50 years of the ILL: a personal view

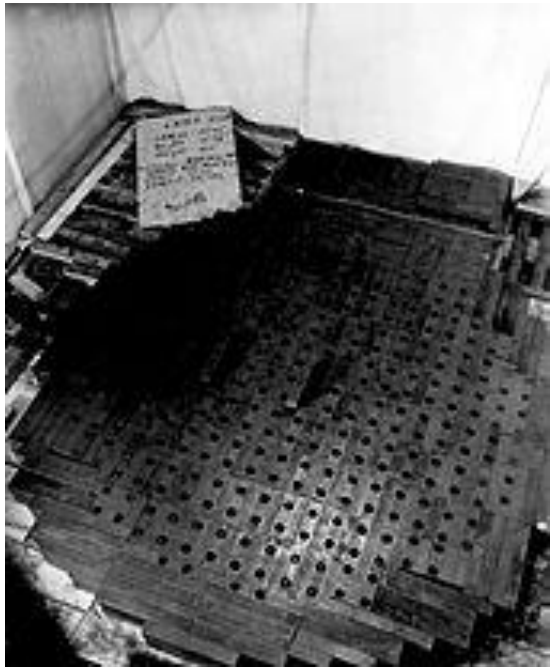
Bill Stirling

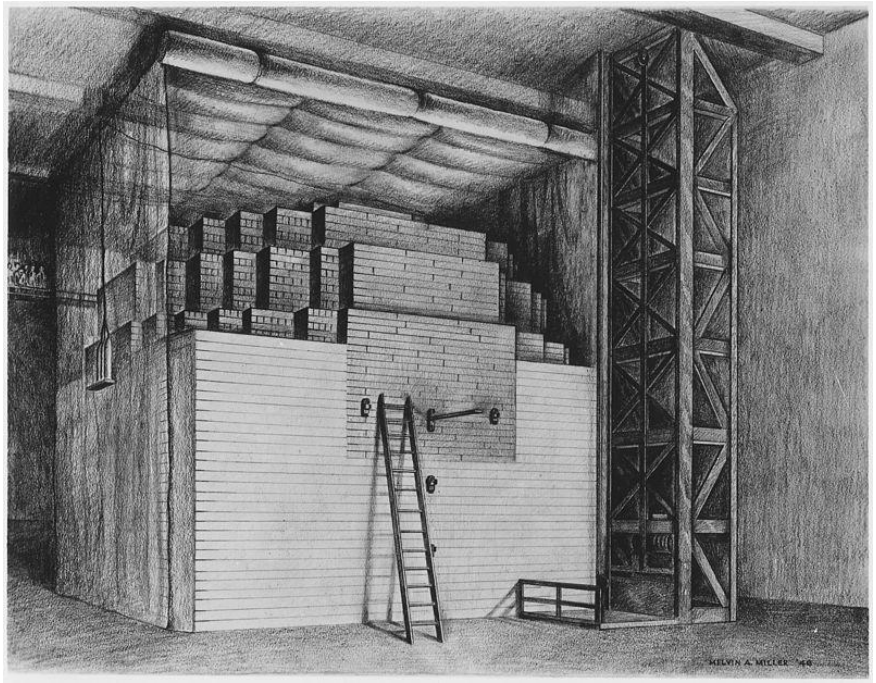
What I want to talk about

- The start of the ILL: the international context (reactor sources)
- The early days: some instruments, some people and some science
- The ILL today

With thanks to Francoise Vauquois, Mark Johnson, Julia Higgins, Giovanna Cicognani, Joe Zaccai, Serge Claisse, Peter Timmins – and the staff of the ILL

The first man-made reactor





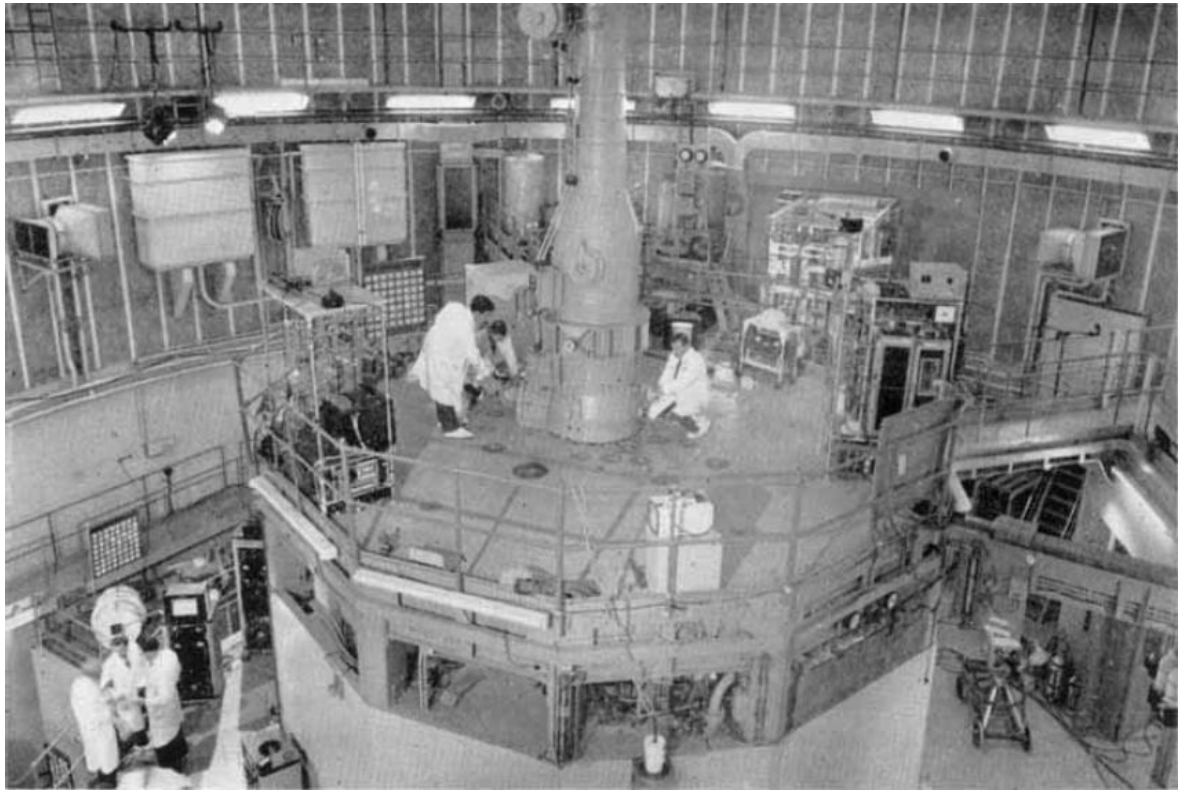
- 02/12/1942, the first nuclear reactor – Fermi's CP-1 (Manhattan project)
- Squash court, Stagg (football) field, University of Chicago
- "*a crude **pile** of black bricks and wooden timbers*"
- 5000 carbon bricks, 36 tonnes of UO_2, 6 tonnes of U; Cd control rod

The international context in the 60s and 70s

- By the 60s, lively neutron scattering research programmes (and nuclear physics) at many labs
- Experts at centres, plus some university involvement:
  - France: Saclay (50s), Grenoble (Melusine, 1958)
  - Germany: Berlin (BER-1, 1958), Julich (1962), Karlsruhe (1962), Munich (1957)
  - Denmark: Risø (1960)
  - UK: Harwell (1957), Aldermaston (1959)

The international context in the 60s and 70s

Harwell reactors DIDO and PLUTO (25 MW); 1957 - 1990



The international context in the 60s and 70s

Harwell in the 70s: University user programme

- Reactor instruments
  - single crystal diffractometers, powder diffractometers, triple axis spectrometers, time-of-flight cold neutron twin rotor spectrometer, beryllium filter spectrometer, MARX spectrometer, Harwell small-angle scattering spectrometer
- LINAC instruments
  - total scattering spectrometer, back scattering spectrometer, active sample spectrometer, inelastic rotor spectrometer, constant Q spectrometer
- Ancillary equipment
  - cryostats, superconducting magnets, electromagnets, furnaces

NEUTRONS FOR SOCIETY

The international context in the 60s and 70s

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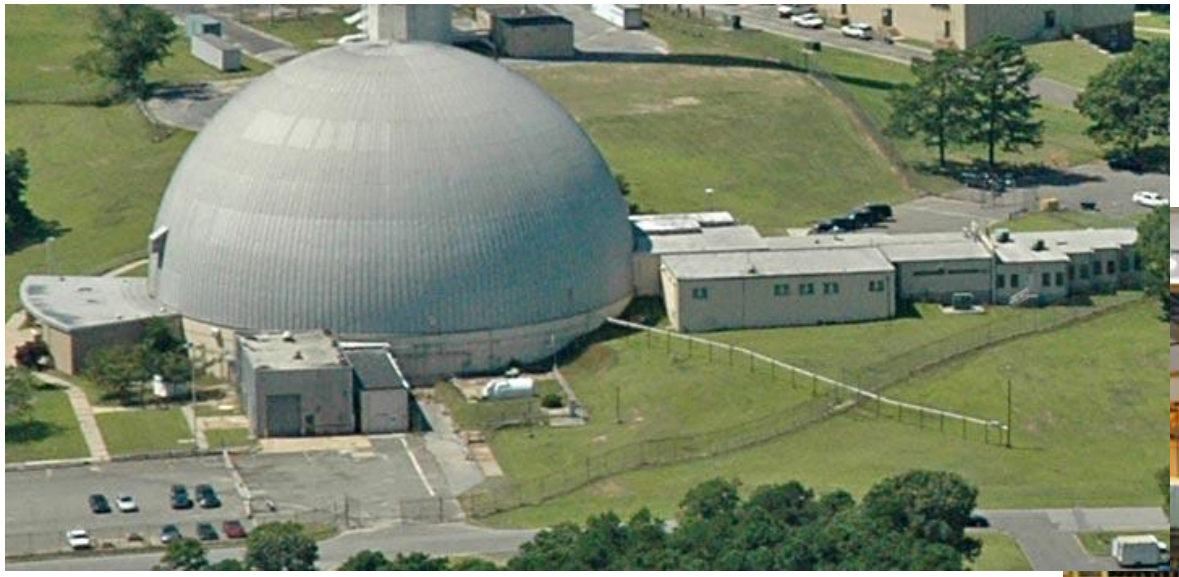
- Germany: Berlin, Julich (1962), Karlsruhe (1962), Munich (1957), ???
- Denmark: Riso (1960)
- UK: Harwell (1957), Aldermaston
- USA: Brookhaven (BNL), Oak Ridge (ORNL), … …

The international context in the 60s and 70s

HFBR, Brookhaven National Laboratory, 1965-1999



- High Flux Beam Reactor
- 60MW
- "a small research reactor that operated at BNL"

The international context in the 60s and 70s

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- Denmark: Riso (1960)
- UK: Harwell (1957), Aldermaston
- USA: Brookhaven (BNL), Oak Ridge (ORNL), … …
- Canada: Chalk River (CRNL)

The international context in the 60s and 70s

Chalk River Nuclear Laboratories (AECL), Canada

- NRX: 1947 - 1992, 20MW
- NRU: National Research Universal reactor, 1957 - 2018, 200 MW → 60 MW → 135MW

