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Kurt Clausen :: Deputy Director :: Paul Scherrer Institut

Neutron Sources in Europe

Danish CANS Workshop, A Compact Accelerator-driven Neutron Source in Denmark?

3 November 2016 at DTU Nutech

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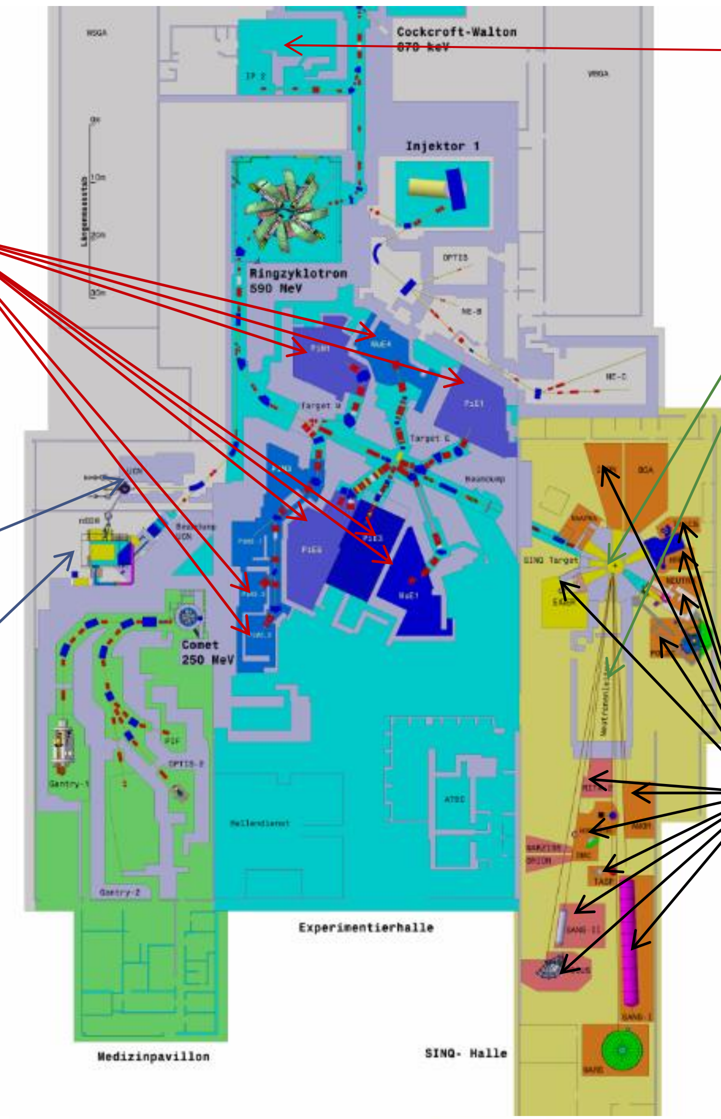
An example of an accelerator driven neutron source
590 MeV proton driver – 1.4 MW

SμS: Myonenquelle, weltbeste Anlage ihrer Art
8 Experimentierareale für Myonen auf dem Gebiet kondensierte Materie und Teilchenphysik

UCN: Quelle ultrakalter Neutronen
nEDM-Experiment zur Messung des elektrischen Dipolmomentes des Neutrons – weltweit empfindlichstes Experiment



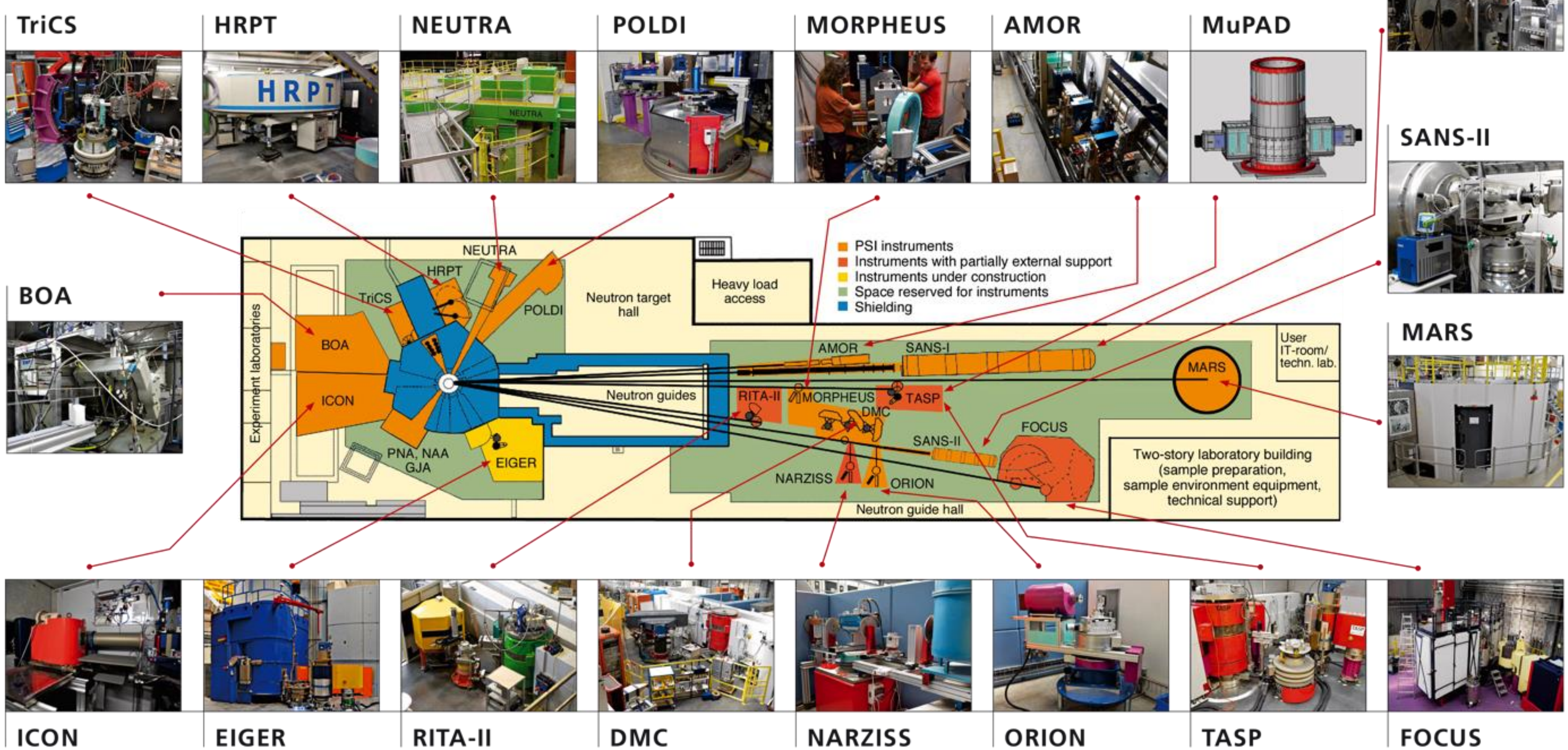
Isotopes:
(72 MeV protons)

SINQ – Spallations-Neutronenquelle:
Erste und einzige kontinuierliche MW-Spallationsquelle weltweit, erste Anlage, die vollständig mit Superspiegeltechnologie ausgerüstet war.

