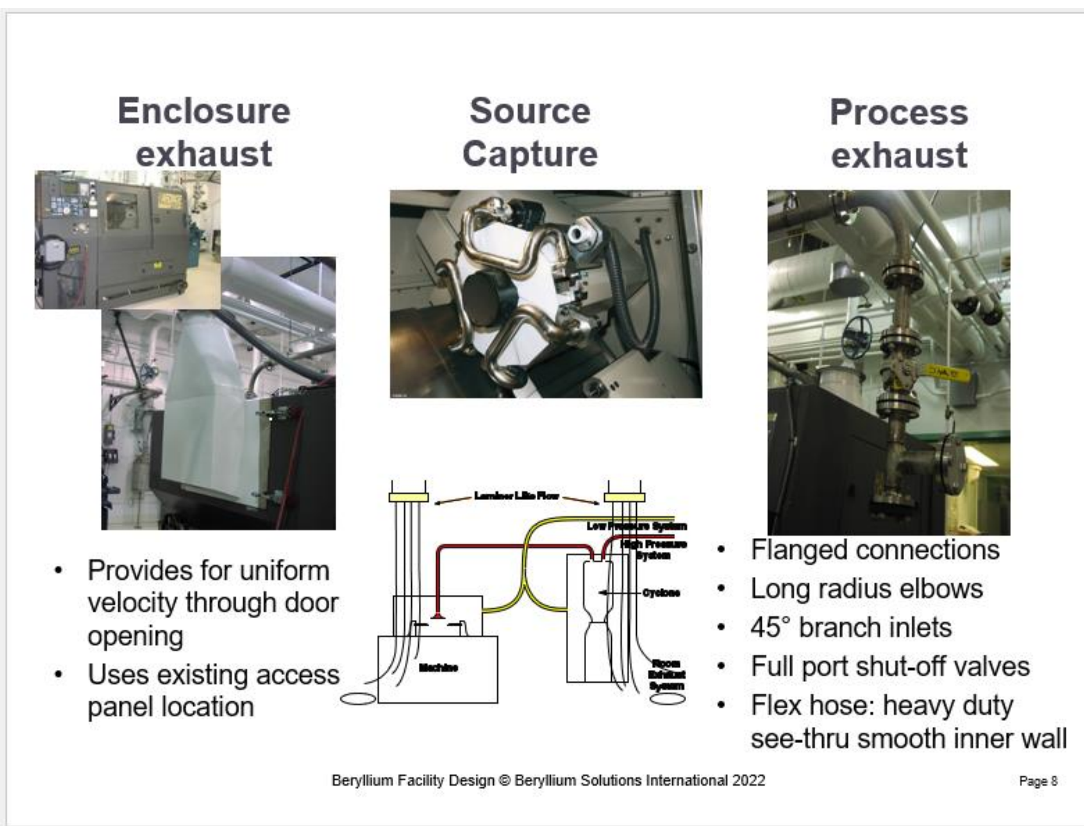
Beryllium Facility Design © Beryllium Solutions International 2022 Page 5

Basic Facility Layout



Beryllium Facility Design © Beryllium Solutions International 2022 Page 6


Robust Exhaust System
Exhaust Fans
Exhaust Stack
Supply Fans
Outside Air
Supply Filters 95% Efficient @ 5 µ
HEPA Filter 99.97% Efficient @ 0.3 µ
Pre Filters 95% Efficient @ 5 µ
Room Exhaust
Supply
High Suction Blower
Pre Filters 95% Efficient @ 5 µ
Cyclone with Hopper
Glovebox Exhaust
Enclosure/ hood Exhaust
Capture Hood Exhaust
Enclosure
Flexible hose
Component
Glovebox
Workstation
bsi
Beryllium Facility Design © Beryllium Solutions International 2022
Page 7

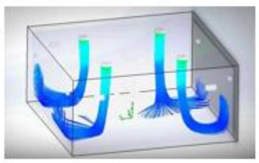

Enclosure exhaust
Source Capture
Process exhaust
Laminar Like Flow
Low Pressure System
High Pressure System
Cyclone
Machine
Room Exhaust System
• Provides for uniform velocity through door opening
• Uses existing access panel location
• Flanged connections
• Long radius elbows
• 45° branch inlets
• Full port shut-off valves
• Flex hose: heavy duty see-thru smooth inner wall
Beryllium Facility Design © Beryllium Solutions International 2022
Page 8

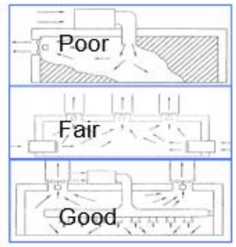
Design Features

Limit Personnel

Quality and Durable Equipment

Laminar Flow





Good mixing

Smooth Surfaces

Beryllium Facility Design © Beryllium Solutions International 2022

Page 9

bsi

Questions?