NEUTRONS FOR SOCIETY

The international context in the 60s and 70s

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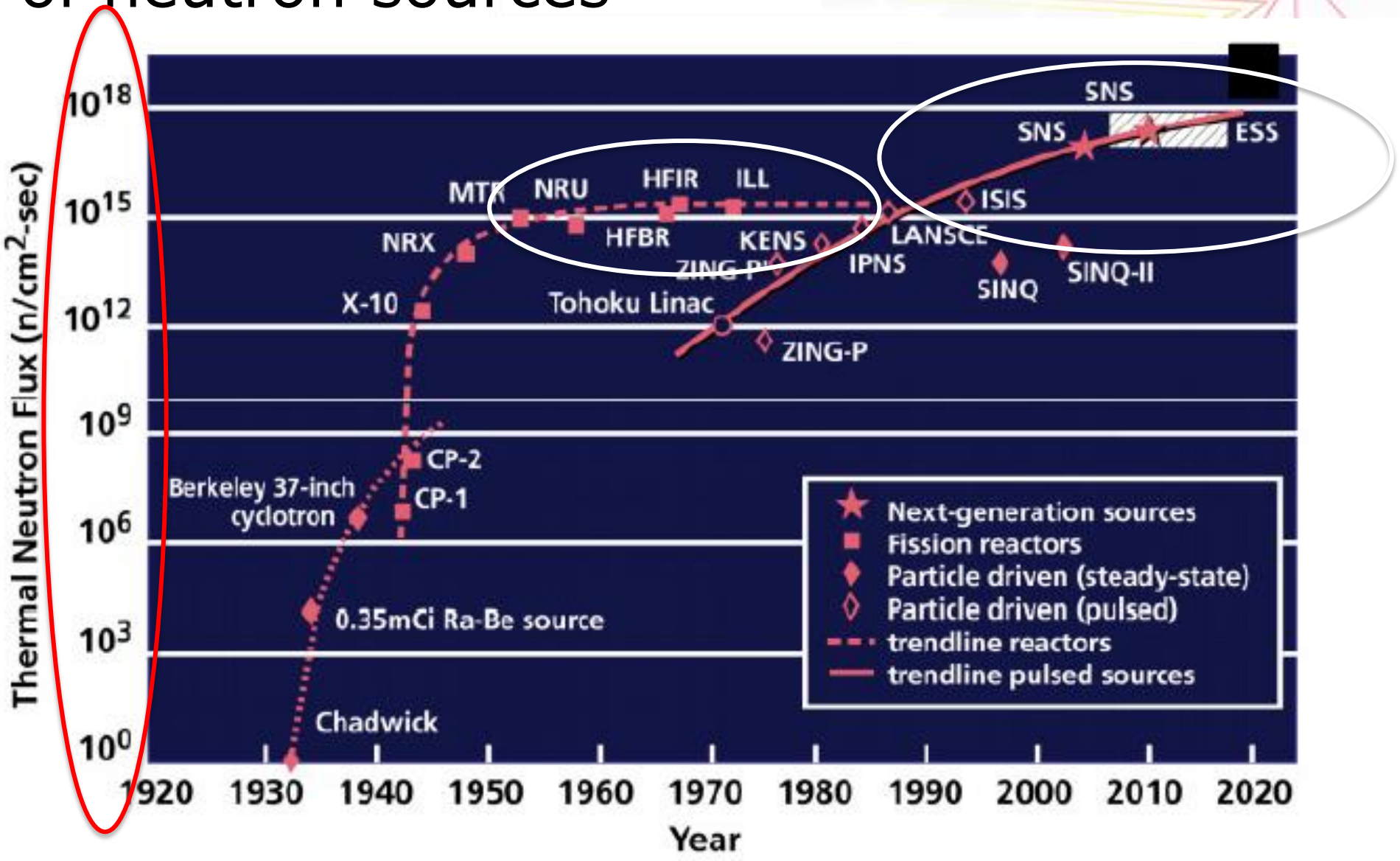
- Canada: Chalk River (CRNL)
- Russia, Japan, … …

Comparison with power reactors …

Hinkley Point B
- 2 x 470 MWe

Hinkley Point C (future)
- 2 x 1600 MWe (4500 MWth)

History of neutron sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price: eds., Academic Press, 1986)

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NEUTRONS FOR SOCIETY

The early days (slide show)

The birth of the ILL (simplified)

- 1960s: after the success of CERN (1954), ideas for future European cooperation in science
- OECD*: several projects including high flux research reactor (advanced planning for BNL HFBR)
- First project failed (rejected by UK despite involvement in project)
- CEA revived project: discussions with Germany (Heinz Maier-Leibnitz)
- 19 January 1967:
  Intergovernmental Convention between France and Germany to construct ILL in Grenoble (50/50 for 18 years)

* OECD: Organisation for Economic Co-operation and Development

NEUTRONS FOR SOCIETY

Founding fathers

Heinz Maier-Leibnitz (1911 – 2000)
Louis Eugène Félix Néel (1904 – 2000)

Heinz Maier-Leibnitz
Bernard Jacrot (1926 – 2016)

- plus many other French and German scientists, engineers, technicians …

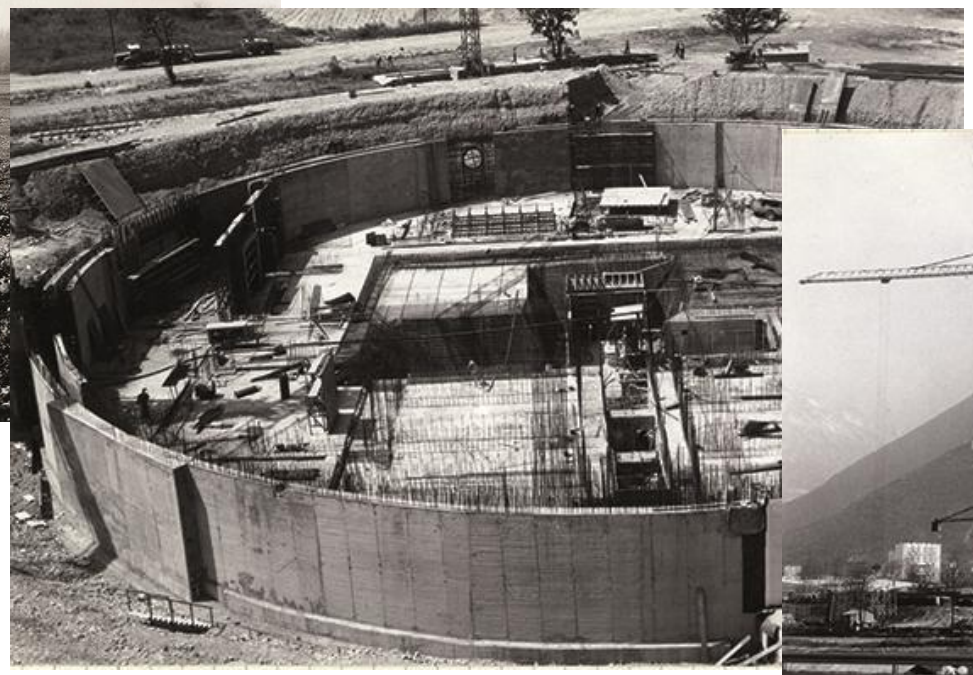
NEUTRONS FOR SOCIETY

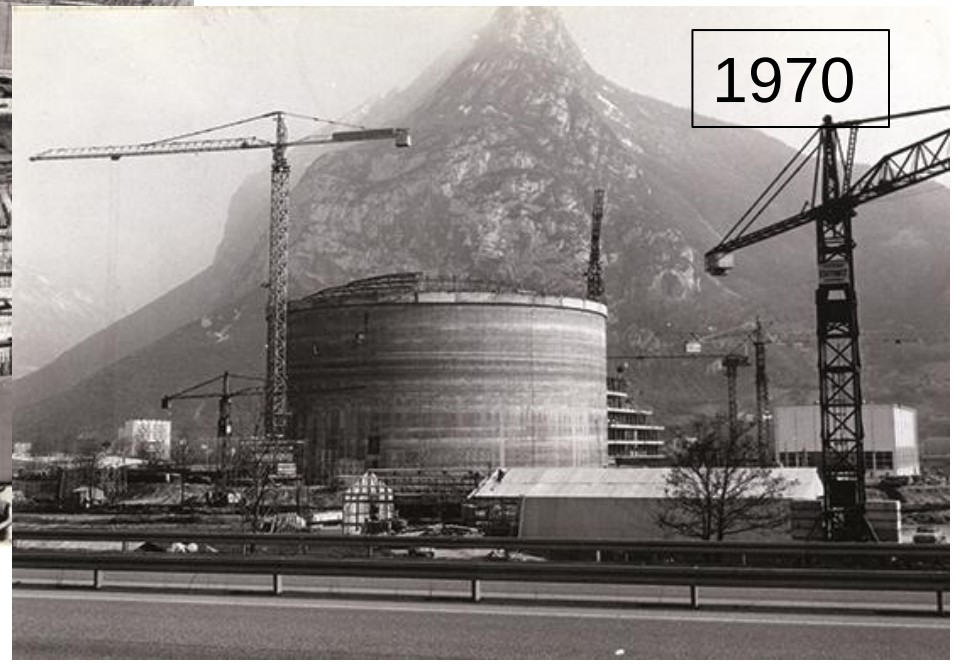
The birth of the ILL (simplified)

- 1960s: after the success of CERN (1954), ideas for future European cooperation in science
- OECD: several projects including high flux research reactor (advanced planning for BNL HFBR)
- First project failed (rejected by UK despite involvement in project)
- CEA revived project: discussions with Germany (H M-L)
- 1967: Intergovernmental Convention between France and Germany to construct ILL in Grenoble (50/50 for 18 years)
- 1967: two Directors (H M-L, BJ) + Secretary and Head of Admin
- **NB: Important (unusual?) concepts - external users; 5 year contracts for scientists; T&S costs covered**
- 1969: work starts on reactor
- 1971: 31 August - *divergence*

