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TLK portfolio flyer

Tritium Laboratory Karlsruhe

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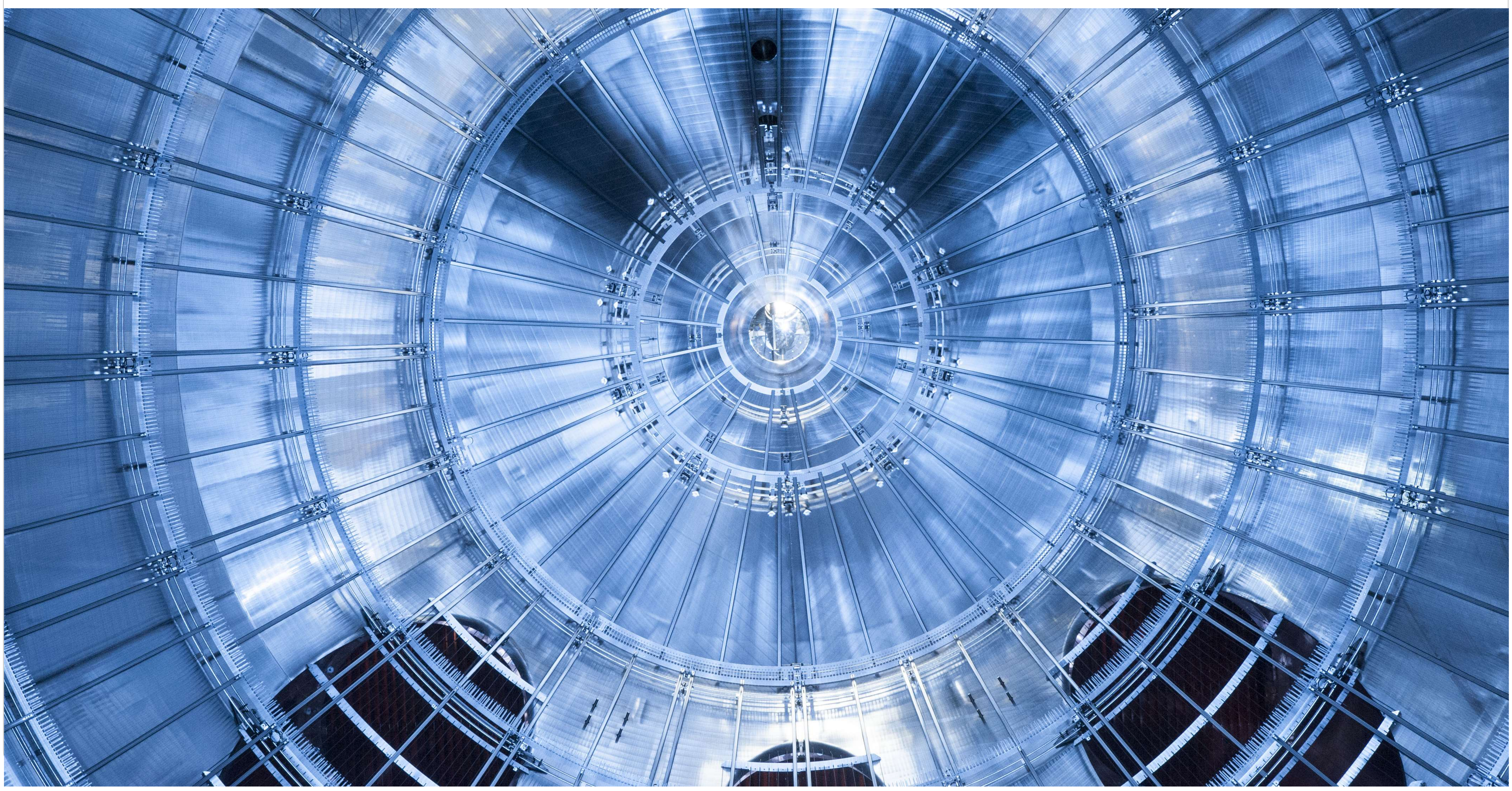
tritium research for astroparticle physics & fusion



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Institute for Astroparticle Physics (IAP
Tritium Laboratory Karlsruhe (TLK)

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Germany

https://www.iap.kit.edu/tlk/

We are open for scientific and industrial cooperations!

Possible opportunities

- tritium test of components / systems with high activities (10^{16} Bq)
- qualification of materials or analytical systems
- performance studies of equipment at operational tritium loops
- analytical service (sample calorimetry, gas-phase and surface composition, …)
- advisory for tritium technology, best practice, safety frameworks
- tritium training
- joint BMBF-call applications or “paid-for-work”