Kathryn Creek, CIH, MS
Senior Consultant
Beryllium Solutions International

creek@beryllium-solutions.com
www.Beryllium-Solutions.com

Beryllium Facility Design © Beryllium Solutions International 2022

Page 10

Appendices

History of the BeYOND Workshop Series

History of the BeYOND Workshop Series [1]

In the technical field of beryllium, there are currently two workshops that take place in alternating years, the IEA International Workshop on Beryllium Technology (BeWS) in the odd-numbered years and the BeYOND Industrial Forum in the even-numbered ones. The name BeYOND is an acronym which stands for "Beryllium Opportunities and New Developments".

After trying various timing with respect to other conferences, it evolved that the BeYOND workshops would take place on alternate years from the BeWS, and normally held in conjunction with the SOFT Conference (Symposium on Fusion Technology), which is always held in Europe. Meetings to date:

- BeYOND-1: Karlsruhe, Germany, 2009
- BeYOND-2: Porto, Portugal, 2010
- BeYOND-3: Karlsruhe, Germany, 2011
- BeYOND-4: Karlsruhe, Germany, 2012
- BeYOND-5: Barcelona, Spain, 2013
- BeYOND-6: San Sebastian, Spain, 2014
- BeYOND-7: Berlin, Germany, 2016
- BeYOND-8: Karlsruhe, Germany, 2018
- BeYOND-9: Karlsruhe, Germany, 2022

BeYOND was created with the idea of more emphasis on strengthening the connection between the beryllium research community and the beryllium industry, an aspect not always satisfied by the BeWS. Since BeYOND-5 in 2013, the workshop has generally also placed more emphasis on beryllium health and safety than typically found in the BeWS.

Reference:

[1] Goraieb, A. and Dorn, C. "Overview of the BeYOND Workshop Series". *Proceedings of the 14th International Workshop on Beryllium Technology (BeWS-14)*, held in Long Beach, California, 2019, pp. 441-443. Lemmens Medien GmbH, 2021.

BeYOND-IX Participants List

Family Name	First Name	Organization	Country	Status
Ashley	Kevin	Ashley Analytical Associates LLC	USA	In person
Chakin	Vladimir	KIT	Germany	In person
Cilingir	Engin	GVT – Goraiebversuchstechnik GmbH	Germany	In person
Creek	Kathryn	Beryllium Solutions International LLC	Portugal	In person
Dorn	Christopher	UK Atomic Energy Authority Be4FUSION LLC	UK USA	In person
Frants	Yevgeniy	Ulba Metallurgical Plant	Kazakhstan	In person
Frehn	Andreas	Materion Brush Germany GmbH	Germany	In person
Fretz	Benjamin	GVT – Goraiebversuchstechnik GmbH	Germany	In person
Freund	Heike	Marvel Fusion GmbH	Germany	In person
Gaisin	Ramil	KIT	Germany	In person
Goraieb	Aniceto	KBHF	Germany	In person
Gorr	Bronislava	KIT	Germany	In person
Hesch	Klaus	KIT	Germany	In person
Huang	Haibo	General Atomics Corp.	USA	In person
Ionescu-Bujor	Mihaela	KIT	Germany	In person
Jamieson	Valerie	UK Atomic Energy Authority	UK	Online
Jilek	Richard	CVR – Research Centre Rez	Czech Republic	In person
Kearney	Maddy	UK Atomic Energy Authority	UK	In person
Kenzhina	Inesh	Al-Farabi Kazakh National University	Kazakhstan	In person
Kim	Jae-Hwan	QST	Japan	In person
Kizane	Gunta	University of Latvia	Latvia	In person
Klimenkov	Michael	KIT	Germany	In person
Knudson	Theodore	Materion Brush Inc.	USA	In person
Kovalskiy	Sergey	KIT	Germany	In person
Kuksenko	Viacheslav	UK Atomic Energy Authority	UK	In person
Lemmens	Markus	Lemmens Medien GmbH	Germany	In person
Maehlmann	Peter	TROPAG GmbH	Germany	In person
Maier	Lisa	National Jewish Health	USA	Online
McCawley	Michael	West Virginia University	USA	Online
McKeon	Eilish	UK Atomic Energy Authority	UK	In person
Moeslang	Anton	KIT (Retired)	Germany	In person
Nebe	Dan	Marvel Fusion GmbH	Germany	In person
Pearson	Richard	Kyoto Fusioneering Ltd.	UK Japan	In person
Radloff	Dirk	KIT	Germany	In person
Reimann	Joerg	KIT (Retired)	Germany	In person
Renier	Angelique	NGK Berylco	France	In person