NEUTRONS FOR SOCIETY

Construction of the reactor

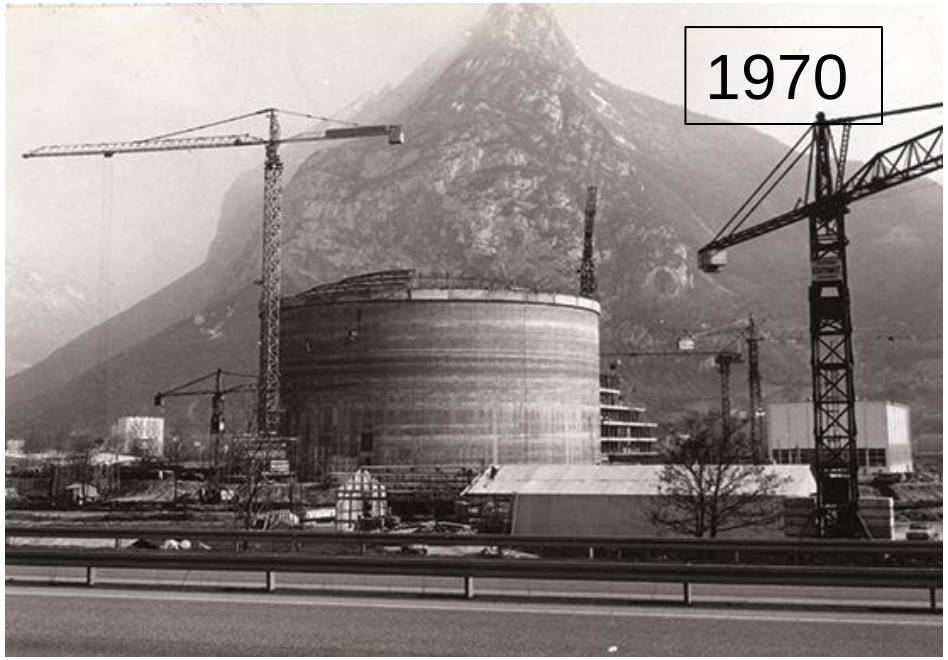




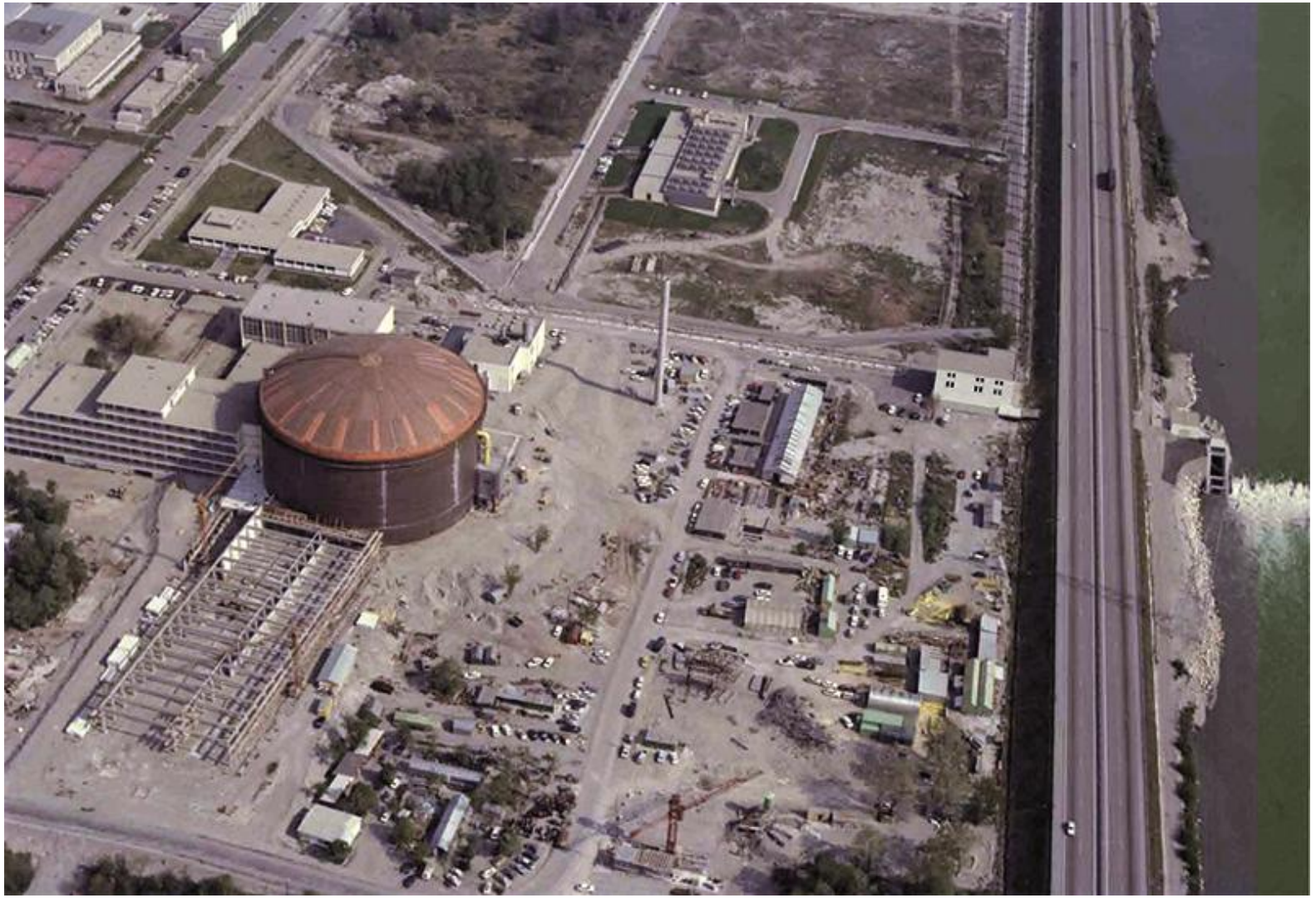
NEUTRONS FOR SOCIETY

Construction of the reactor

- Tragic accident, 13 February 1970
- Roof (under construction) collapses
- 5 workmen dead, 2 seriously injured
  - Albert Botta (29)
  - Abder Khader Benfatem (22)
  - Rabah Ben Mohamed Dahmani (28)
  - Abdel Khader Bachir-Elezaar (30)
  - Belkhacem Khadraoui (22)
- Courts found that company that mounted the scaffolding was responsible



Construction of the reactor



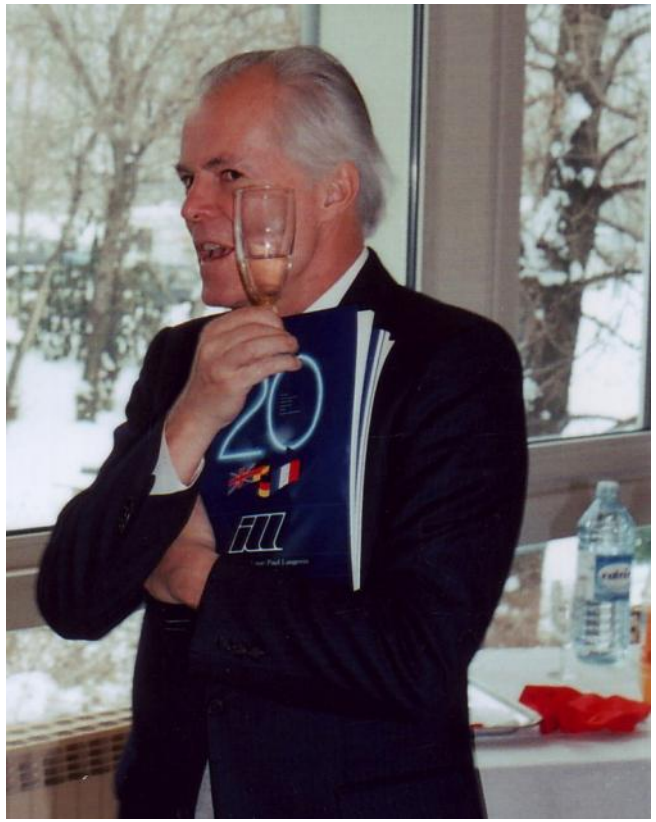
1970

The ILL site before the arrival of the ESRF

1980s

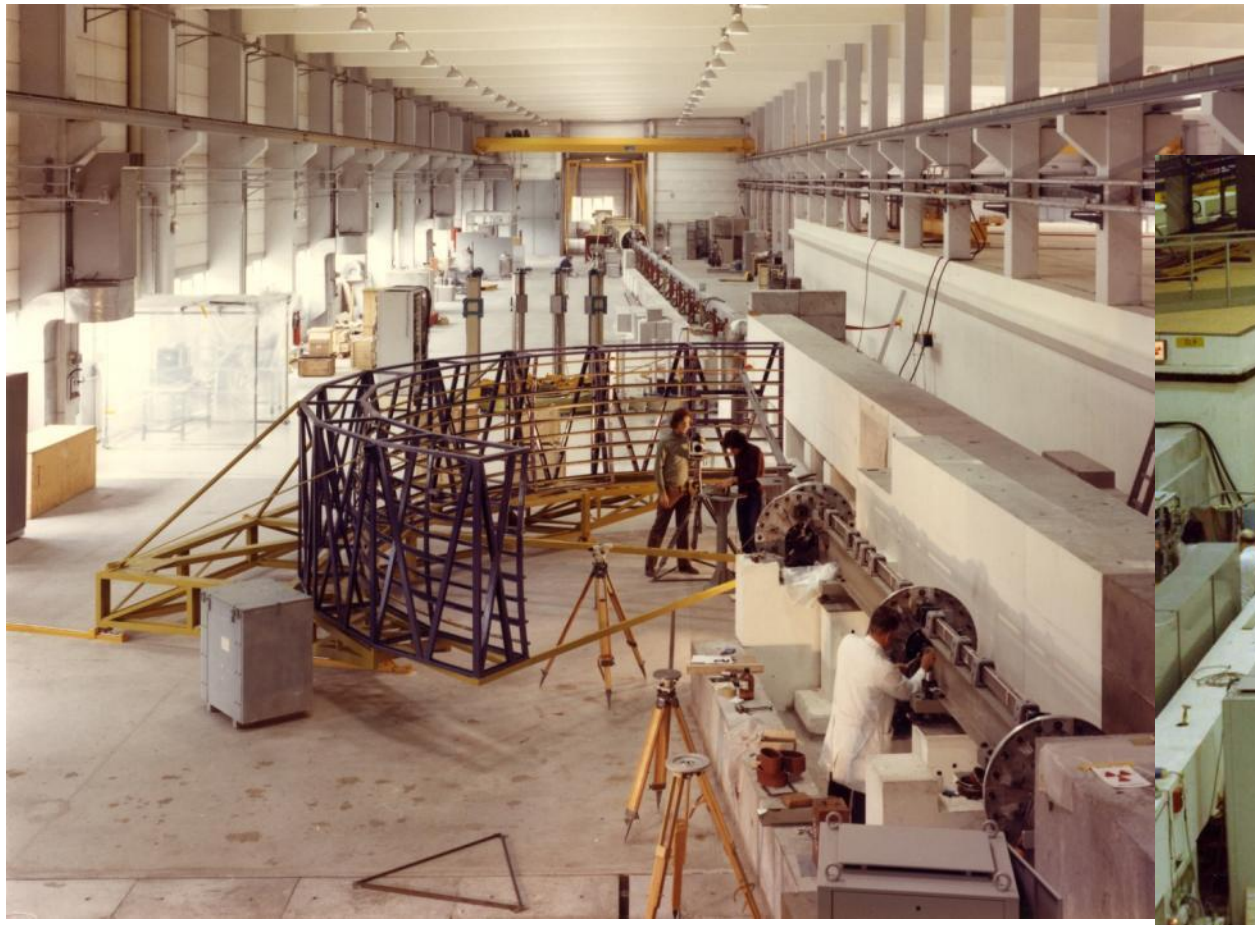
The EPN Science Campus site today

The next Directorate - from construction to operation …



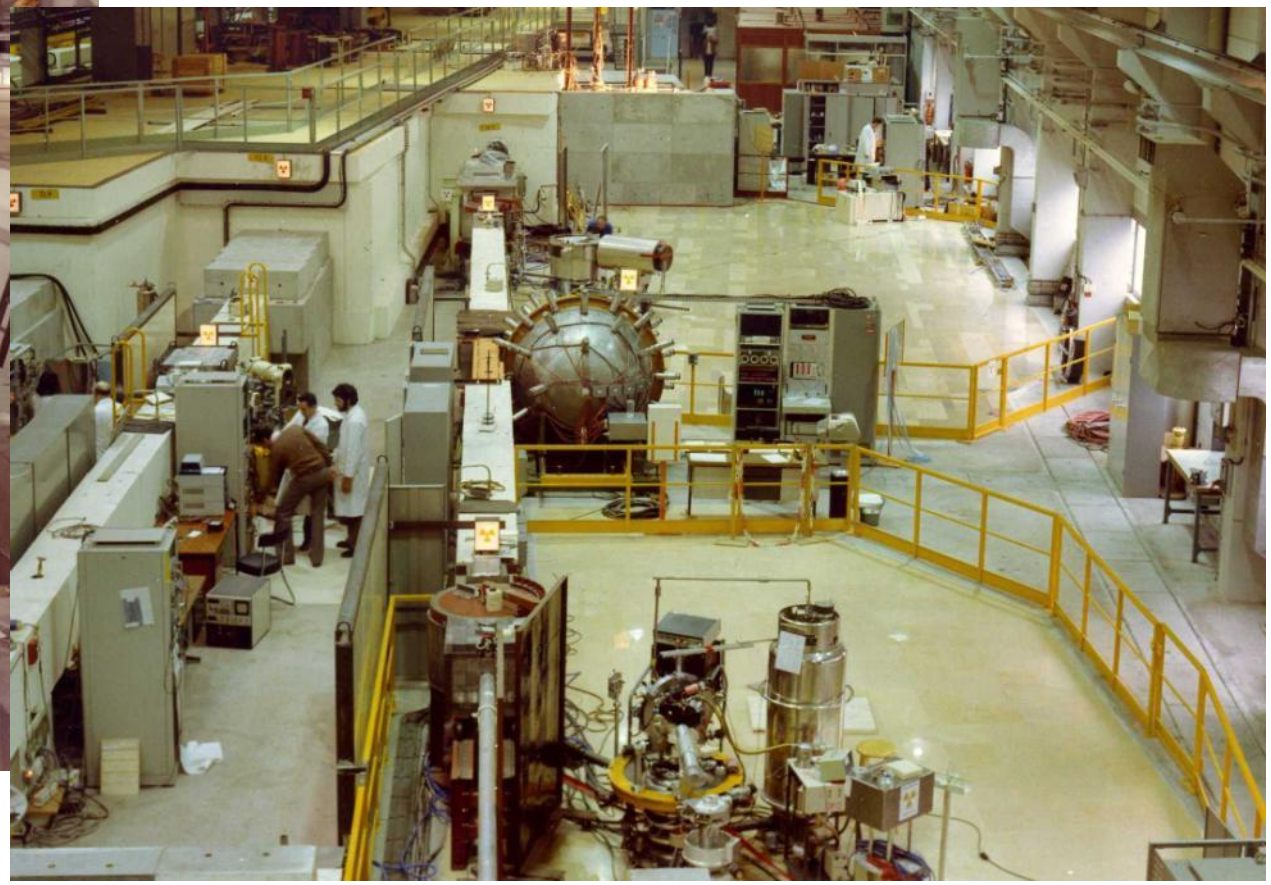
Rudolf Mössbauer	Bernard Jacrot	Mick Lomer