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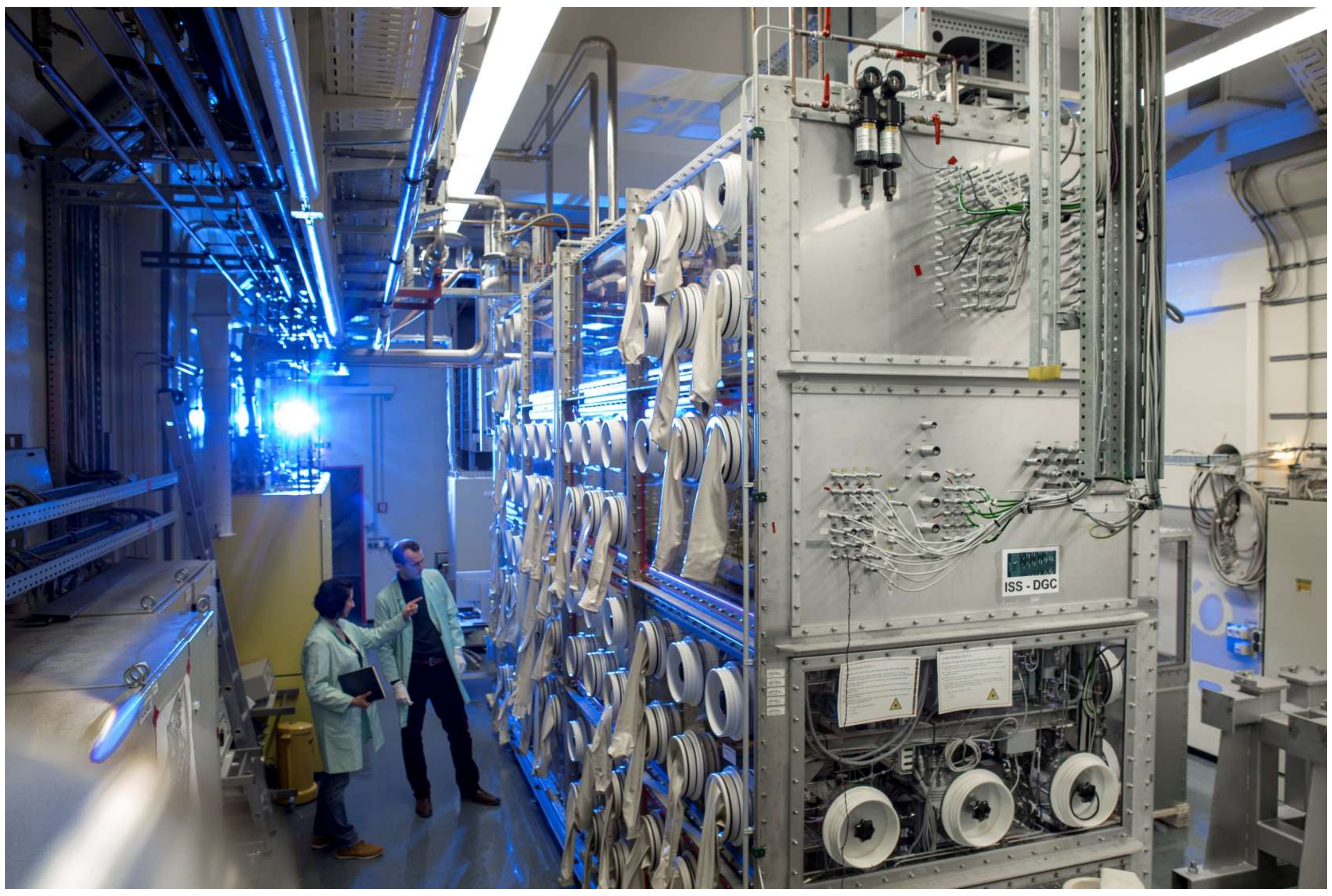
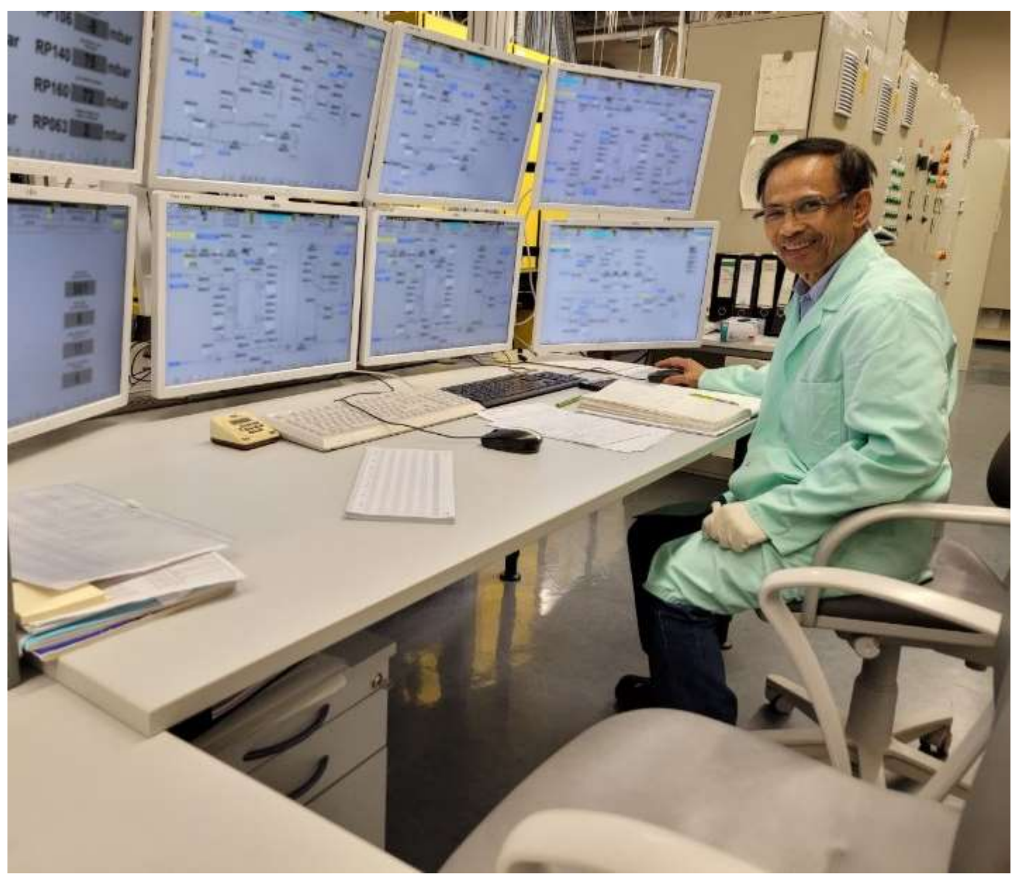
Tritium Laboratory Karlsruhe (TLK)

The Tritium Laboratory Karlsruhe was founded in the early 1990s as a technical laboratory. Today, the TLK has a handling licence for 40 g of tritium and a current inventory of around 30 g. With this and its extensive infrastructure systems and experimental facilities, the TLK is unique worldwide and can only be realised on this scale in Germany within the Helmholtz Association. The founding task of the TLK was to develop the deuterium-tritium fuel cycle for nuclear fusion. The R&D results are used in the ITER inner fuel cycle for which the first integrated design was provided by TLK. The once experimental systems now form the backbone of the closed tritium cycle at TLK and enable many experiments with high-purity tritium.

With an area of 1600 m² and more than 20 individual glove-boxes, a large number of experiments are run in parallel, set up, and dismantled again. This is essential in a rapidly developing environment such as research with and on tritium. The Karlsruhe Tritium Neutrino Experiment (KATRIN) has achieved worldwide visibility through its recent successes in direct neutrino mass measurement. It has been in operation at the TLK since 2018 and provides the world's leading and recognised results on the upper limit of neutrino mass. This is mainly due to the gaseous windowless tritium source developed at TLK in combination with the TLK tritium infrastructure. Until June 2024, more than 1000 days of tritium circulation with a total throughput of 31 kg of tritium (98.5% purity) were achieved, which no other laboratory in the world can match.