13 Instrumente im Nutzerbetrieb
Festk.-Physik, Mat. Wiss., Life Sciences, Engineering, Cultural Heritage, …

Instrumented fully covering a broad range of science

Neutron Scattering and Imaging Instruments at SINQ

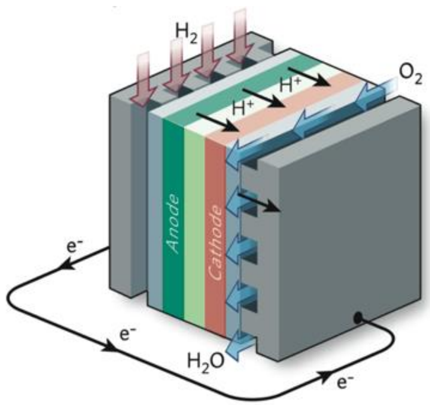


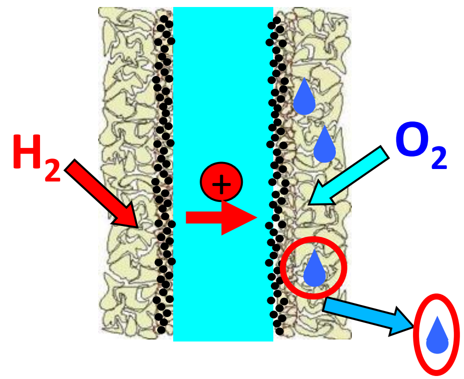
Further Information: www.psi.ch/sinq/instrumentation

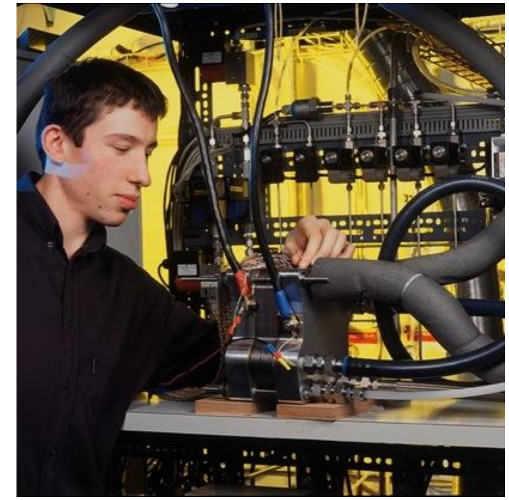
all instruments are open to the national and international user community

Instrumentation allowing to use the specific strength of the neutron

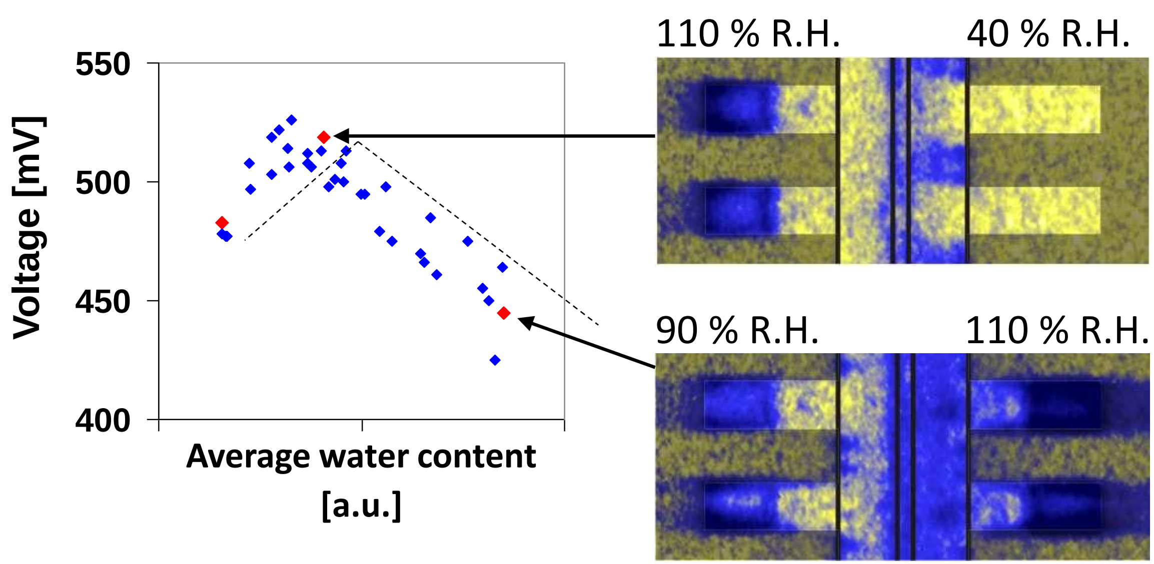
water balance of fuel cells is crucial





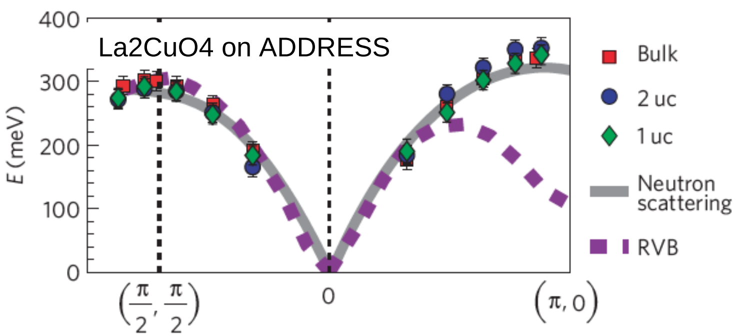


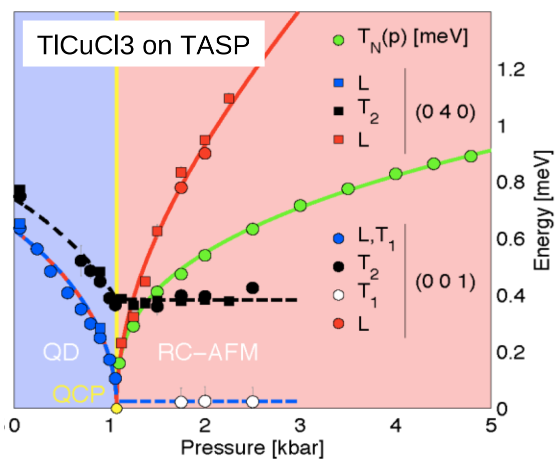
neutron radiography of operating fuel cells



Competitive, state of the art – other techniques are developing too

Unique Combination of Neutron and Photon Spectroscopy at PSI





Photons RIXS (ADDRESS)

Energy range: 100-10’000 meV

Neutrons (SINQ Spectrometers)

Energy range: 0-10 meV

10-70 meV

one site

photons

neutrons

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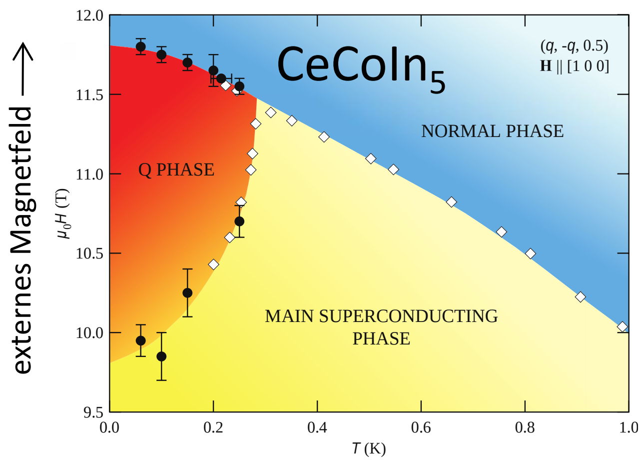
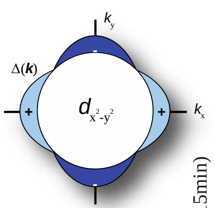
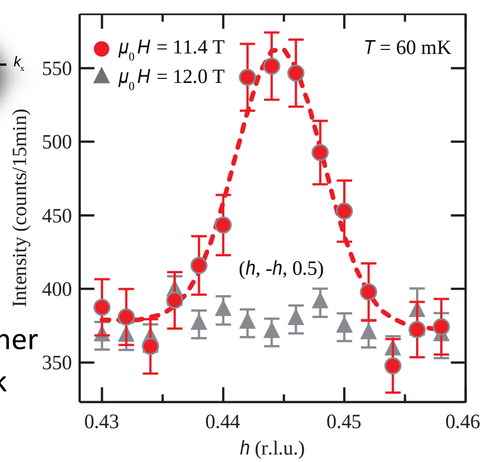
Attractive to users – adressing key problems.