The (first) guide hall



1970

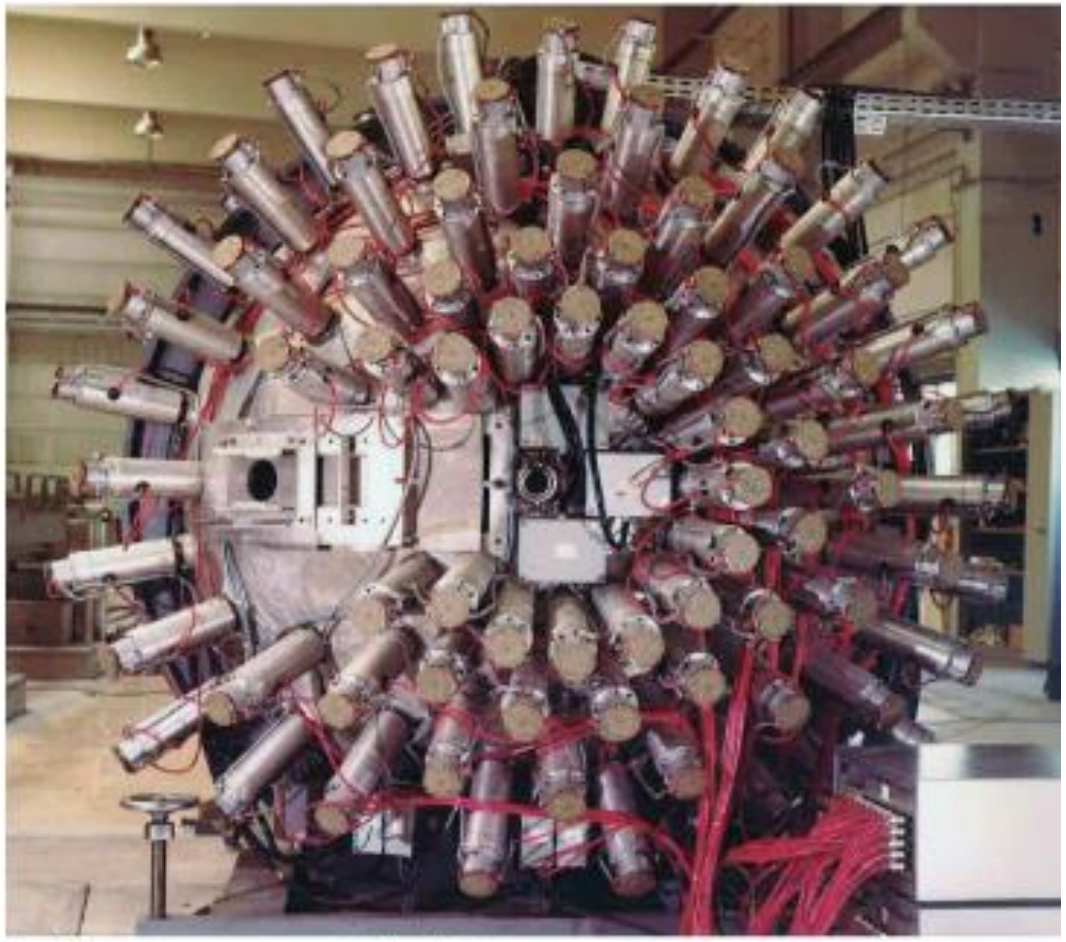
1974



NEUTRONS FOR SOCIETY

Early instruments

D8 1973



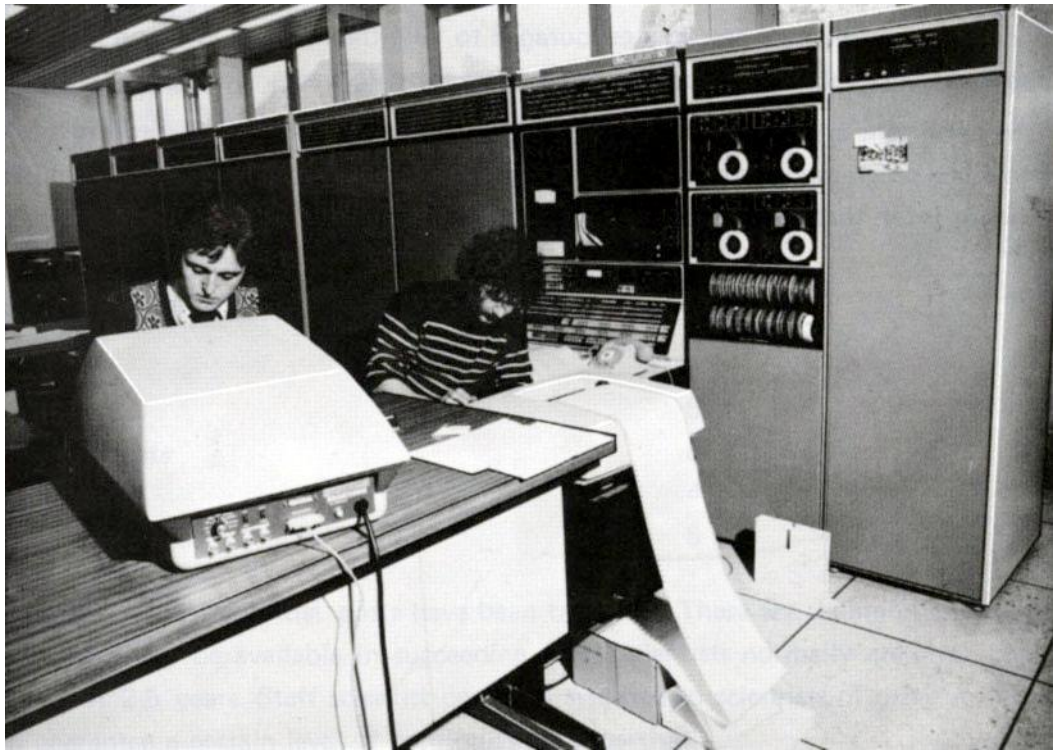
D6: *le hérisson*

Early instruments

D11 1975

Early instruments

IN2 1973



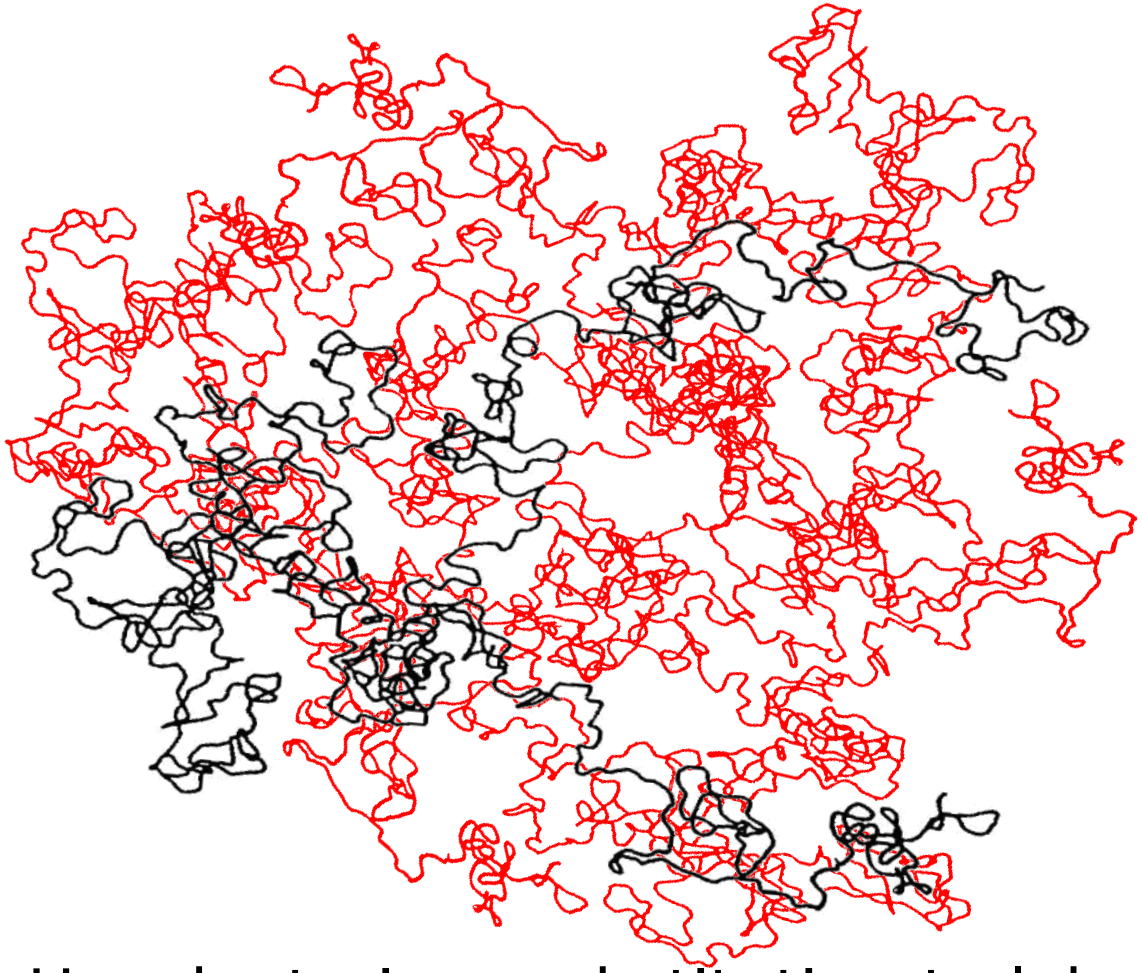
Dec10 1974

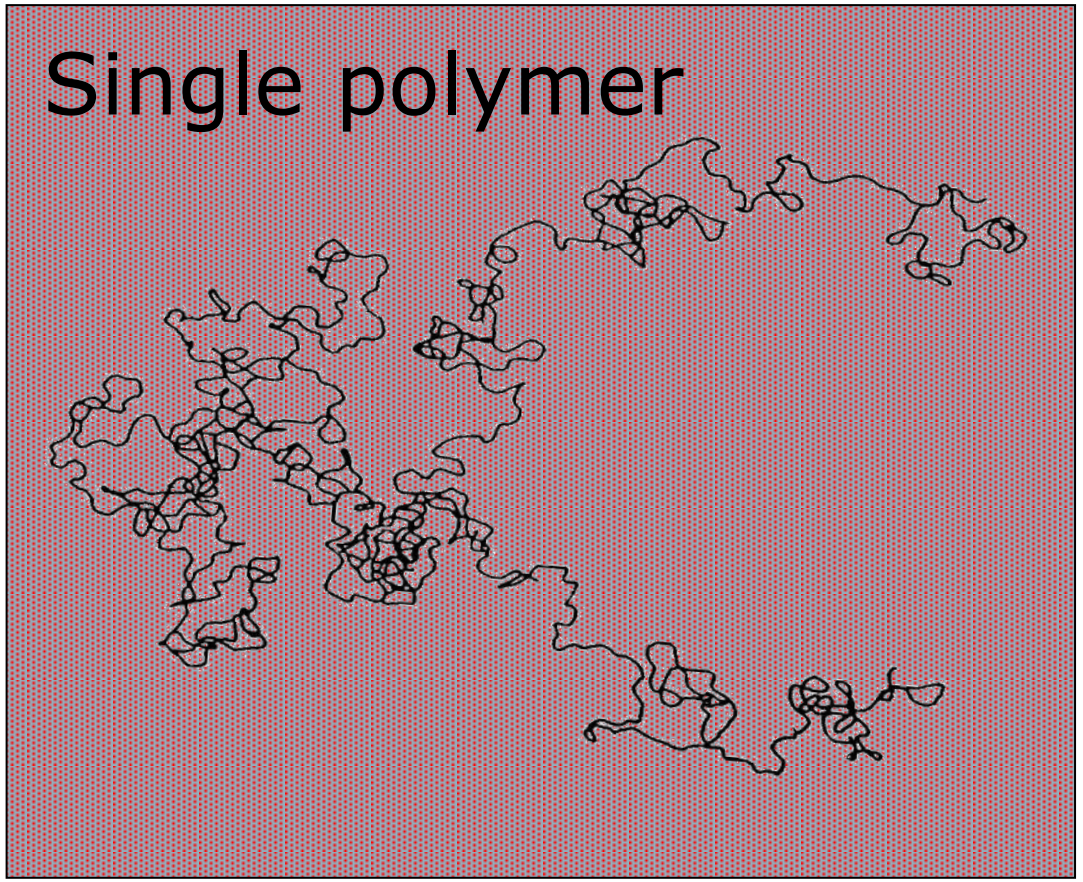
Early science

- Julia Higgins (ILL, IC London): soft condensed matter with neutrons
- SANS (D11 …), QENS …
- Among the big questions for polymer scientists still open in 1970:
  - Is the individual polymer molecule a “random walk” in a melt sample (Flory)?