In addition to the work for KATRIN and on the fuel cycle for fusion, TLK conducts research in the R&D fields of astroparticle physics with tritium and fundamental properties of tritiated molecules. Furthermore, the TLK develops techniques and components to master the demanding challenges in the handling and processing of tritium on an industrial scale. TLK is leading the development and application of tritium analytics embedded in these processes.

This puts the TLK in an excellent position to meet future challenges in fusion, especially tritium extraction from breeding blankets, tritium analysis and tritium accountancy.

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Fuel cycle for fusion power plants

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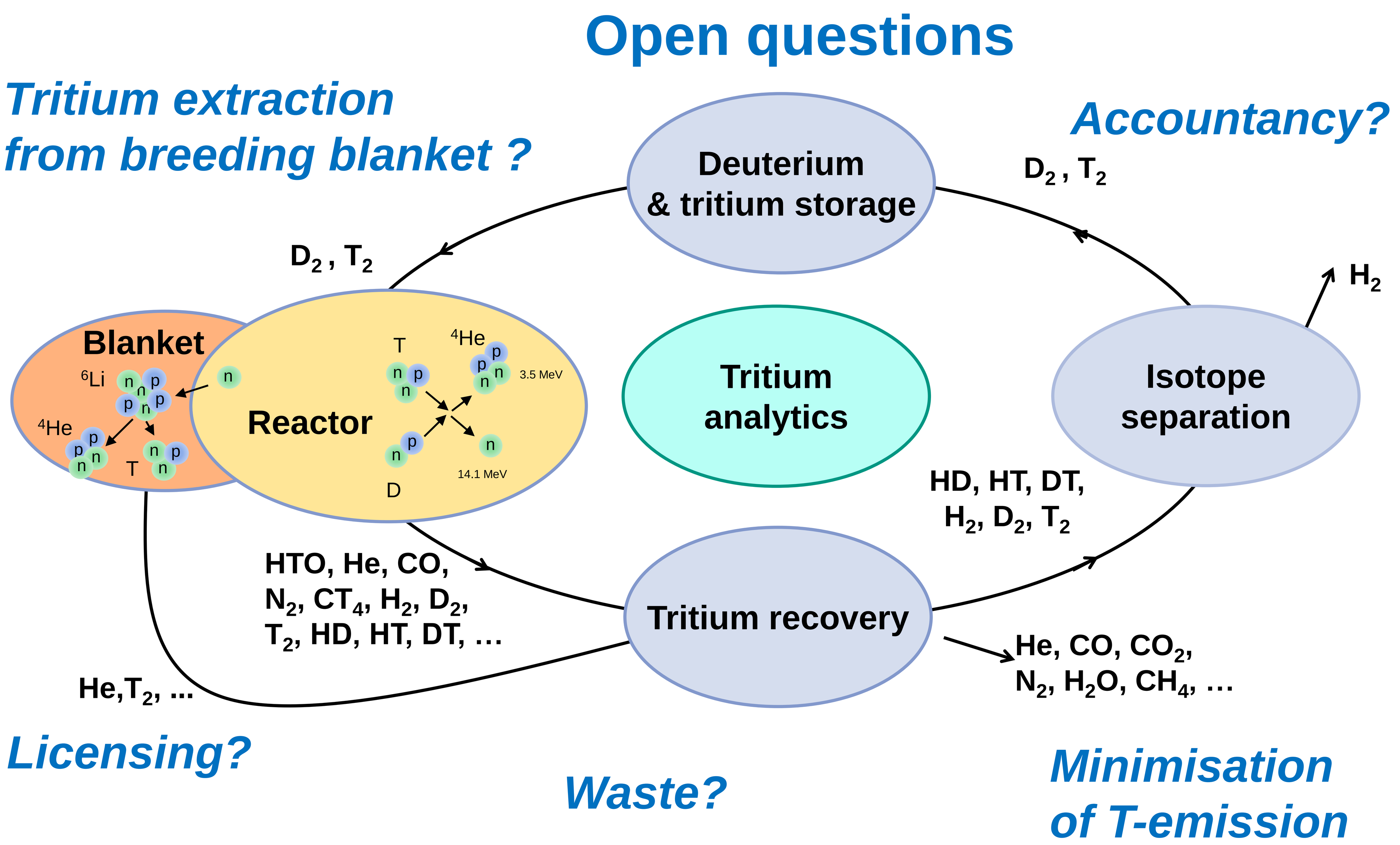
What is the TLK und who are we?

- **State-of-the-art laboratory** with 30 y experience
- Closed tritium cycle
- Licence for **40 g** T_2
- **Prioritized infrastructure** of KIT
- Two missions: “**neutrino mass**” and “**fuel cycle**”
- ~55 persons „on board" (incl. 8 PhDs, ~10 undergrad.)
- **Talented, motivated and diverse** team composed of young as well as experienced researchers, engineers and technicians
- **Highly skilled labour** by continuous training and assignment of demanding and rewarding task

Tritium R&D: from **fundamentals** up to **processes on technical scale** at a single lab;
Collaboration with international partners from industry for implementations

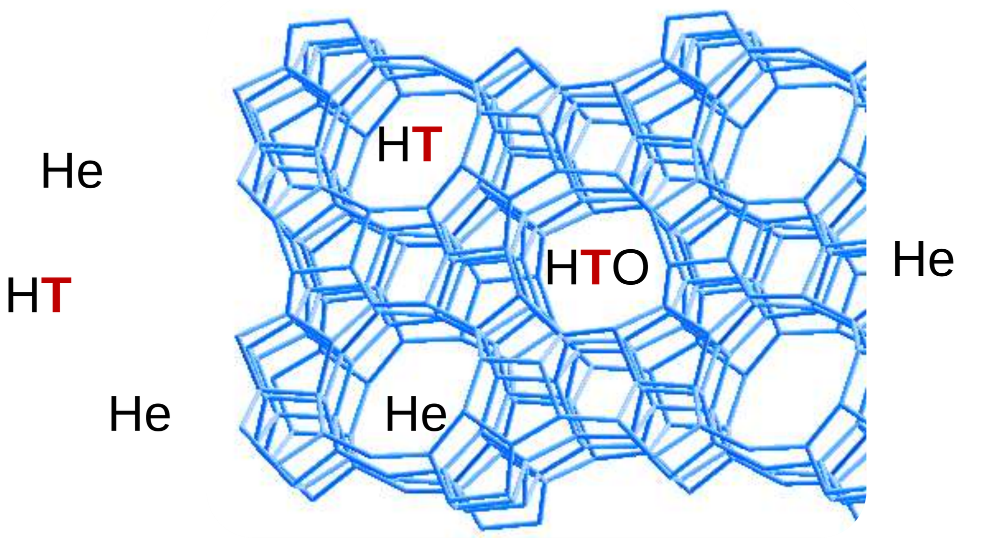
Development of safe and efficient fuel cycle for fusion reactors