Neutronen

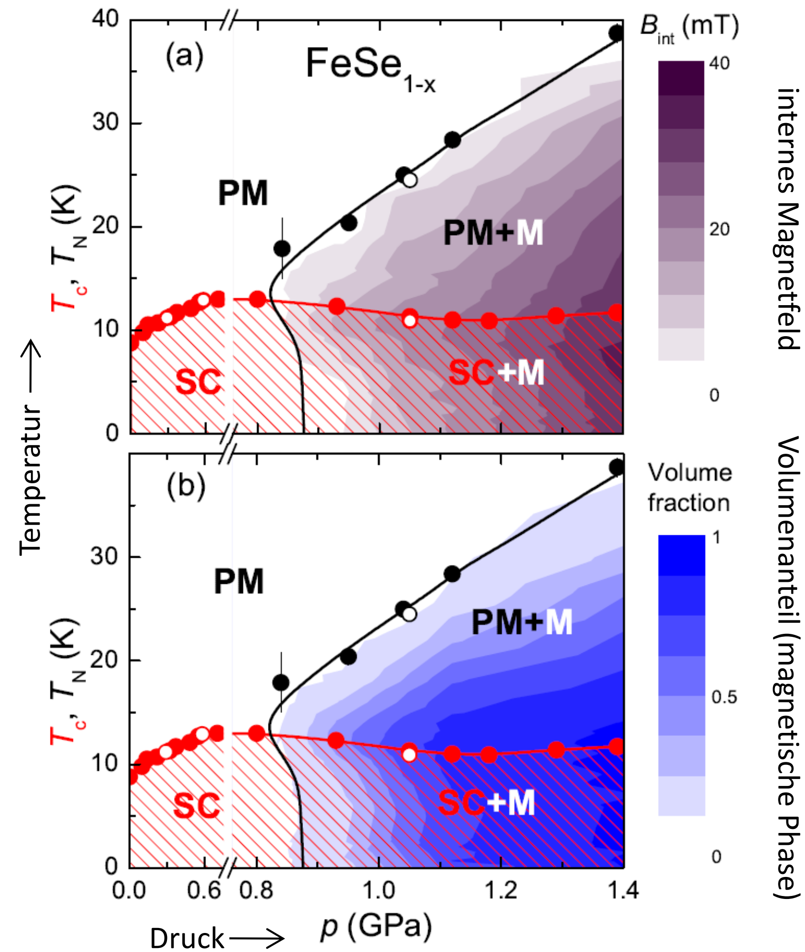






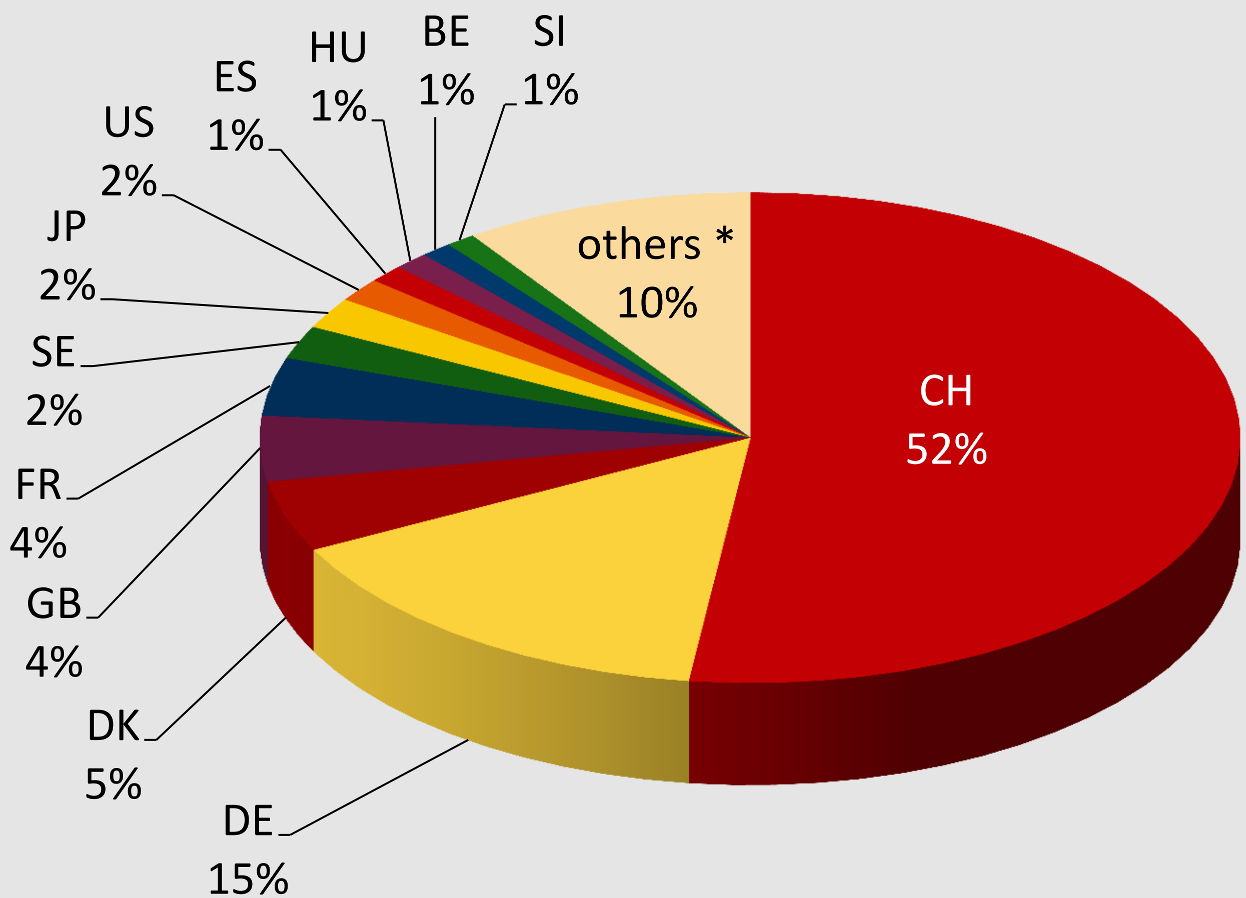
Phys. Rev. Lett. **104**, 127001 (2010)

Myonen



Phys. Rev. Lett. **104**, 087003 (2010); Phys. Rev. Lett. **104**, 087004 (2010)