NEUTRONS FOR SOCIETY

Early science: entangled polymer chains





Use deuterium substitution to label the black molecule in a neutron scattering experiment

Early science: entangled polymer chains

Macromolecules
Vol. 7, No. 6, November–December 1974

Conformation of Polymer Chain in the Bulk

J. P. Cotton,[1a] D. Decker,[1b] H. Benoit,[1b] B. Farnoux,[1a] J. Higgins,[1c] G. Jannink,[1a] R. Ober,[1d] C. Picot,[1b] and J. des Cloizeaux[1e]

ABSTRACT: Neutron coherent scattering techniques have been used for the determination of the conformation of polymer in bulk and experimental details are given about the application of this method to the study of polymeric systems. Measurements have been made for small and intermediate momentum ranges on a series of eight monodisperse deuterated polystyrenes of molecular weight ranging from 21,000 to 1,100,000. The results lead to the conclusion that in amorphous state the conformation of the polymer molecule is indistinguishable from that in θ solvent and that the Debye scattering function which is valid for unperturbed chains applies for q^{-1} as low as 10 Å.

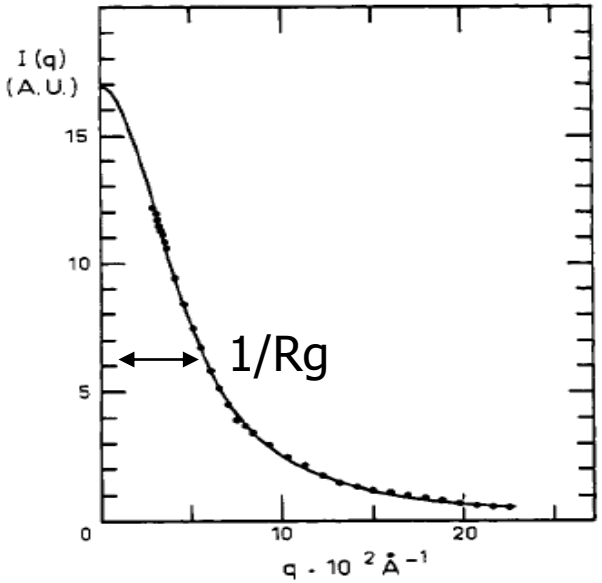
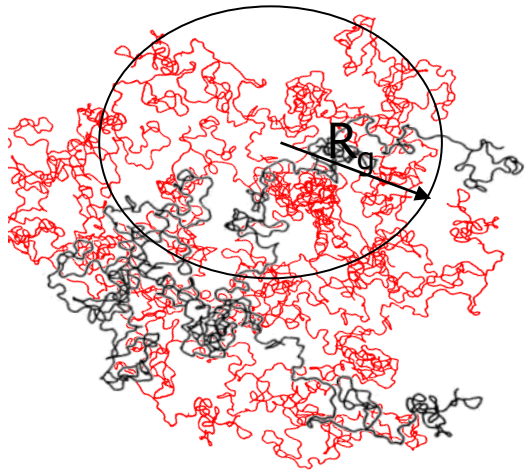


Figure 6. Intensity, in arbitrary units, obtained as a function of q by difference of the curves of Figure 5. The full line is a calculated curve which is explained at the end of this paper.



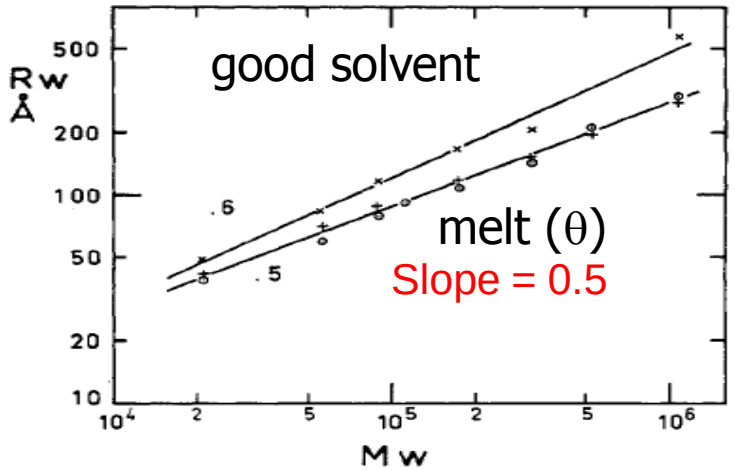
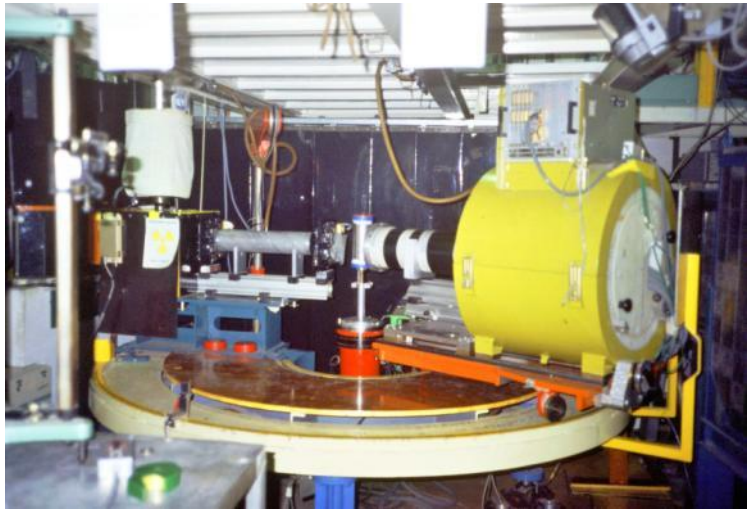


Figure 8. Log R_w is plotted *vs.* log M_w. The experimental data are obtained in different environments: (X) in a good solvent CS_2, (+) in a θ solvent, (⊙) in the bulk. The slopes of 0.6 (in CS_2) and of 0.5 are obtained by a best fit method.

Early science

- Joe Zaccai (ILL, CNRS): biology with neutrons
- SANS (D11 …), membrane diffraction (D16 …) …
- Membrane protein structure

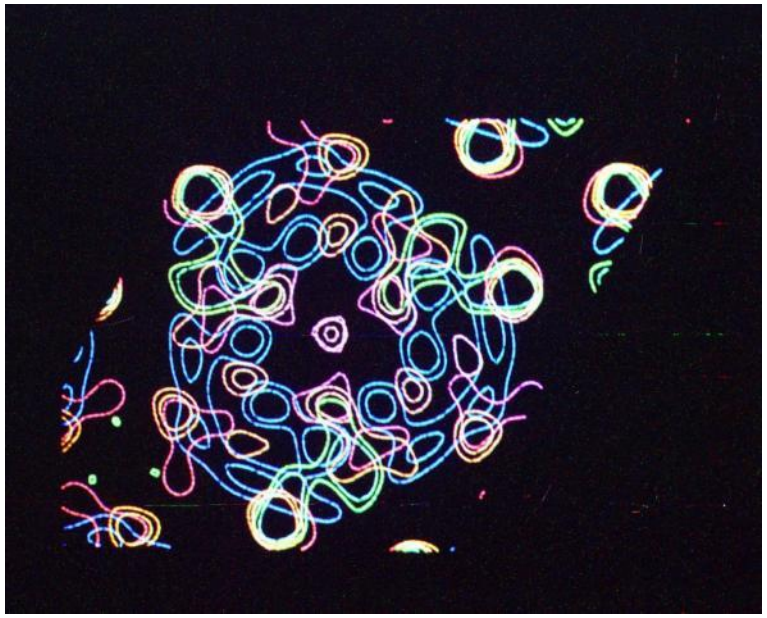
BNL low-angle diffractometer that inspired D16



Early D16
Zaccai ,Wilson

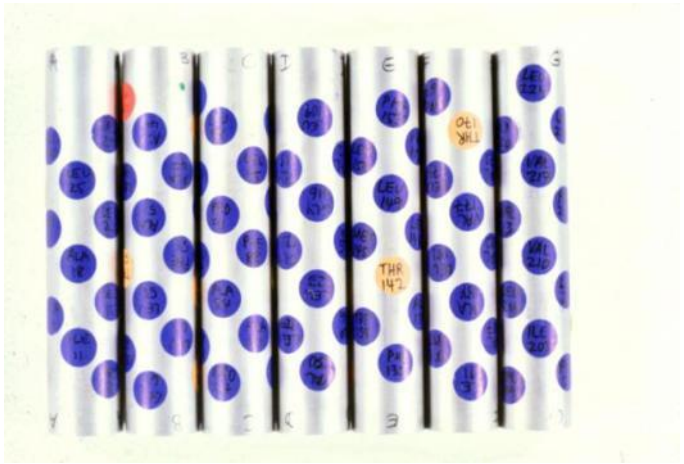
D16 now
Deme, Cristiglio

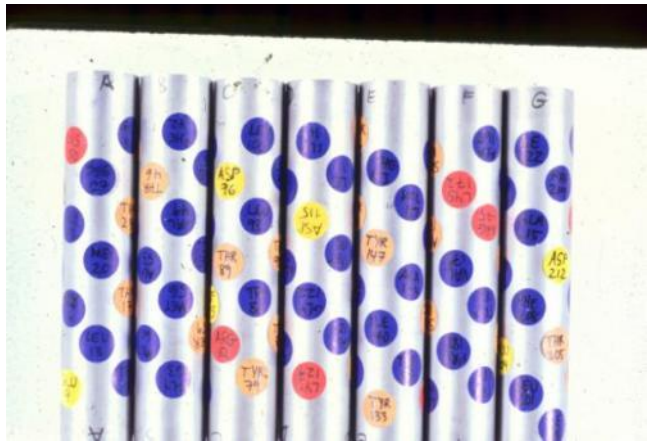
Early science: membrane protein structure



Difference Fourier peaks due to specific deuterated amino acids superposed on the BR projection (in blue)

- Specific deuteration of amino acids used to determine the orientation of the seven alpha helices in bacteriorhodopsin (BR) by neutron diffraction
- Difference Fourier analysis
- Results showed polar faces on the inside of the structure with apolar faces towards the membrane lipids





'Cigar tube' representation of the seven BR alpha helices; apolar amino acids in blue, polar amino acids in other colours according to their charge

Early science

- Michael Steiner (HMI/HZB, U of Mainz, TU Berlin): condensed matter physics with neutrons
- TAS (IN2 … …)
- Magnetic excitations in 1-D magnet ($CsNiF_3$)

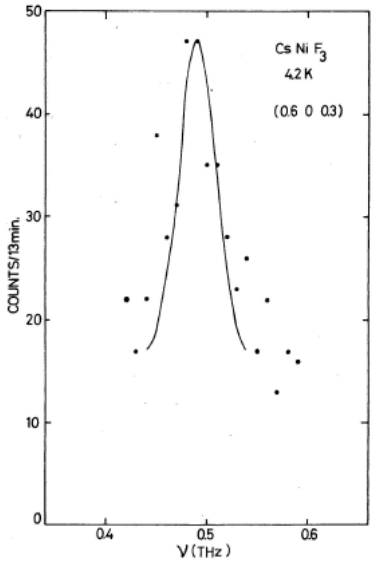


FIG. 2. Results of a const-Q scan, no background subtracted. The instrumental resolution is given by a Gaussian.