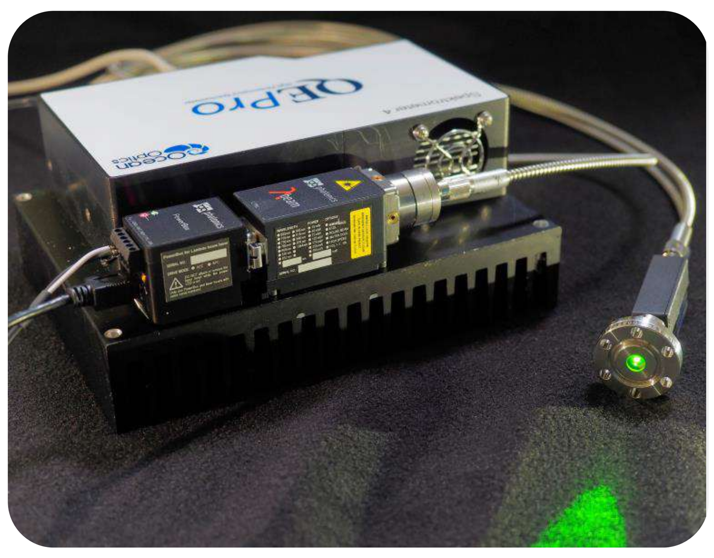
Answering of questions requires significant tritium amounts

Current key questions for ITER, DEMO, ... addressed at TLK

Tritium extraction from blanket purge gas



Developement of tritium analytics for ITER



Testing of novel cryogenic separation column in 1:1 scale

TLK is **main actor** in **worldwide** tritium research – located in Germany, Europe.
→ **We are ready, able and motivated** for the transition from **fundamental research** towards **commercial fusion applications**

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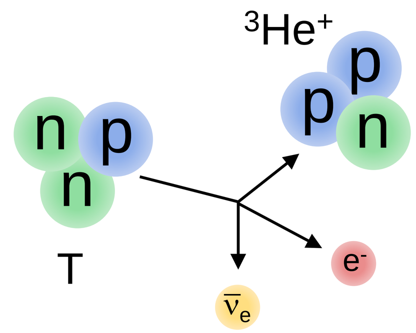
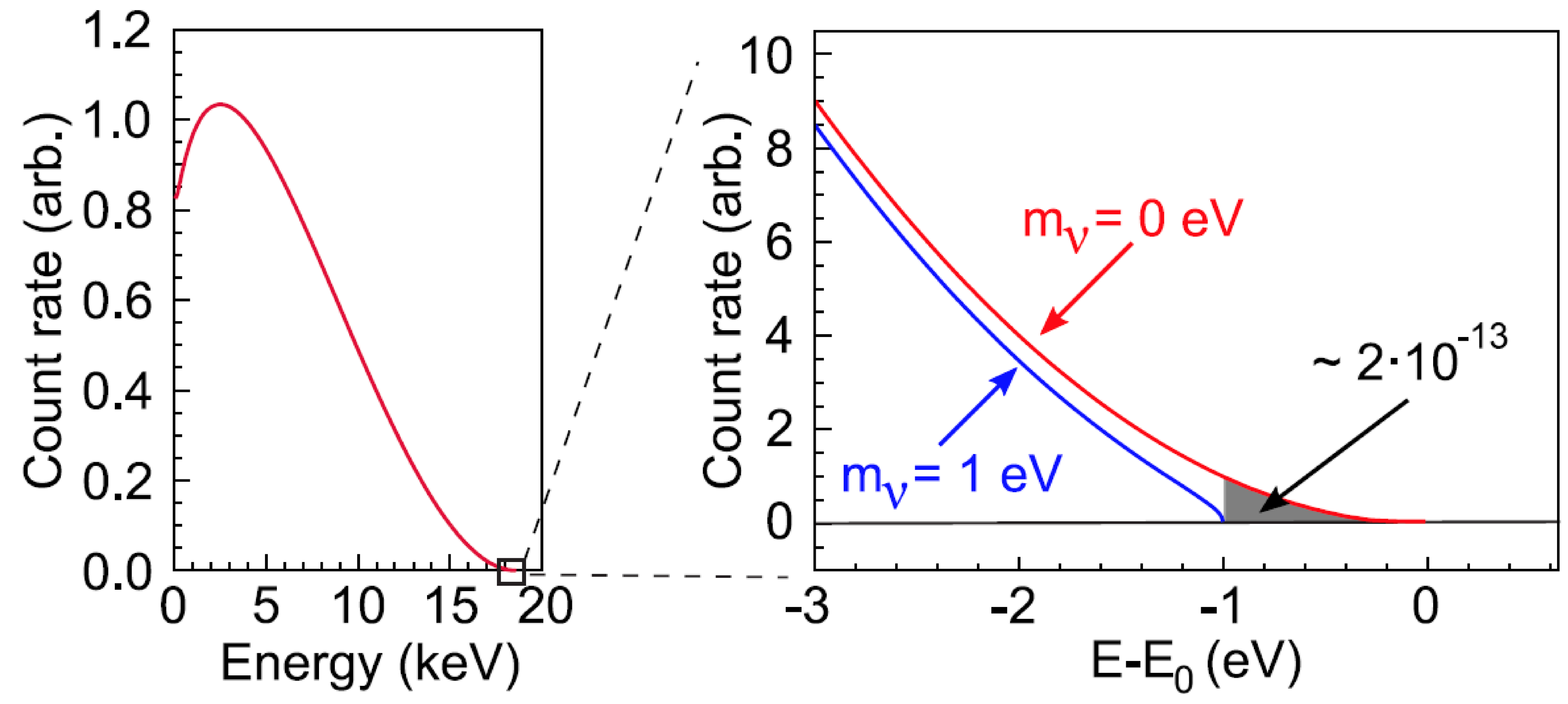
Properties of tritium