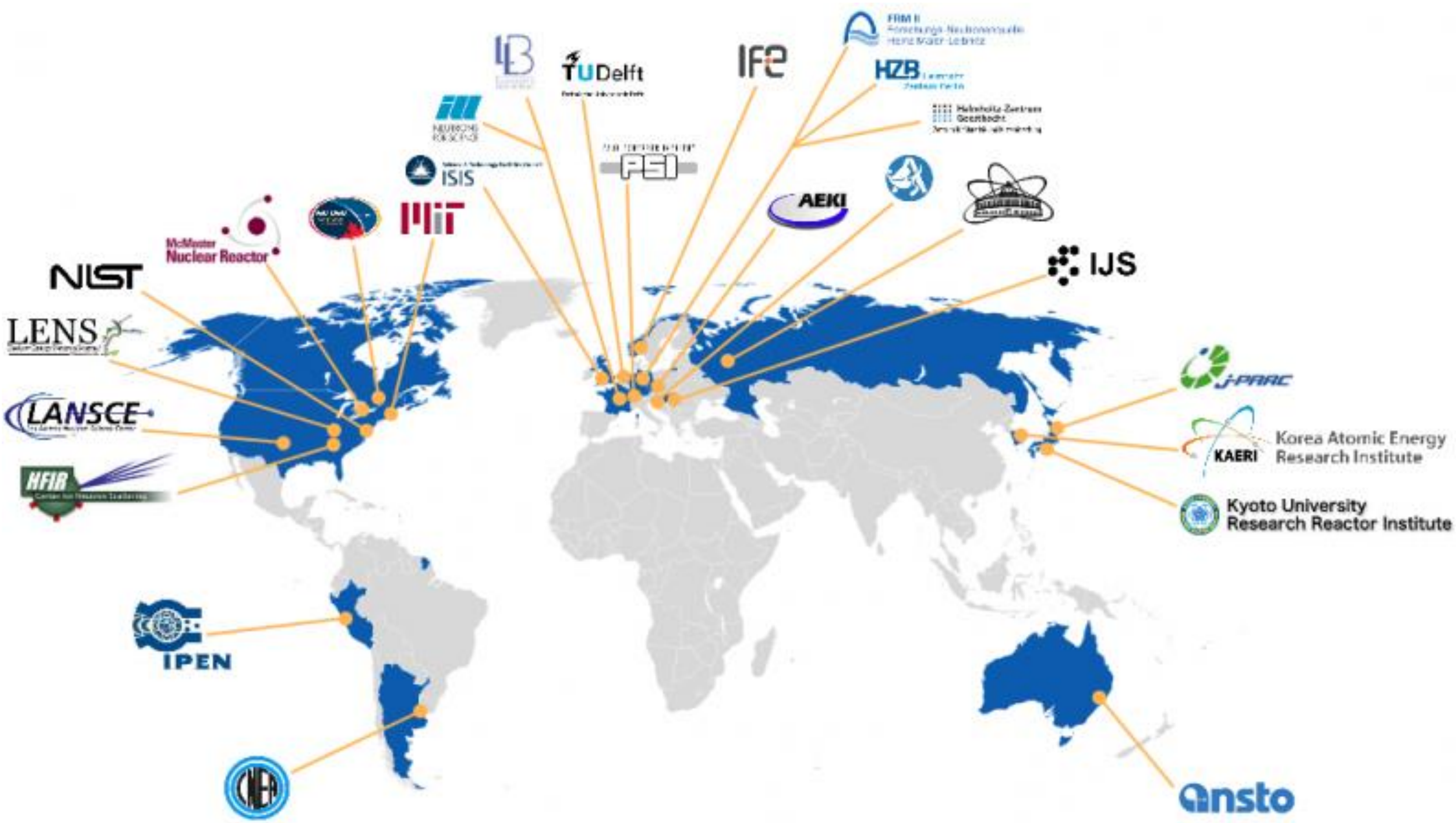
Example SINQ – to fully exploit the source a userbase is important– in general international



(*) others: 22 countries with less than 1%

Source: S. Janssen, PSI User office

Major Neutron sources of the world
- sources with a substantial user base



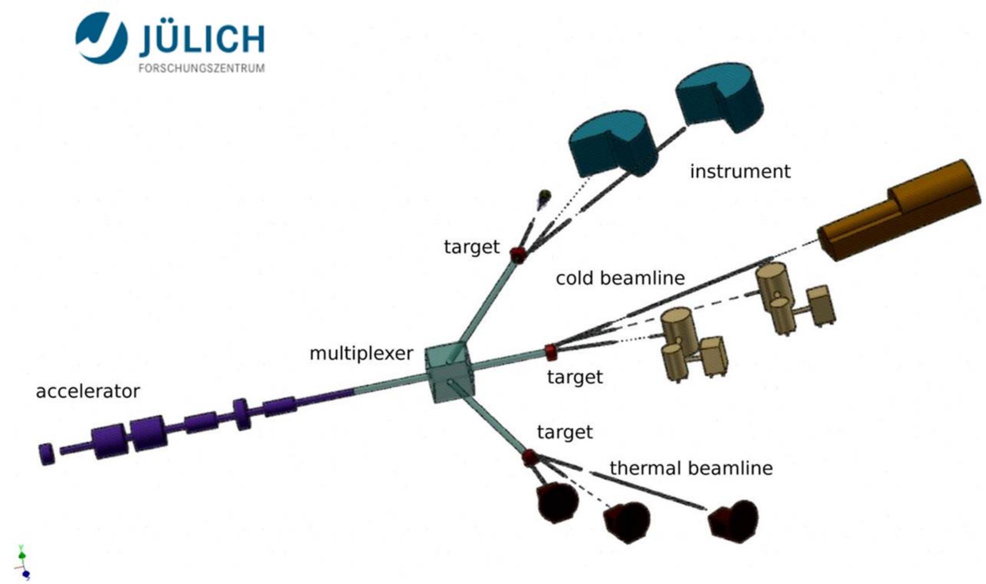
www.veqter.co.uk

New initiatives – NOT on the Map

European Spallation Source ESS to be built in Lund, Sweden

- 17 European countries
- operational by 2019
- 22 instruments by 2025
- 1.8 B€ project, 140 M€ for operation

Compact neutron source studies:
– FZ-Jülich and LLB Sacclay both with strong interest in accelerator and neutron instrumentation and having the infrastructure necessary for radioactive infrastructure are pursuing this idea.



Neutron scattering use of neutron sources

- **1st generation:**
  - «Parasitic users» of facilities mainly build for other purposes:
    - All the early research reactors like DR3, nuclear fuel, materials tests, irradiation, isotopes, transmutation doping of Si, etc. etc.

- **2nd generation:**
  - Neutron sources build predominantly for neutron scattering:
    - ILL, LLB, BENSC, ISIS, SINQ, Munich,

- **3rd generation:**
  - Neutron sources build for neutron scattering – optimised from moderator – instrument
    - ESS, ISIS TSII … (ILL, SINQ and Munich upgrades .. In this category)

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Major Neutron sources of the world - sources with a substantial user base

Sources closed: Harwell, Risø, Jülich, Studsvik, Gestacht ……..