Early science: low dimensional magnetism

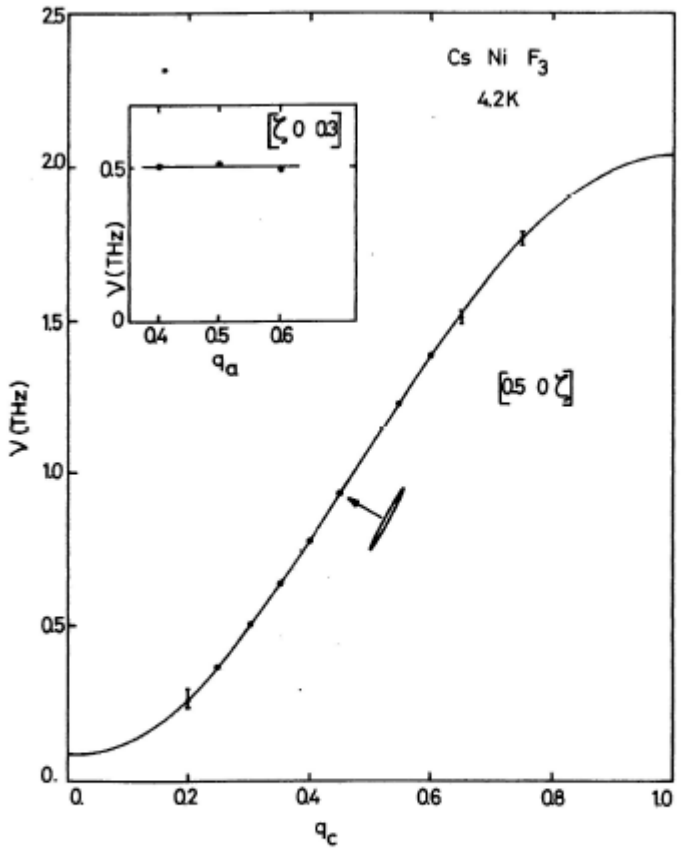
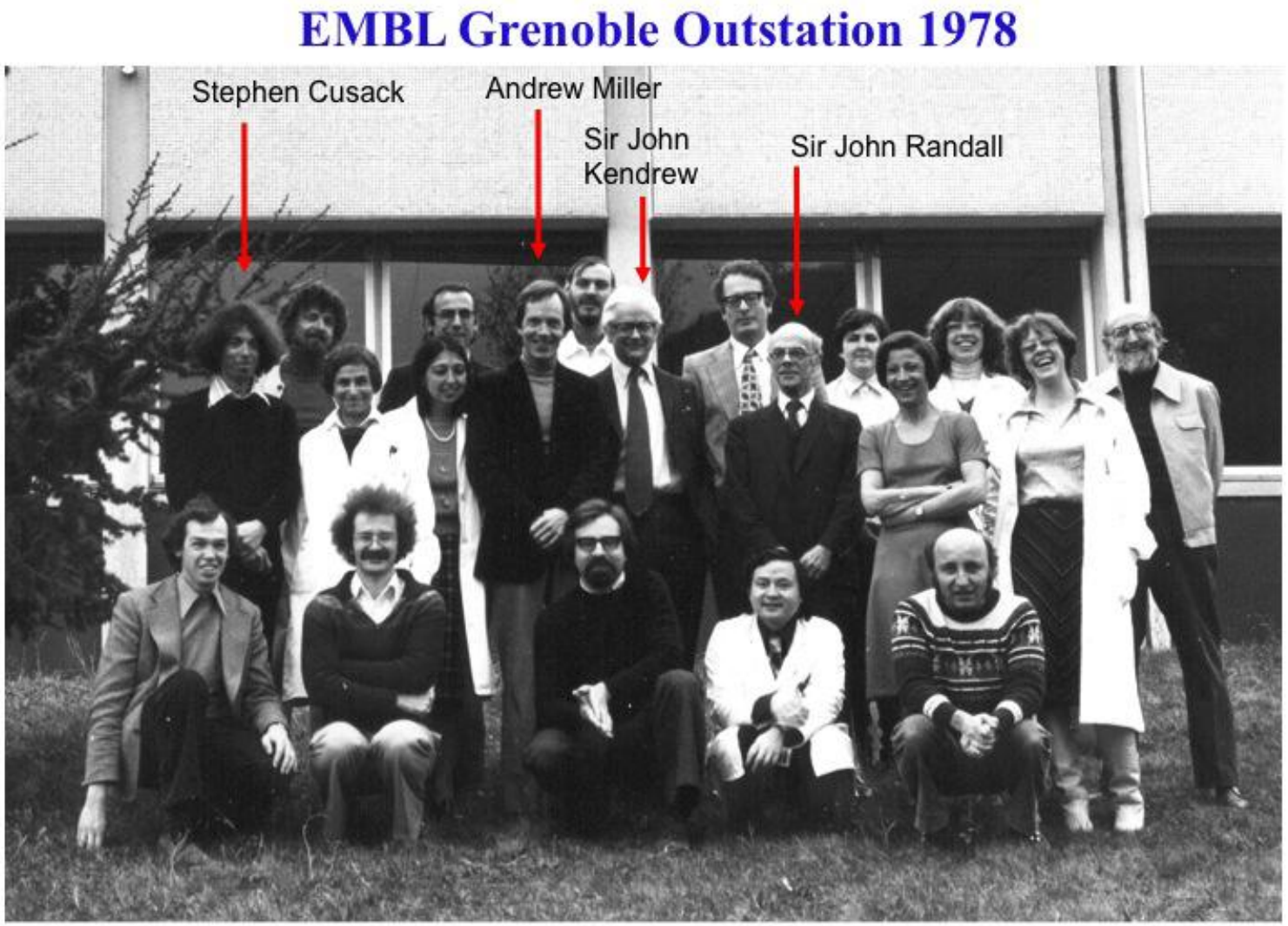


FIG. 3. Dispersion relation of the spinwaves along q_c and for different q_a in the insert. The solid line is the least squares fit of equation (1) to the data. The projected resolution is drawn as an ellipse.

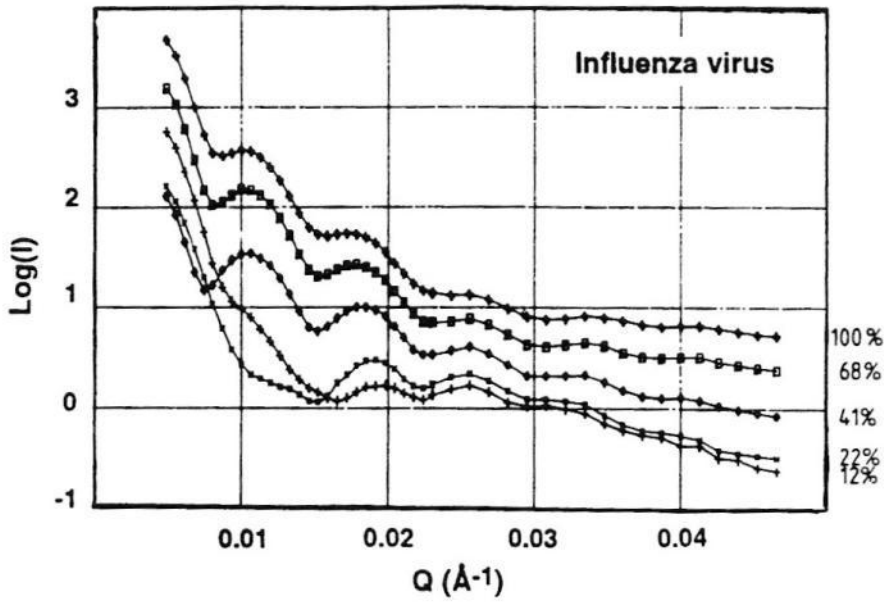
- $CsNiF_3$ ferromagnet
- 1-D spin-wave dispersion curve (nearest neighbour interactions along chain)
- Frequencies ~ constant perpendicular to chain direction (so 1-D)
- First ILL publication
  Steiner and Dorner, Solid State Comm 12, 537, 1973
- First (?) of many neutron studies of excitations in low-dimensional magnets

NEUTRONS FOR SOCIETY

Early science: EMBL (from 1976)



Early science: EMBL (S Cusack (EMBL) et al)



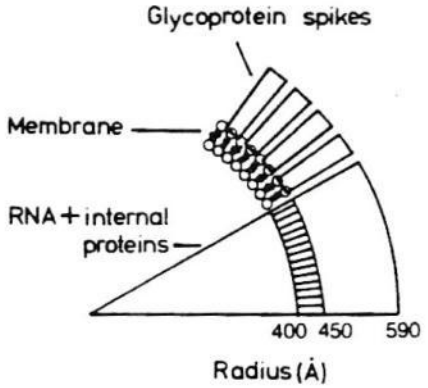


Fig. XIV.6. — (a) Neutron scattering curves from solutions of influenza virus in different D_2O/H_2O mixtures as indicated. (b) Low resolution model of the influenza virus as deduced from the small angle scattering curves. From Cusack (1982) with permission.

The Neutron and its applications, 1982 Inst. Phys. Conf. Ser. No. 64, Section 4, pp 351-355.

The Partnership for Structural Biology (PSB): 2002 EMBL, ESRF, IBS, ILL

The Carl-Ivar Brändén building (CIBB)

But it wasn’t all work …

ILL timeline

1961 - 1970

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
THE ILL STORY		First plans for a heavy water reactor J. Horowitz to R. Dautray: "Draw me a reactor"		The Geneva conference: J. Horowitz suggests a Franco-German initiative H. Maier-Leibnitz puts ILL on the map (at Grenoble!)			19 January: signing of the Intergovernmental Convention		Work starts on the reactor	
WORLD HISTORY	12 April, Y. Gagarin: the first man in space		Paris, 22 January: the signing of the Franco-German Elysée Treaty						Neil Armstrong walks on the moon	
WORLD SCIENCE		Nobel Prize for the work by F. Crick, J. Watson and M. Wilkins on DNA	USA: the world's first human heart transplant				Tectonic plate theory		Description of the molecular structure of insulin	Néel wins Nobel Prize for discoveries in magnetism
ILL SCIENCE										
ILL & NEUTRON TECHNOLOGY						H. Maier-Leibnitz and B. Alefeld invent neutron backscattering A. Heidemann brings it to the ILL with IN10 (commissioned in 1974)				