- Super-heavy hydrogen isotope
- ${}^3_1H \rightarrow {}^3_2He^+ + \overline{\nu}_e + e^-$
- β-emitter with half-life of of $t_{½}$ = 12.323 years
- Second lowest end point energy $E_{max} \approx$ 18.6 keV
- 1 g tritium:
  - Decay heat: 324 mW
  - Activity: 3.56 · 10^{14} Bq (= 9619 Ci)
  - Annual loss per β-decay: ~ 5%

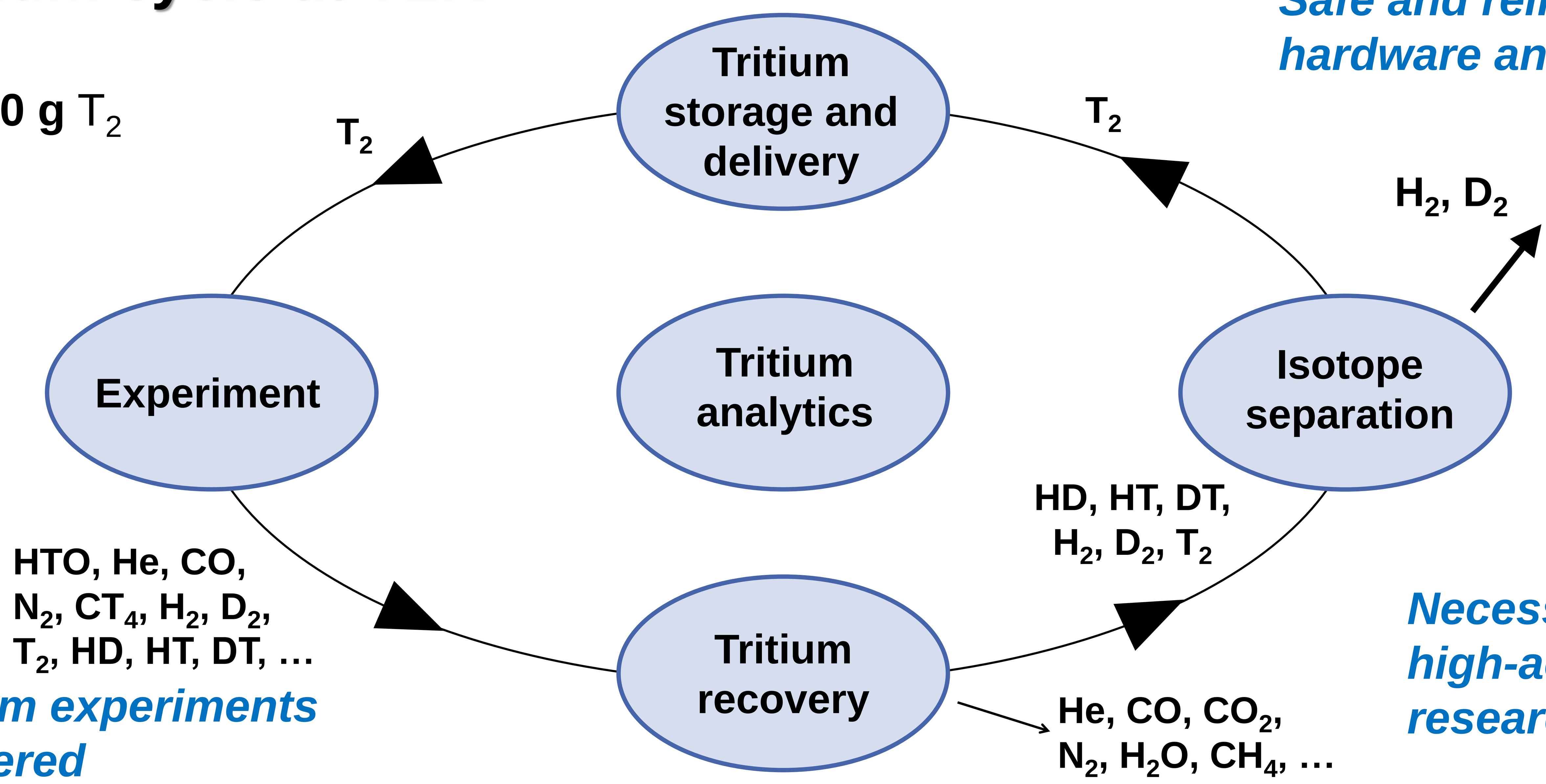




Closed tritium cycle at TLK

- Licence for **40 g** T_2