Sources to close 2020: LLB, HZB

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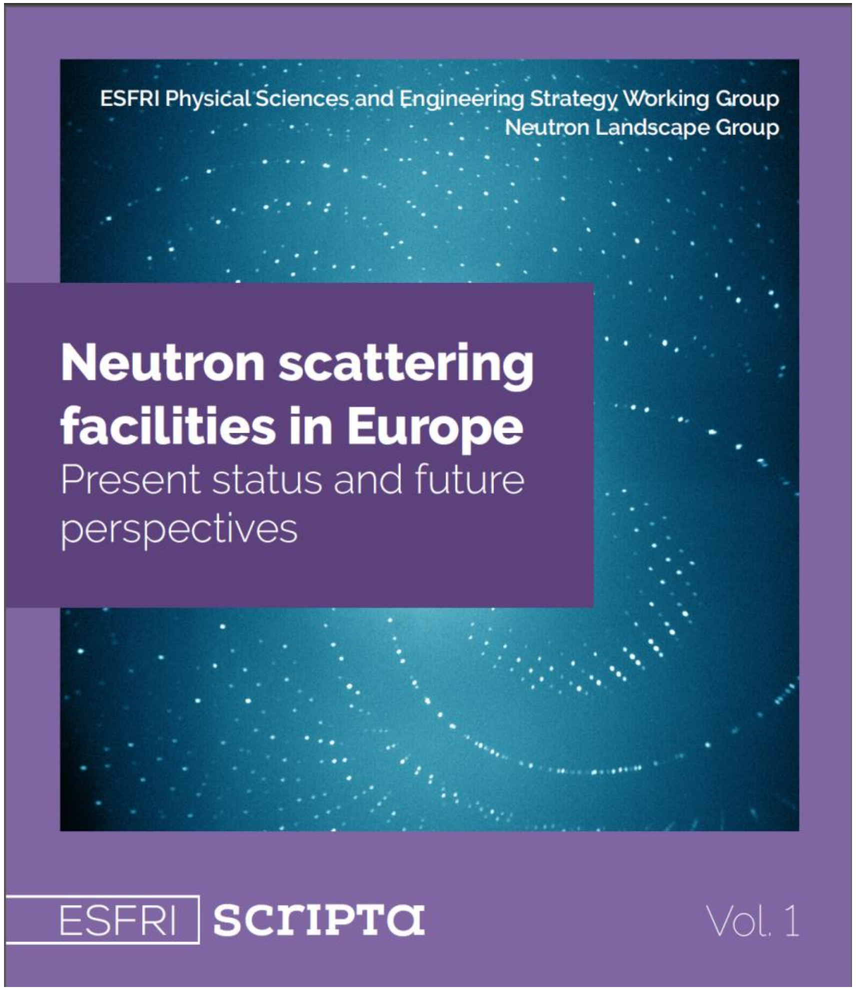
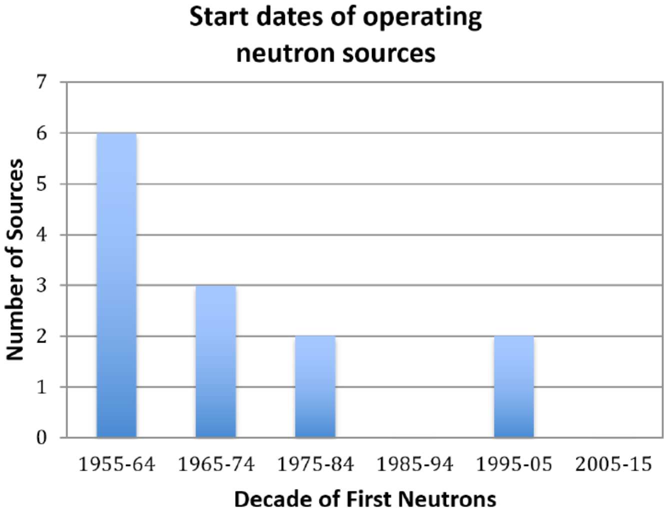
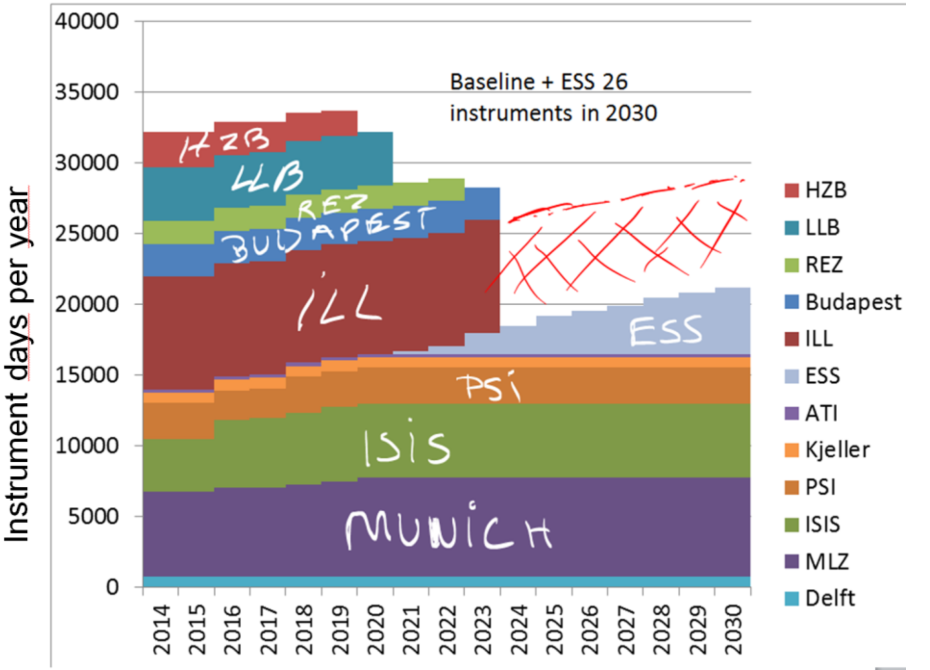
ESFRI study – part of the preparation for the 2016 ESFRI Roadmap





http://www.esfri.eu/esfri-news/european-landscape-research-infrastructures-neutron-scattering-facilities-europe-present

Example of data collected as part of ESFRI Landscape analysis



Some of this already obsolete, development in both directions

Snapshot from 2014, replies from facility directors

2014				
Facility	Instrument days	Operational cost (M€)	normalised k€/inst-day	
ILL	8000	95	12	
ISIS	3720	59	16	ca 12 if they ran to full capacity
MLZ	6000	55	9	operating many days/year for isotope production less productive per day for neutron scat.
LLB	3780	30	8	No investment in the future
PSI	2520	30	12	
HZB	2520	22	9	No investment in the future
Total	26540	291	11	

How do you quantify availability of resources?

Operate only facilities that were "state of the art" when brought into operation and where instruments have subsequently been kept upgraded, so that they are competitive within their area and demanded (oversubscribed) by the user community.

Different experiments have different requirements to, flux, resolution, special sample environment, time on the instrument etc etc.

In the working group we found that:

Instrument-days – is the best overall measure to gauge the size of the user community that can be sustained by a given set of neutron sources, Measures a combination of capacity and capability.