Family Name	First Name	Organization	Country	Status
Roth-Goraieb	Doris	GVT – Goraiebversuchstechnik GmbH	Germany	In person
Rubel	Marek	KTH - Royal Institute of Technology	Sweden	In person
Ruskayova	Petra	ELI Beamlines	Czech Republic	In person
Scherer	Theo	KIT	Germany	In person
Sioui	Daniel	General Atomics Corp.	USA	In person
Smith	Keith	Materion Brush Inc.	USA	In person
Spaeh	Peter	KIT	Germany	In person
Toupal	Lukas	CVR – Research Centre Rez	Czech Republic	In person
Udartsev	Sergey	Ulba Metallurgical Plant	Kazakhstan	In person
Vandermark	Lee	General Dynamics	USA	In person
Verdon	Jon	UK Atomic Energy Authority	UK	In person
Vitins	Aigars	University of Latvia	Latvia	In person
Vladimirov	Pavel	KIT	Germany	In person
Walker	Beth	Safer Environment Ltd.	UK	Online
Whalen	Lance	General Dynamics	USA	In person
Zenkov	Konstantin	Ulba Metallurgical Plant	Kazakhstan	In person
Zhou	Guangming	KIT	Germany	In person

Workshop & Venue Photos

This year's BeYOND Workshop was held as a joint event together with the Beryllium Workshop (BeWS-15), which preceded it. On the evening of 15 September, after the two days of BeWS-15 sessions, there was a joint workshop social event, which included a tour of a local brewery followed by a beer tasting and buffet dinner. There was also a short awards ceremony held just after the dinner.

Left: The special logo created for the joint event: BeWS-15 and BeYOND-IX. The timing of the Workshop Dinner ended up making it the first real activity for BeYOND-IX. Right: View of the historic Hoepfner Brewery buildings taken during the tour (Photo Credit: E. McKeon of UKAEA).

Prior to the start of the Workshop Dinner, participants had the option to join a tour of the historic brewery followed by a beer tasting of the Hoepfner products. Above are images from the tour showing some of the original old equipment on the left, and beer in the brewing process on the right (Photo Credits: E. McKeon of UKAEA).


Left: Workshop participants gather in the dinner venue at the brewery after the conclusion of the tour. Right: The beer tasting took place at the same tables where the dinner would later be served.

As dinner was drawing to a close, there was a short awards ceremony at which recipients from both the Beryllium Workshop and BeYOND were recognized. The award for the BeWS had been established several years ago, but this year marked the first time for a new, regular recognition to be given at BeYOND, which is now the Glen Longhurst Memorial Award, named in honor of Dr. Glen Longhurst, one of the founders of the Beryllium Workshop series and a long-time supporter of BeYOND and beryllium-related research for the development of fusion energy.


Left: The awards ceremony led by BeYOND-IX Chair Aniceto Goraieb and BeWS-15 Chair Pavel Vladimirov of KIT. Right: BeYOND-IX Chair Aniceto Goraieb on the left and Chris Dorn of UKAEA and Be4FUSION on the right. Dorn was the recipient of the first Glen Longhurst Memorial Award for achievement in beryllium research for fusion over a 35-year career in the field.

The following morning began with a tour of the Karlsruhe Beryllium Handling Facility (KBHF), which is located on the KIT North Campus, not far from where the BeYOND-IX presentation sessions would be taking place.

Left: Participants gather for the KBHF laboratory tour, which was a chance to see all the facilities where research work is ongoing for beryllium neutron-multiplier materials and lithium-ceramic breeder material. Right: Aniceto Goraieb, founder and Managing Director of KBHF explains some of the lab operations to the participants (Photo Credits: K. Creek of Beryllium Solutions International).

After the KBHF tour, the BeYOND-IX workshop presentation sessions were held in the Aula/ Seminar Room at KIT's FTU (Fortbildungszentrum für Technik und Umwelt in German, Training Center for Technology and Environment in English) facility, which is located just outside the gate to the KIT North Campus, the main entrance to which is shown in the photo below.

Exterior view of the entrance to the FTU where BeYOND-IX was held. Photo Credit and Image Copyright to the Karlsruhe Institute of Technology (KIT), URL: https://www.fortbildung.kit.edu/.

This year's BeYOND was set up as a hybrid workshop, with both in-person and online attendees and presenters. This format ensured the fullest range of available material on trending subjects in fusion.

Left: Dr. Markus Lemmens of Lemmens Media and a KBHF shareholder, presented jointly with Aniceto Goraieb of KBHF to explain the goals of their program "Fusion for Future." Right: Dr. Kevin Ashley of Ashley Analytical Associates LLC (Arizona, USA) presented on analytical methods using fluorescence to resolve beryllium samples in the laboratory.

Dr. Lisa Maier of National Jewish Health (Colorado, USA) is shown here online, displayed on the big screen to introduce her talk on genetic research related to beryllium health effects to the in-person participants at BeYOND-IX.