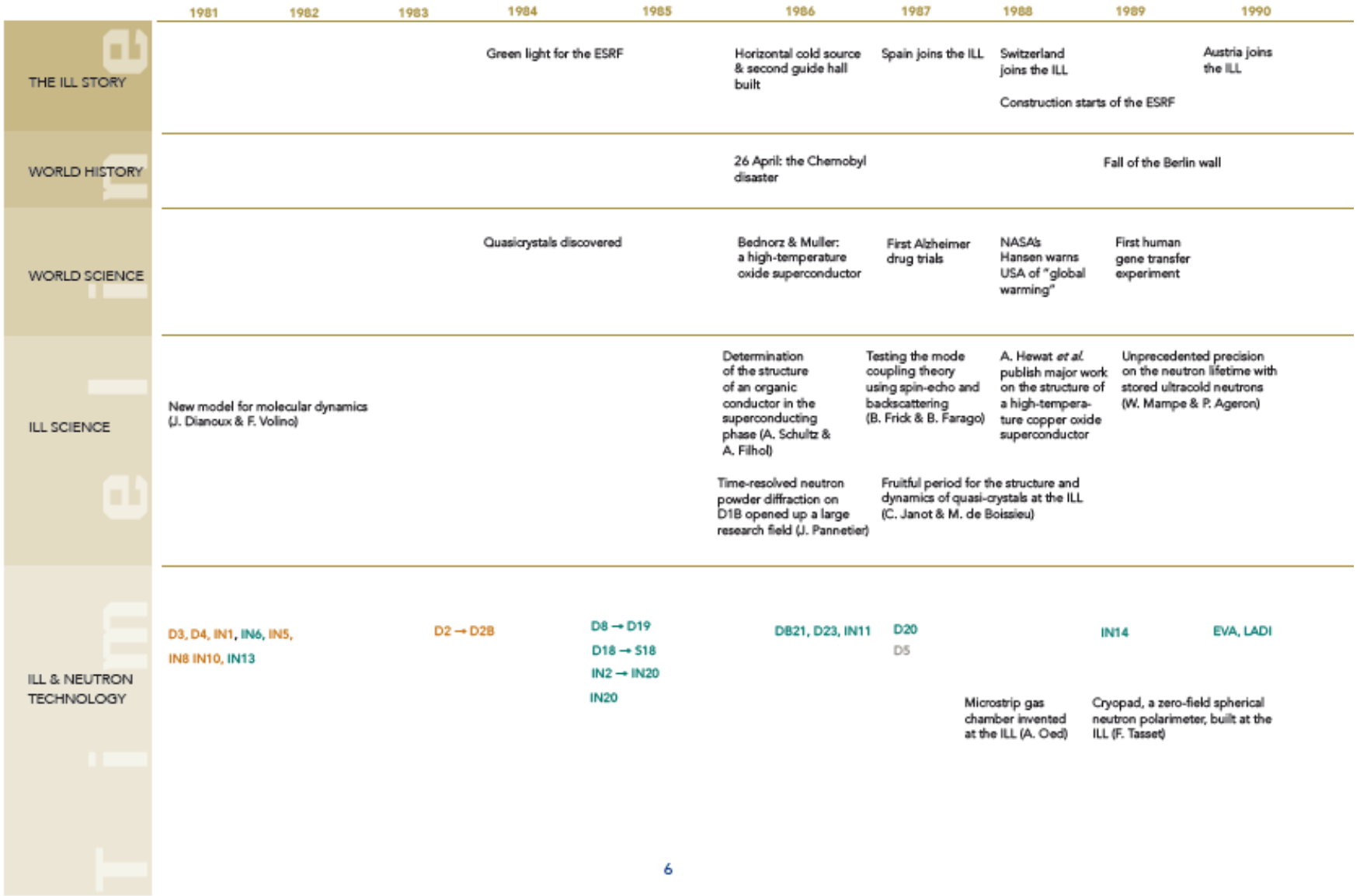
1971 - 1980

1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
31 August - Reactor goes critical	The founders confirm a user service philisophy for the ILL	UK joins the ILL						The 'Deuxième souffle'	
	First Earth Summit (Stockholm)	UK joins the EEC							
G. De Gennes' reptation theory		Gavaler discovers Nb_3Ge, a super-conductor at 22 K				The first complete genome sequence		First "World climate conference", Geneva	The world awakes to AIDS
Neutron bottles for ultracold neutron storage (F. L. Shapiro *et al.*)	First experiment on ILL's IN2 (B. Dorner & M. Steiner)		First neutron scattering experiment on (normal) liquid ^{3}He (Cowley, Scherm & Stirling) Stuhrmann develops the mathematical formula for the contrast variation method	Key experiments on IN10 and D1A: tunnelling motions of CD_4 and CD_3 groups and Rietveld refinement First QNS experiment in a polymer (Higgins, IN10)			Experimental evidence for dynamic scaling predictions in polymer solutions (F. Mezei, Richter *et al.*)	Structural characterisation of a natural biological membrane (J. Zaccai) Spin-wave observations in in the actinide α–uranium compounds (J.C. Marmeggi) Discovery of the dynamic nature of spin glass transition by NSE and 3-directional polarisation analysis (F. Mezei & A. Murani)	Incommensurate phase of biphenyl (C. Zeyen *et al.*)
	D2, D4, IN1, IN2 Neutron spin-echo invented and tested by F. Mezei First tanzboden instruments at the ILL (IN2, IN3, ...)	D1A, D1B, D5, D8, IN3, IN4, IN5, IN7, IN10, PN1 PN2-BILL, PN3, 4-GAMS Ibel and Roth build SANS D11 and D17 on cold source guide		D3, D17 Orange cryostat built at the ILL (D. Brochier & S. Pujol) J. Paureau (CNRS) and C. Vettier develop the first high pressure cells (5-6 kbar) and first Al_2O_3 clamps (20-30mbar)	D18, IN8 F. Mezei invents supermirrors	IN11 PN5/SN5 (FUTURE PF2) PN7 (FUTURE PF1)		IN12 PN8 P. Aldebert's neutron furnace for solid samples reaches 2400°C	D5

5

Instrument start - First upgrade - Second upgrade - Instrument closure

1981 - 1990


1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
THE ILL STORY
Green light for the ESRF
Horizontal cold source & second guide hall built
Spain joins the ILL
Switzerland joins the ILL
Construction starts of the ESRF
Austria joins the ILL
WORLD HISTORY
26 April: the Chernobyl disaster
Fall of the Berlin wall
WORLD SCIENCE
Quasicrystals discovered
Bednorz & Muller: a high-temperature oxide superconductor
First Alzheimer drug trials
NASA's Hansen warns USA of "global warming"
First human gene transfer experiment
ILL SCIENCE
New model for molecular dynamics (J. Dianoux & F. Volino)
Determination of the structure of an organic conductor in the superconducting phase (A. Schultz & A. Filhol)
Testing the mode coupling theory using spin-echo and backscattering (B. Frick & B. Farago)
A. Hewat et al. publish major work on the structure of a high-tempera-ture copper oxide superconductor
Unprecedented precision on the neutron lifetime with stored ultracold neutrons (W. Mampe & P. Ageron)
Time-resolved neutron powder diffraction on D1B opened up a large research field (J. Pannetier)
Fruitful period for the structure and dynamics of quasi-crystals at the ILL (C. Janot & M. de Boissieu)
ILL & NEUTRON TECHNOLOGY
D3, D4, IN1, IN6, IN5, IN8 IN10, IN13
D2 → D2B
D8 → D19
D18 → S18
IN2 → IN20
IN20
DB21, D23, IN11
D20
D5
IN14
EVA, LADI
Microstrip gas chamber invented at the ILL (A. Oed)
Cryopad, a zero-field spherical neutron polarimeter, built at the ILL (F. Tasset)

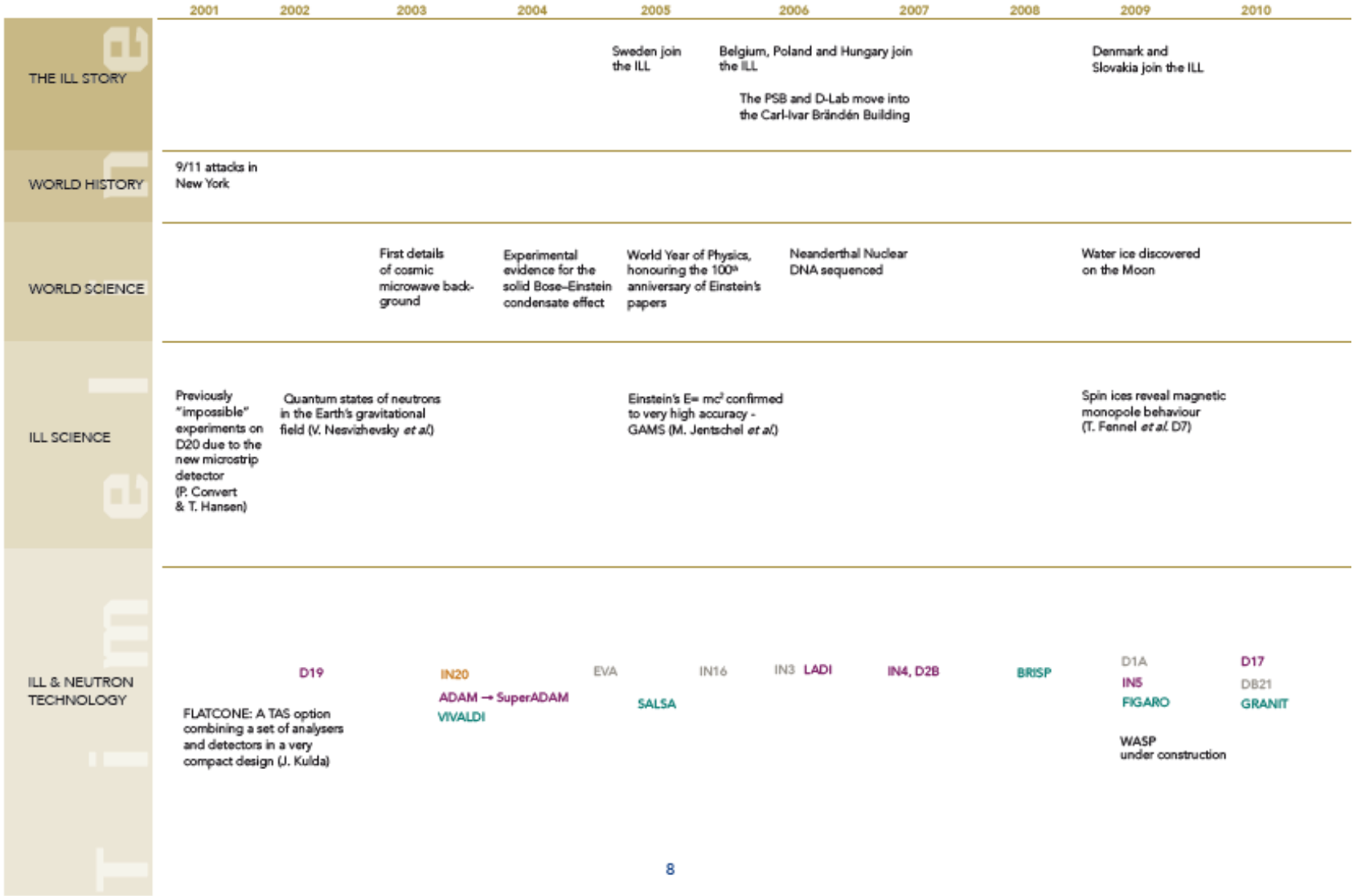
1991 - 2000

1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
			First CRGs at the ILL	Reactor restarts with new reactor vessel	Russia joins the ILL	Italy joins the ILL		Czech Republic joins the ILL	The Millennium Programme is launched
Dissolution of the Soviet Union	Signing of the Maastricht Treaty								
Carbon nanotubes discovered		Andrew Wiles proves Fermat's Last Theorem							
		Advances in magnetic structure determination with neutron powder diffraction (J. Rodriguez-Carvajal, most cited ILL paper)		Explanation of why alcaline batteries cannot be recharged - Real-time powder neutron diffraction on D1B (J. Pannetier)				Discovery of ice XII in two different regions of water's phase diagramm (W. Kuhs & M. Koza)	
PN2 - BILL, PN8					D23		IN16, ADAM	S18 IN22 LADI	D17, IN15	IN8
		Three-directional neutron polarisation analysis (O. Schärpf)								The Xenocs spin-off (optics for industry and research - P. Høghøj)

7

Instrument start - First upgrade - Second upgrade - Instrument closure

2001 - 2010


2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
THE ILL STORY
Sweden join the ILL
Belgium, Poland and Hungary join the ILL
The PSB and D-Lab move into the Carl-Ivar Brändén Building
Denmark and Slovakia join the ILL
WORLD HISTORY
9/11 attacks in New York
WORLD SCIENCE
First details of cosmic microwave background
Experimental evidence for the solid Bose–Einstein condensate effect
World Year of Physics, honouring the 100th anniversary of Einstein's papers
Neanderthal Nuclear DNA sequenced
Water ice discovered on the Moon
ILL SCIENCE
Previously "impossible" experiments on D20 due to the new microstrip detector (P. Convert & T. Hansen)
Quantum states of neutrons in the Earth's gravitational field (V. Nesvizhevsky et al.)
Einstein's E= mc² confirmed to very high accuracy - GAMS (M. Jentschel et al.)
Spin ices reveal magnetic monopole behaviour (T. Fennel et al. D7)
ILL & NEUTRON TECHNOLOGY
D19
FLATCONE: A TAS option combining a set of analysers and detectors in a very compact design (J. Kulda)
IN20
ADAM → SuperADAM
VIVALDI
EVA
SALSA
IN16
IN3
LADI
IN4, D2B
BRISP
D1A
IN5
FIGARO
WASP under construction
D17
DB21
GRANIT