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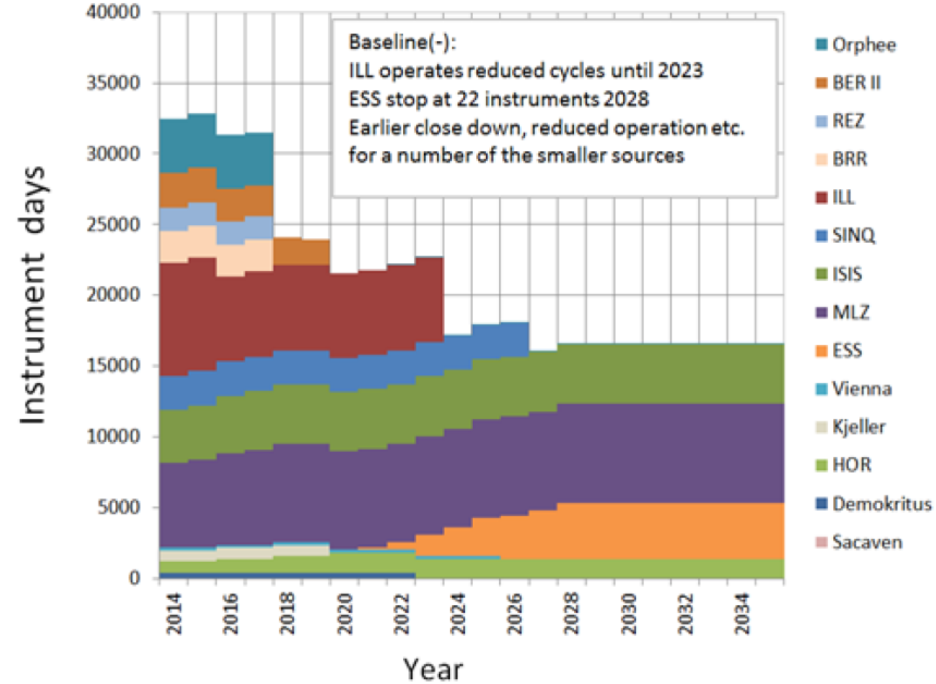
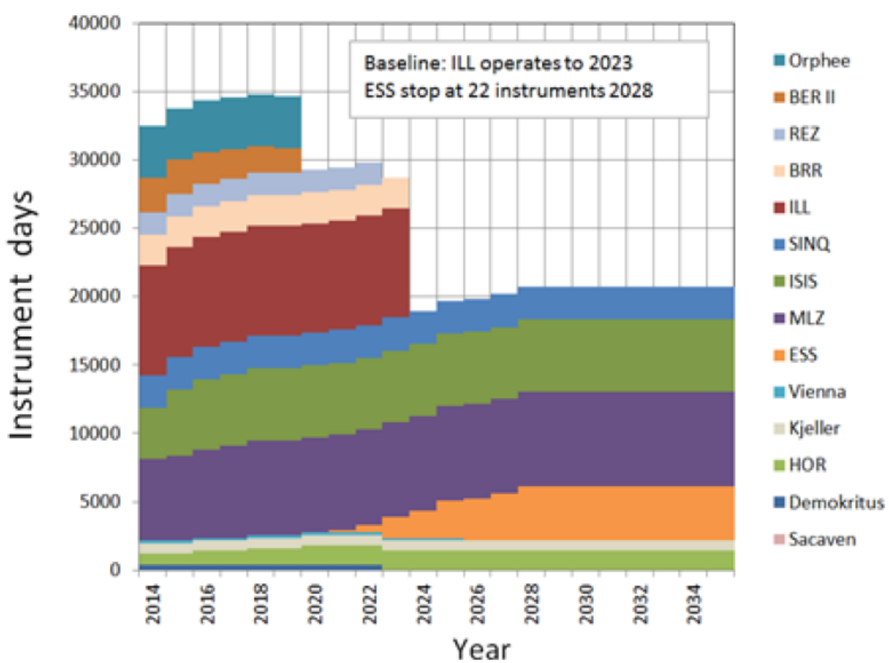
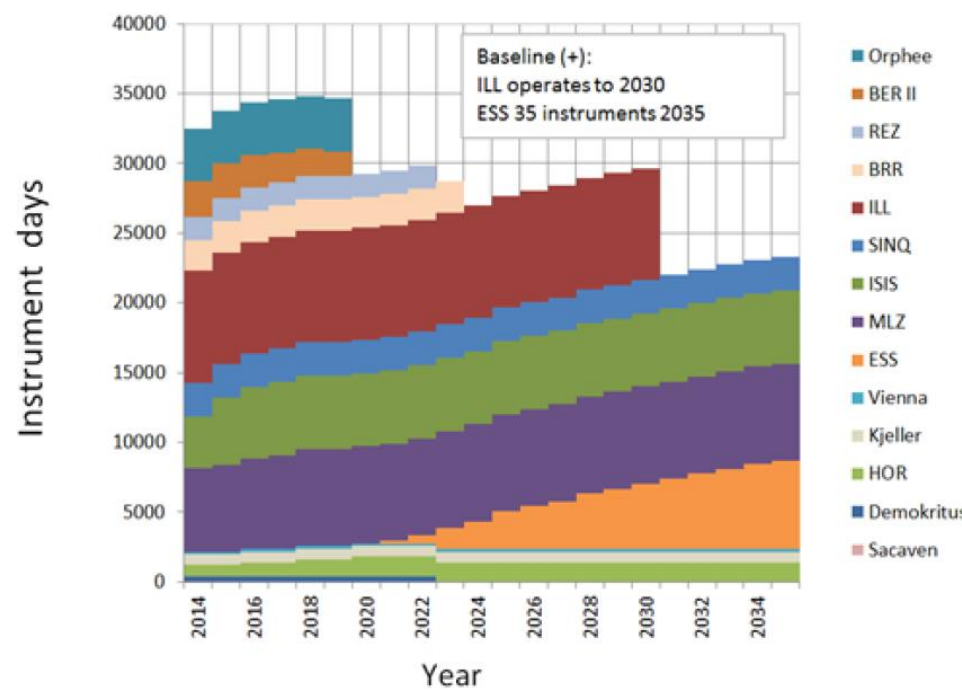
Various scenarious – based on the 2014 data.

A longer term analysis needed.







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Pertinent Headline Facts derived from the Data

Europe has **13 operational neutron sources**

These sources operate for **2,280 days for science** in total

8 sources began to operate before 1980; 3 began to operate after 1980

There are **183 operational instruments**

These instruments provide **32,469 instrument days for science**

The total number of distinct users is **5,469** (source duplication unaccounted for).

The integrated output is **1,848 scientific papers p.a.**

Industry pays for ~400 beam days p.a. (1.2%) at the top 6 sourcesin total.

The **capital replacement value** of all sources is estimated to be **5.7 B€**

Operational costs integrated over all sources are **314 M€ p.a**.

The average ratio of **operations costs p.a. to capital invested is 5.9%**.

Pertinent Headline Facts derived from the Data

The data in the report results in **following global averages**:

Average cost to operate a source for one day ~ 138 k€

No. of papers generated per source day ~ 0.81 papers

One published paper costs (excluding users costs) ~ 170 k€

No. of operational hours to produce one paper ~ 30 hours

Cost to operate one instrument for one day ~ 9.7 k€

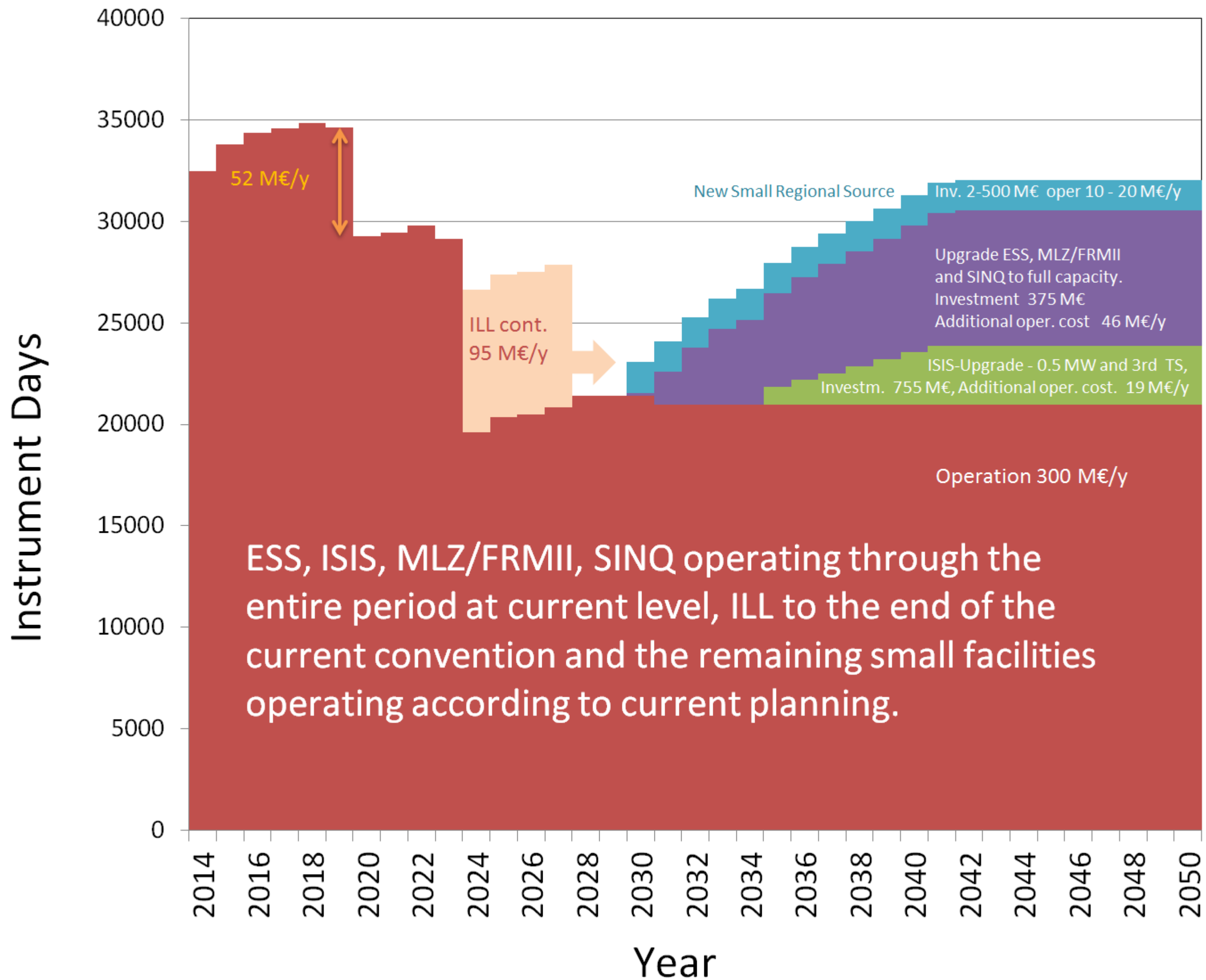
No. of instrument days to generate one paper ~ 17.6 days

No. of papers published from one instrument p.a. ~ 10.1 papers

A longer term scenario → a «stable» supply

We could not see a scenario or /option that would avoid a decline in instrument days in the intermediate future.

Keep existing facilities going, upgrade and new sources key for a sustainable future



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My suggested key cost figures to bear in mind when planning for a new neutron source:

Operational cost per instrument day:**

6 k€/day (small research reactor) → 22 k€/day (ESS class)

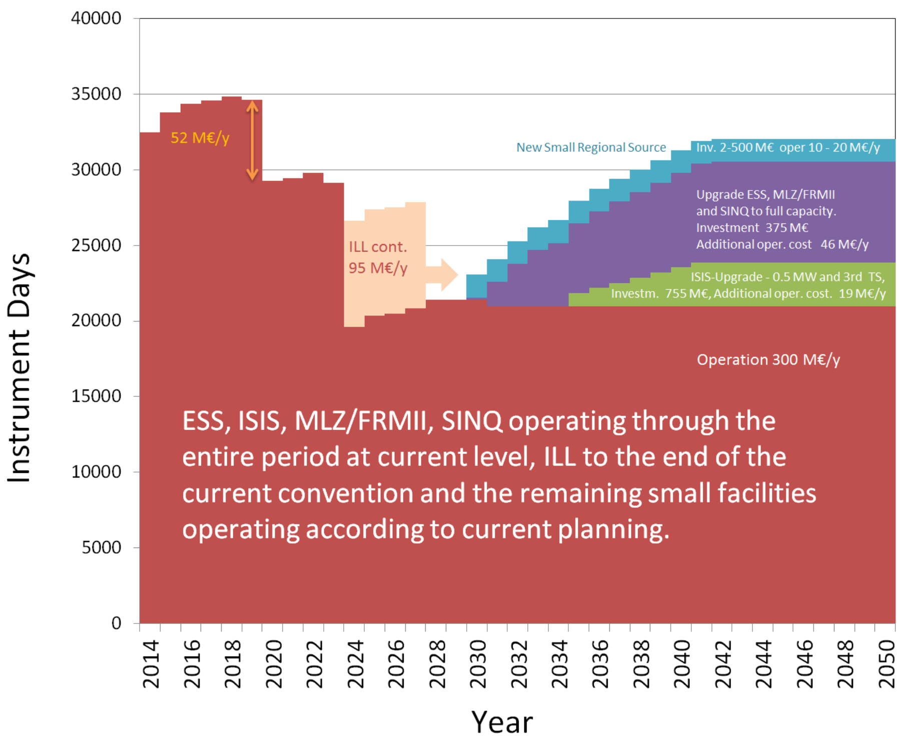
Total Investment cost/instrument:**

20 M€/inst (small research reactor) → 60 M€ /inst (ESS class)

*** Dedicated neutron Source fully instrumented*

Key issues

- How much capacity does Europe need? And which role does DK want to play beyond co-hosting ESS
- What is the national strategy for the scientific use of neutrons? And where do you best invest money and talent.
- What is the national strategy for developing large facilities – acc, targets, instruments etc.



Thank you for your attention.

I apologize for the quality of the presentation – an eye infection has made it impossible for me to us a PC since the weekend – please ask questions…