Safe and reliable hardware and procedures

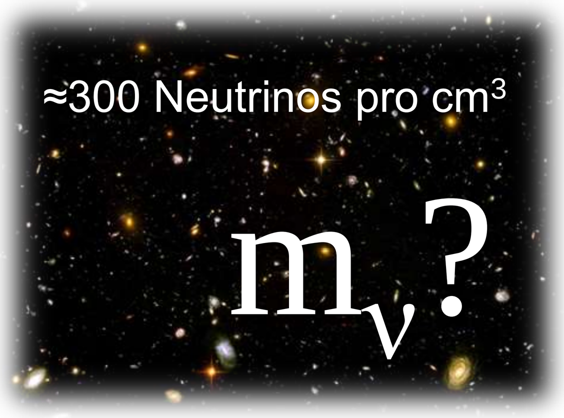


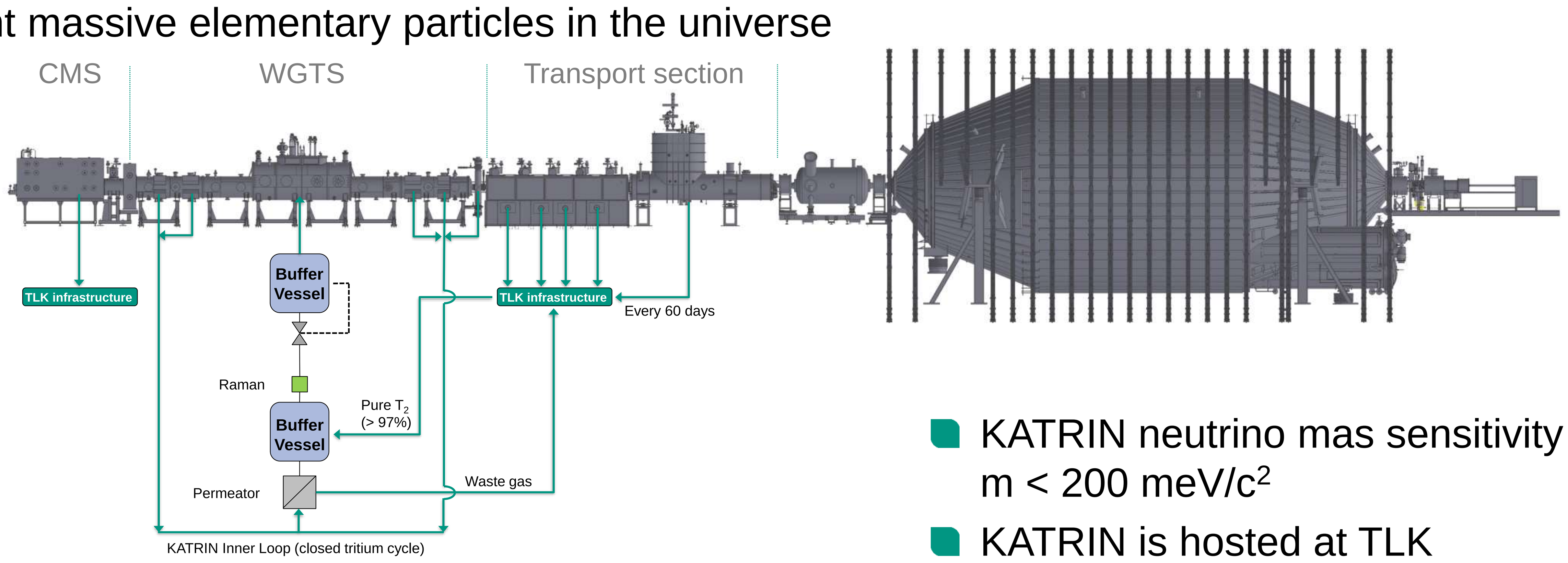
All tritium from experiments can be recovered

Necessary for high-activity tritium research

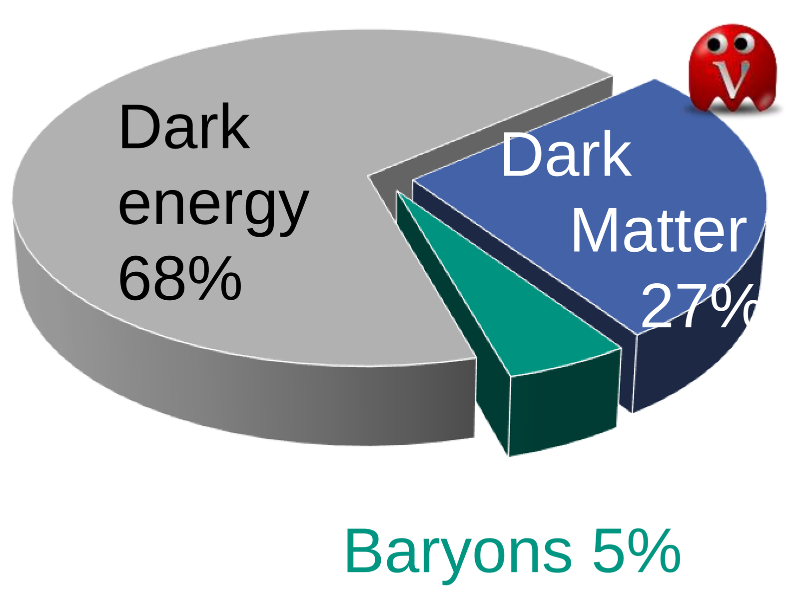
Karlsruhe Tritium Neutrino Experiment (KATRIN)

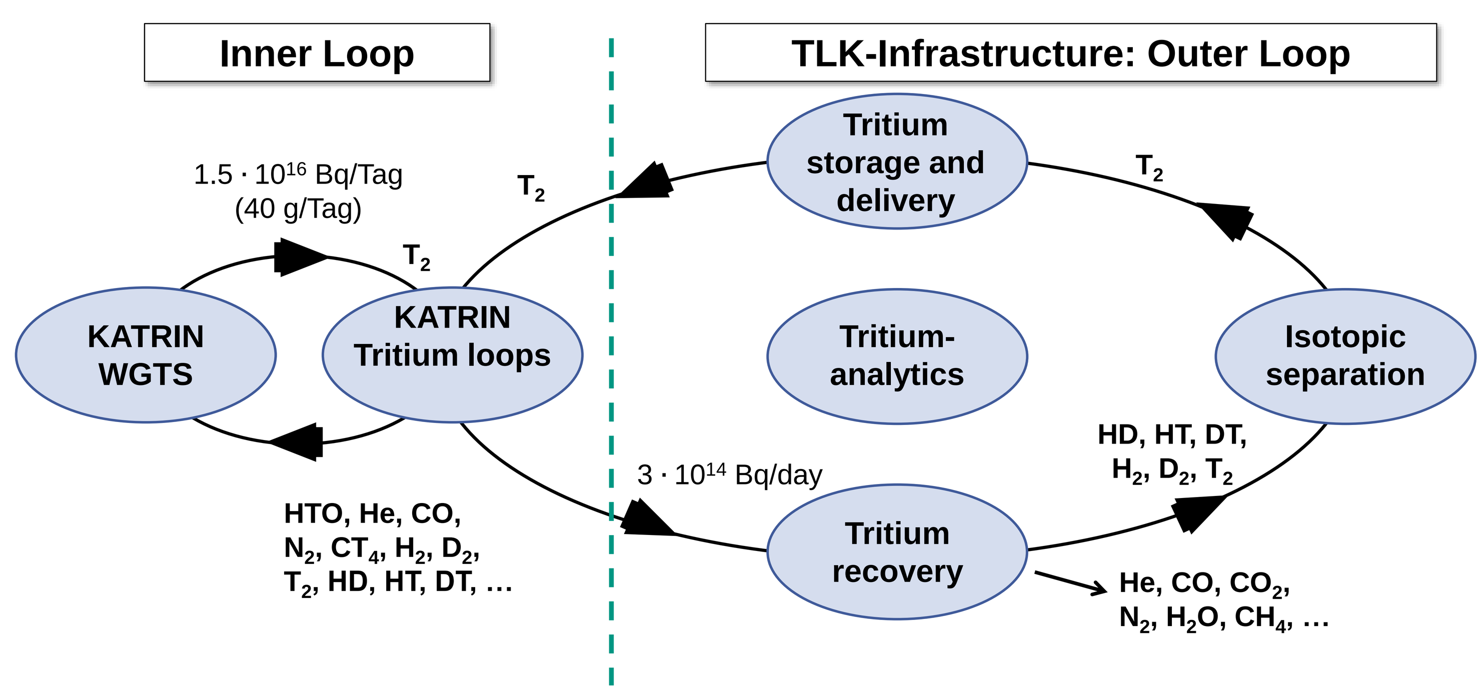
- Neutrinos are most abundant massive elementary particles in the universe





- Neutrino mass unknown





- KATRIN neutrino mas sensitivity m < 200 meV/c^2
- KATRIN is hosted at TLK
- TLK responsible for operation of tritium source and loops at throughput of 40 g (T_2) / day
- 24/7 monitoring of tritium purity by Raman spectr. at 10^{-3} accuracy.
- KATRIN uses unique asset of TLK **Infrastructure of closed tritium cycle**

- Contribution of neutrinos to dark matter?

Total tritium throughput since 2019:
> 30 kg T_2 (>1000 days of operations)

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Unique contributions to the Fusion Roadmap

Four main thrusts in one place (with ongoing examples)

1) Tritium properties and material interactions

- Measurement of thermodynamic properties as input for process modelling
- Systematics-controlled study of Sieverts' constant (T in LiPb) for blanket concept and design

2) Tritium and hydrogen analytics and accountancy

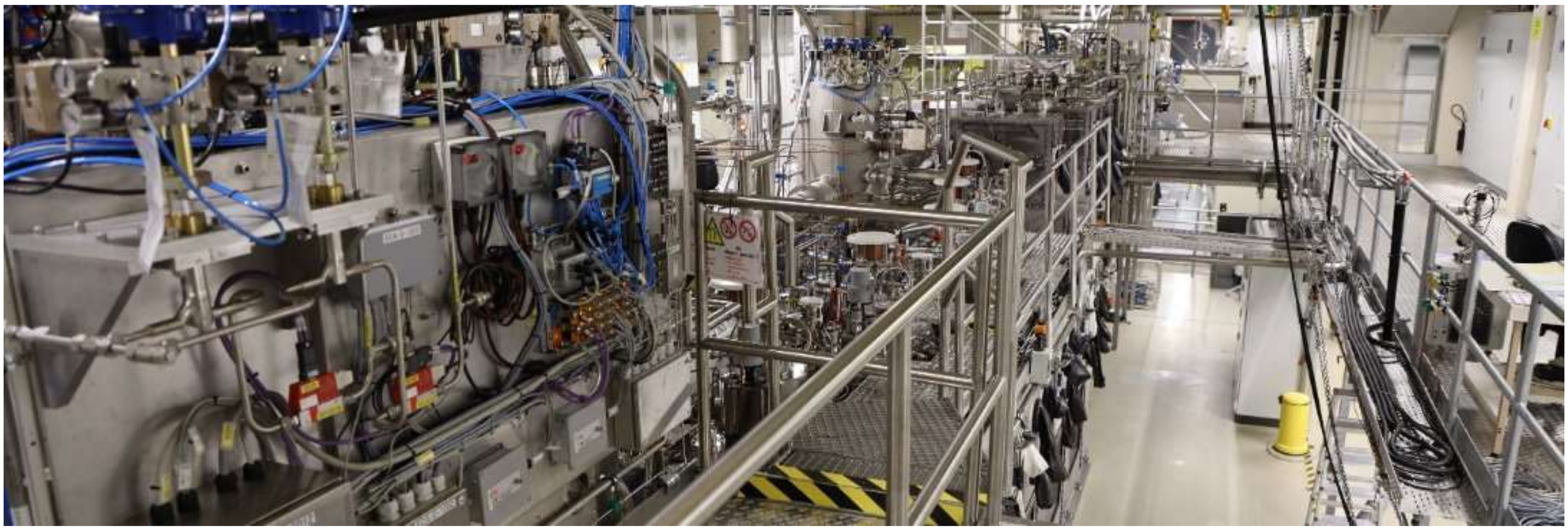
- Leading development and in-field testing of tritium-tailored technologies (e.g. Raman, IR and beta-induced x-ray spectroscopy systems, calorimeters, …, novel approaches) for rugged application in accurate process monitoring
- Validation of accountancy strategies in large throughput tritium loops

3) Tritium qualification of processes and scaling-up of systems to technical scale

- Development of permeation barrier concepts for reducing tritium migration
- Implementing established and novel isotope separation systems for increasing recycling factor of tritium plant
- Offering tritium experimental rigs for full-tritium qualification of processes, components and entire systems.