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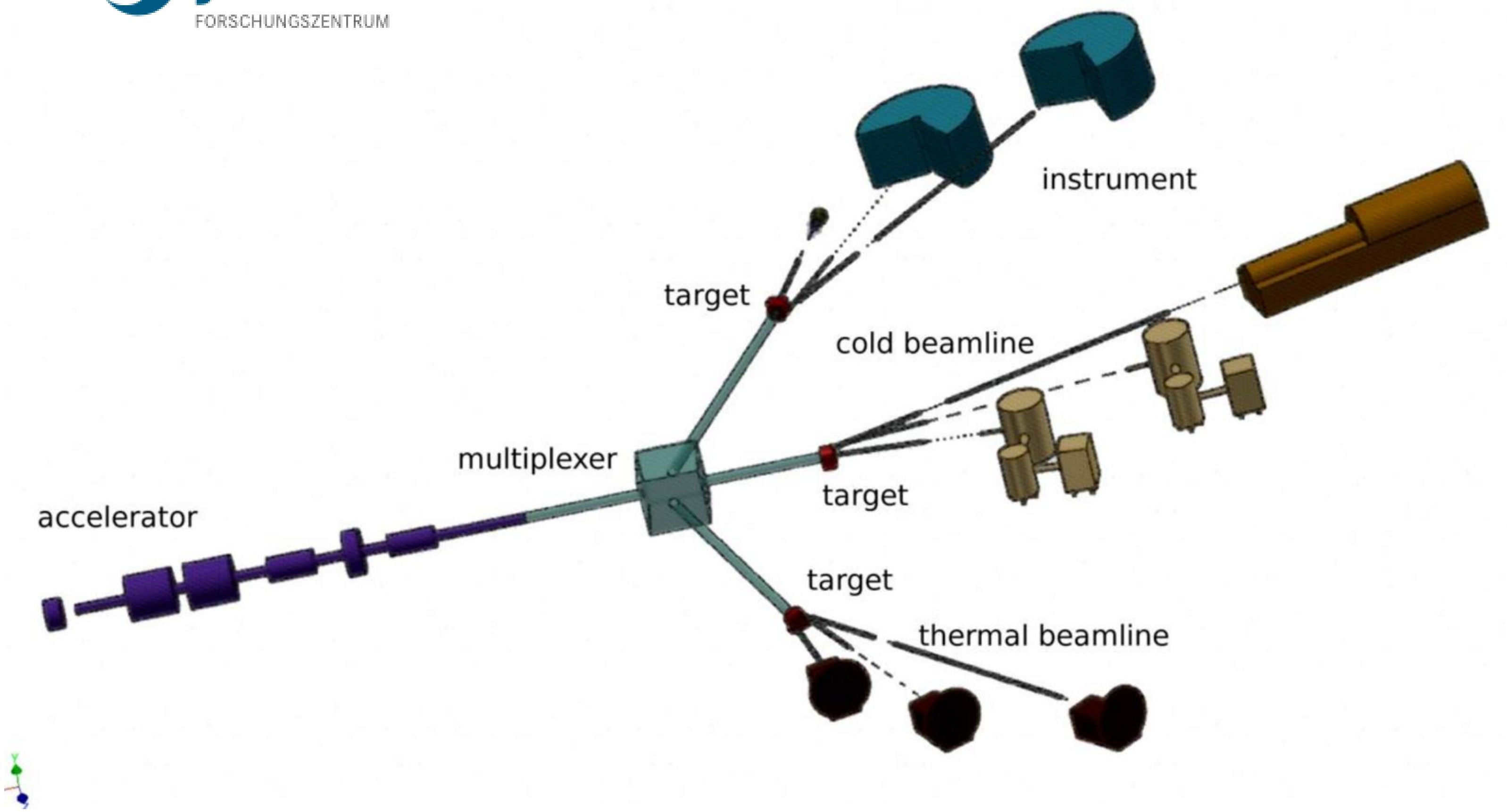
- **High Brilliance Neutron Source**
- The high brilliance accelerator-based neutron source HBS represents a unique infrastructure for neutron analysis (imaging methods and scattering) to be used in a multitude of scientifc disciplines such as physics, chemistry, biology, geology, materials and engineering sciences.
- The newest developments in the area of targets, moderators, beam extraction, beam guidance and neutron optics, make the realization of an extremely compact neutron source possible, with accelerators of relative low final particle energy. Thanks to its target stations dedicated to specific applications and optimized for investigating small samples, it ideally complements the larger international facilities such as the future European Spallation Source ESS.

- **Scientific Background**
- Due to their unique properties, neutrons are the ideal probes for studies in condensed matter. They tell us where atoms are, what kind of spin they have and how they move. A source which has been optimized for brilliance, providing small, intensive beams for customized instruments will intensify the use of neutron analysis to many modern scientific research questions arising from nanostructures or in biological materials and offer a spatial resolution appropriate to the systems used in energy technology or structural materials.
- **Future Prospects**
- The development of new materials and material systems made possible by the rapid advances of modern technology on which society's future prosperity is based, is closely associated with the availablilty of efficient microscopic analysis methods. Neutrons are a vital tool for scientists of many disciplines. The variety and complexity of research questions requires a network of different sources for training, method development and specialization. In this network, the HBS plays a central role. Within the "Strategy Paper on Neutron Research in Germany 2015 - 2045" in the research area "Materials", the HBS is presented as a future national neutron source.

High Brilliance Neutron source



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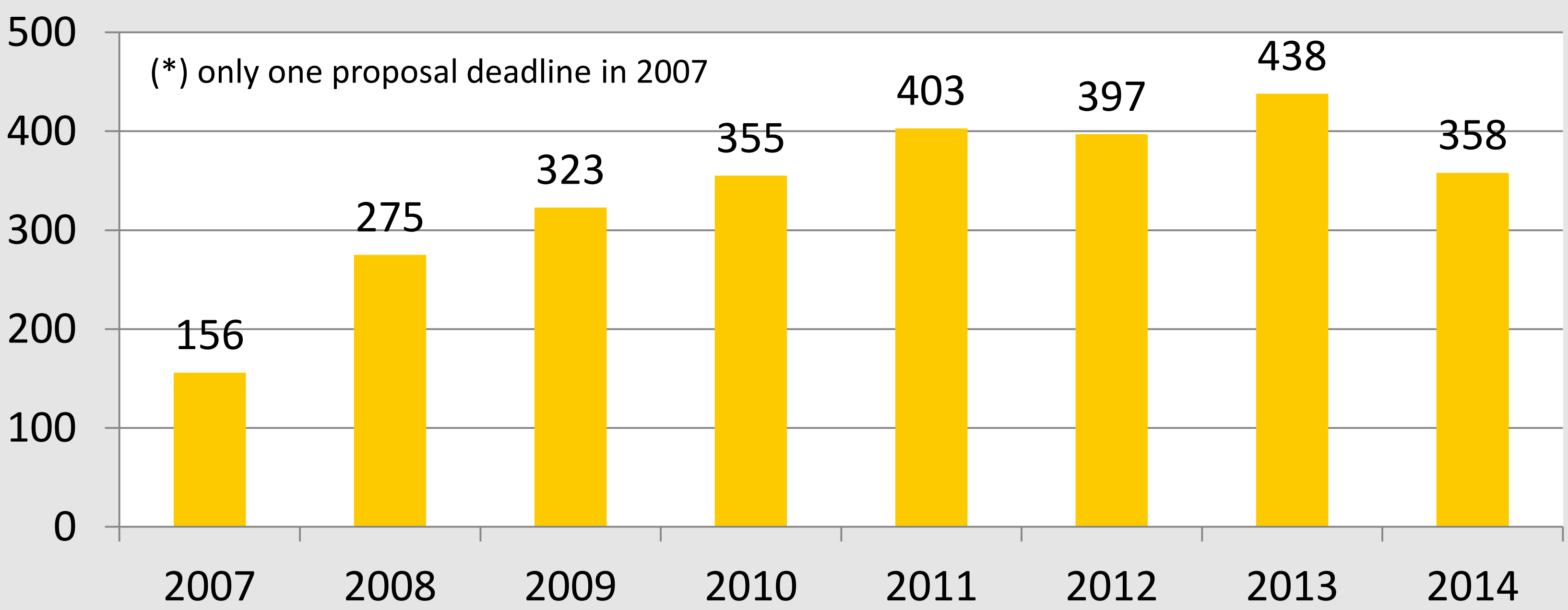
SINQ User Program

SINQ key numbers 2014 (2013)

New Proposals	358	(438)
Visits	962	(870)
Individual Users	515	(486)
Experiments	453	(431)
Experimental days	1965	(1841)

Source: S. Janssen, PSI User office



Status Instrumentation WPs Oct 2014

ESS

WP 1 CH-DK: Extreme Environment Spectrometer – **ToFTAS**
Submitted proposal 2014, **recommended by SAC for construction**

WP 2 CH-DK: Focusing Reflectometer - **ESTIA-SELENE**
Submitted proposals 2014, **recommended by SAC for construction**

WP 3 CH-DK: Compact Chopped SANS – **BioSANS**
Submitted proposal 2013/14, science likely covered by ESS instrument

WP 4 CH-DK: Hybrid Diffraction-SANS-Imaging – **HEIMDAL**
Submitted proposals 2014, **recommended by SAC for construction**

WP ESS-D-CH: Neutron Imaging – **ODIN**
Submitted proposal 2013, **approved by SAC and SC, construction started**

WP 5 CH-DK: Neutron Optics and Background Simulations
No instrument proposal planned, continue activity on WP level