4) Tritium decontamination, safety and waste management

- Establish UV/ozone cleaning methods for removal of large-area surface contamination
- Decontamination of process components by vacuum furnace treatment as end-of-life-cycle solution



Selected achievements of TLK

General achievements (overarching)

- Safe operation of a technical-scale tritium plant with a closed tritium loop for 30 years
- Development of tritium-compatible process components (permeators, methane crackers, pumps, …) and life-time investigations of components under high tritium load
- Development and implementation of tritium design standards and tritium handling

Achievements in fusion fuel cycle development

- JET Fuel cycle: Detailed design of WDS and qualification of catalyst/packing mixture
- ITER fuel cycle:
  - First integrated design of the inner tritium fuel cycle
  - Development and experimental verification of reference process for Tokamak Exhaust Processing (three-stage CAPER process)
  - Detailed WDS design for ITER (based Combined Electrolysis Catalytic Exchange) process
  - Technical support for ITER WDS/ISS within F4E EU procurement package
    - Endurance tests with tritium for WDS catalyst and for electrolyzer membrane
    - Experimental validation of catalyst/packing performance for WDS including influence of gas composition on decontamination factor
    - Measurement of liquid hold-up and separation performance of packings for ISS based on cryogenic distillation
    - Qualification of modelling (TRIMO) of WDS and ISS against experimental data

Achievements tritium analytics and accountancy

- Worldwide first calibration of IR absorption spectroscopy for liquid H_2, D_2, HD mixtures
- First to monitor simultaneously all 6 hydrogen isotopologues in-line with Raman spectroscopy
- Operation of TriHyDe facility to produce reference gas mixtures, reached the world leading calibration accuracy of tritium monitoring systems (< 1%)

Successful setup and operation of source and transport system of KATRIN experiment

- Successful design and setup of the source and transport system including the tritium loops. For this challenging requirements had to be fulfilled:
  - Design of superconducting source magnet cryostat system with stabilized beam temperature of 30 K and 110 K, beam tube fully tritium compatible
  - Development of pumping system for tritium retention by 14 orders of magnitude along the beam line to avoid tritium migration into of spectrometer (outside TLK).
- The combined operation of KATRIN tritium loops with TLK infrastructure (>30 kg tritium throughput last 2019 - 2024) has many similarities to the operation of the inner fuel cycle of a fusion reactor (e.g. Direct Internal Recycling Concept)

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Other fuel-cycle-related fusion research units at KIT

Fusion Materials Laboratory
Institute for Applied Materials

- Characterization of neutron-irradiated and thus radioactive materials for future fusion reactors
- Tritium-uptake and -retention behavior of materials
- Handling of radio-toxic materials
- Development of safe handling- and adapted examination-techniques

Tritium licence ✓

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Fusion Fuel Cycle Technologies
Institute for Technical Physics

- Fuel cycle architecture development & optimization
- Simulation of transport phenomena, incl. interface to plasma
- Matter injection and tritium compatible vacuum pumping technologies
- Test facilities for vacuum pumps and fuel cycle equipment

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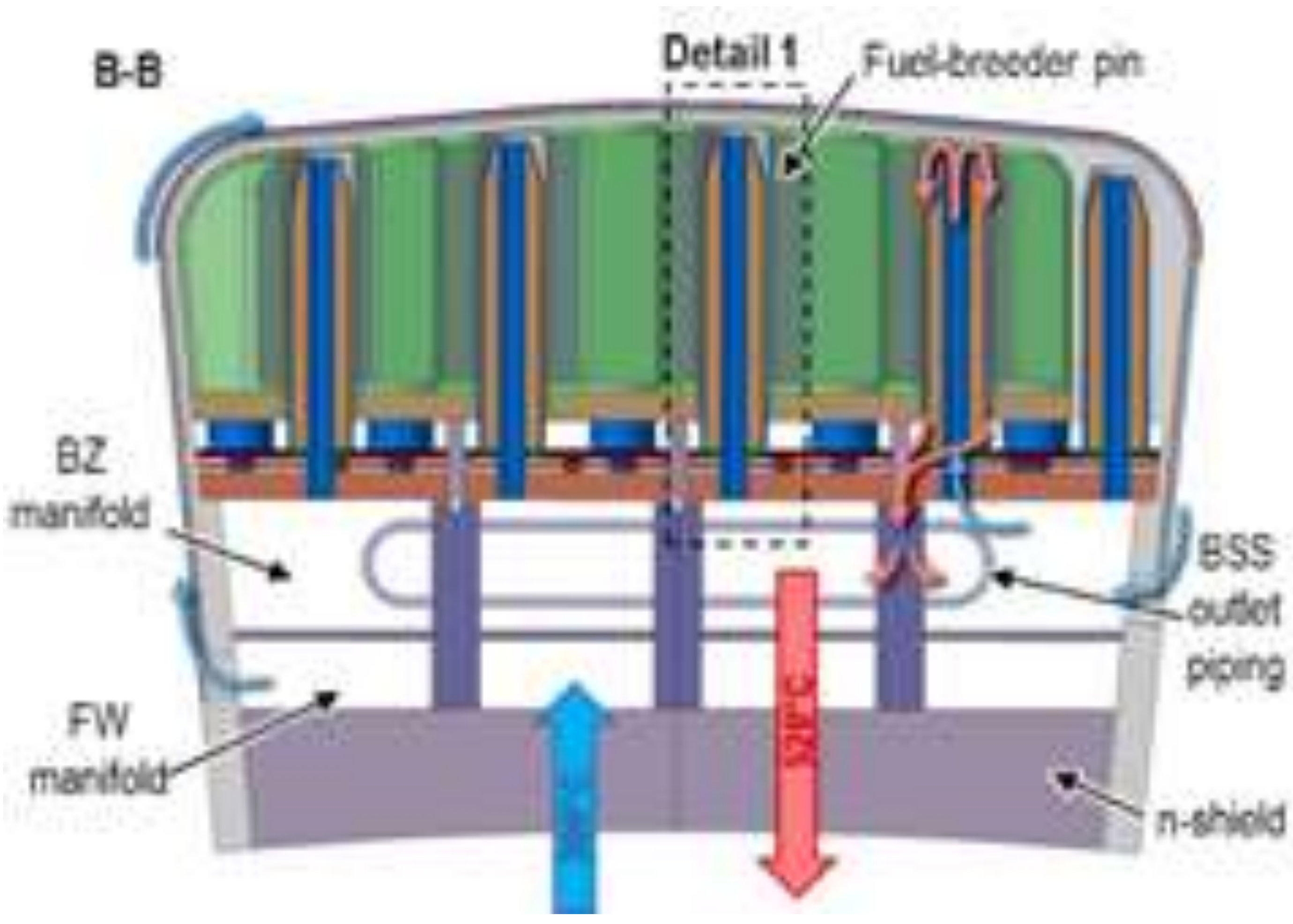
Breeding Blanket system for Fusion Devices
Institute for Neutron Physics and Reactor Technology

- Thermal, structure mechanical, and electromagentic analyses
- Design of blankets in the fusion technology
- Qualification and analyses of advanced fabrication technologies



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