2011 - 2017

2011	2012	2013	2014	2015	2016	2017
India joins the ILL	Post-Fukushima reinforcement work starts	The Intergovernmental Convention is extended to 2023			The Endurance programme is launched	50th anniversary of the ILL
The Fukushima nuclear accident				Major terrorist attacks in Paris	The Brexit vote	
	Higgs boson discovered at CERN	Creation of human embryonic stem cells by cloning			Gravitational waves detected	
Radioisotope production for cancer treatment (U. Koester *et al.*)		Experimental observation of a "quantum Cheshire cat" (H. Lemmel *et al.*, S18)		Protein water mobility studies (Härtlein & Weik, IN16) improve detection of Alzheimer's disease	Observation of proton transfer by neutron crystallography: key to future HIV drugs (M. Kowalevski & M. Blakeley, LADI) Oxyhalides: A new class of high- TC multiferroic materials (M.T. Fernandez-Diaz & C. Komarek)	

IN14 → ThALES

VIVALDI IN12 IN16 → IN16B IN1 → LAGRANGE IN10

9

Instrument start - First upgrade - Second upgrade - Instrument closure

The ILL today

NEUTRONS FOR SOCIETY

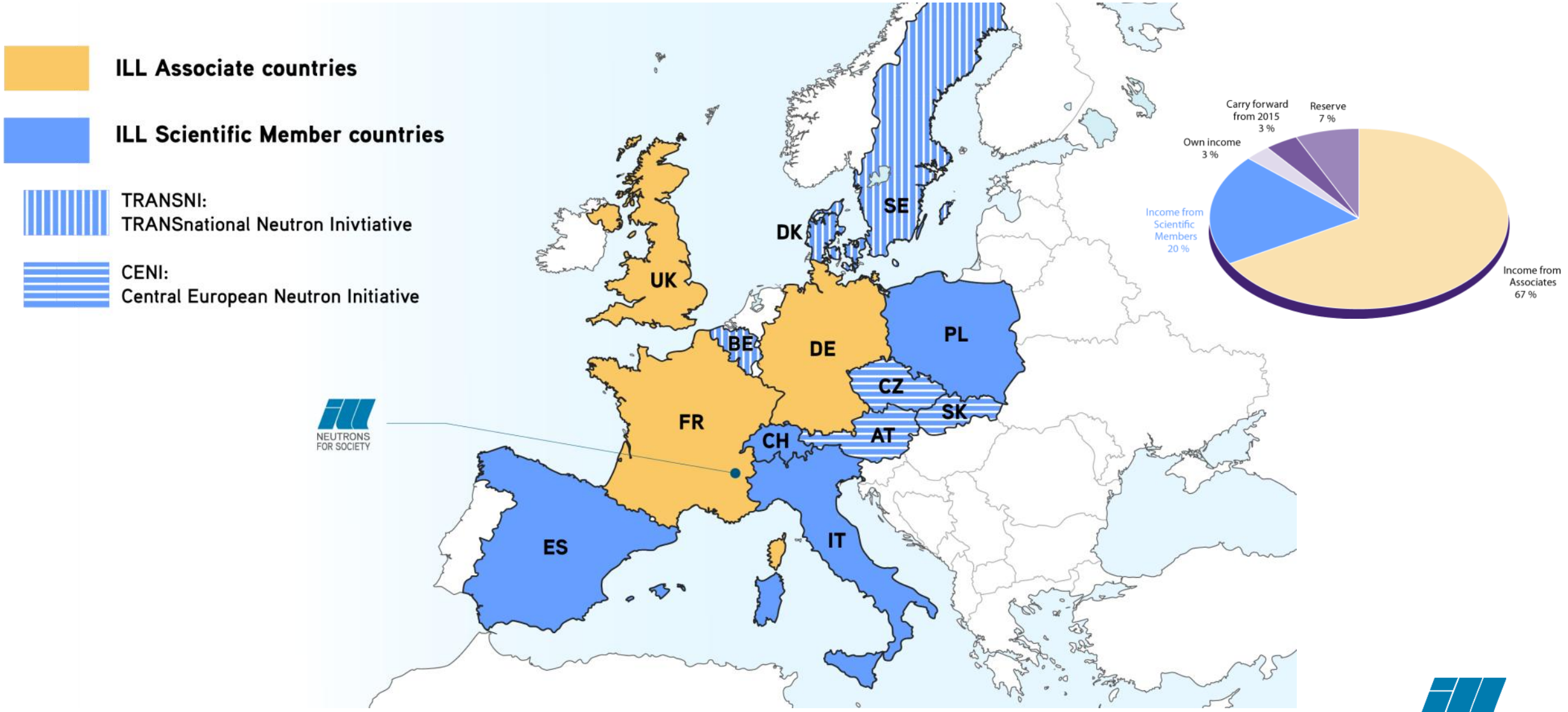
Institut Laue-Langevin

World leader in neutron science and technology

The ILL is the most intense neutron source in the world, at the service of international scientists, to carry out scientific research at the frontiers' of modern science. After 50 years, still number one.

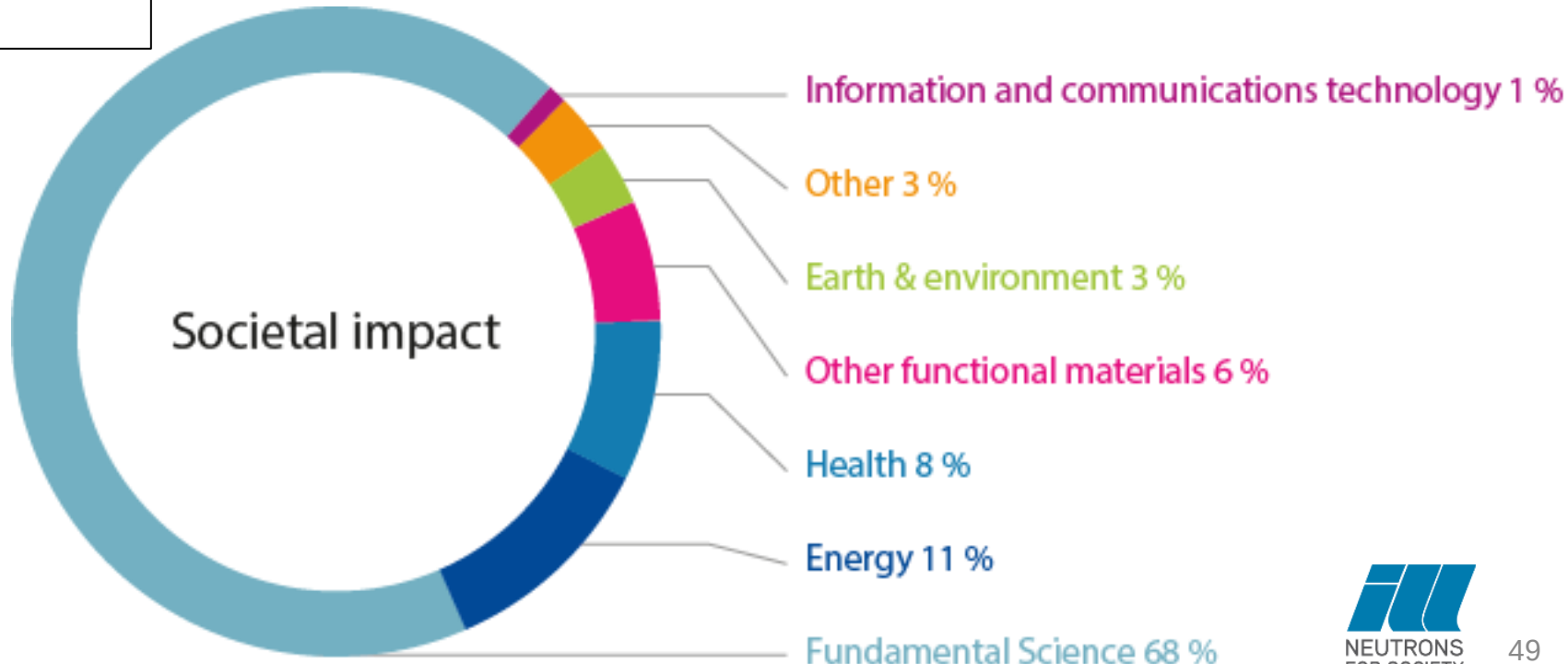
NEUTRONS FOR SOCIETY

ILL member countries and their financial participation



Science at ILL

- 850 experiments/year
- 1400 users
- 38 countries
- 28 instruments + 10 CRG
- 600 publications/year



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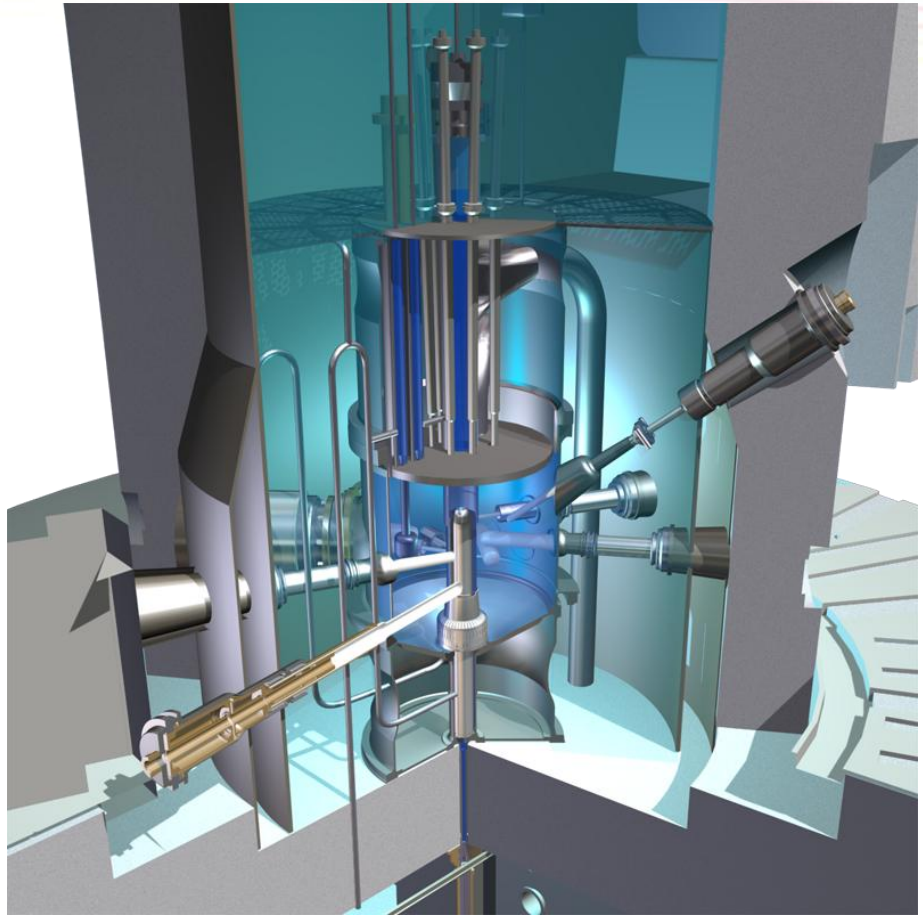
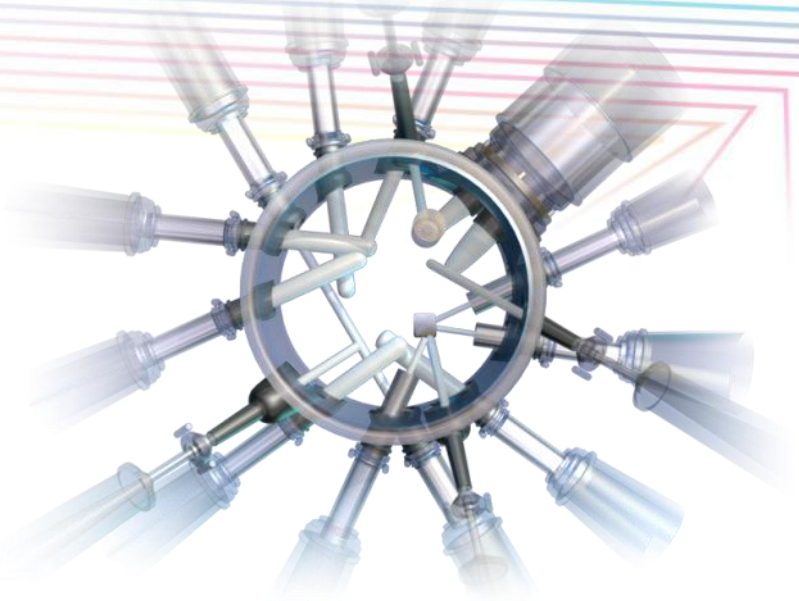
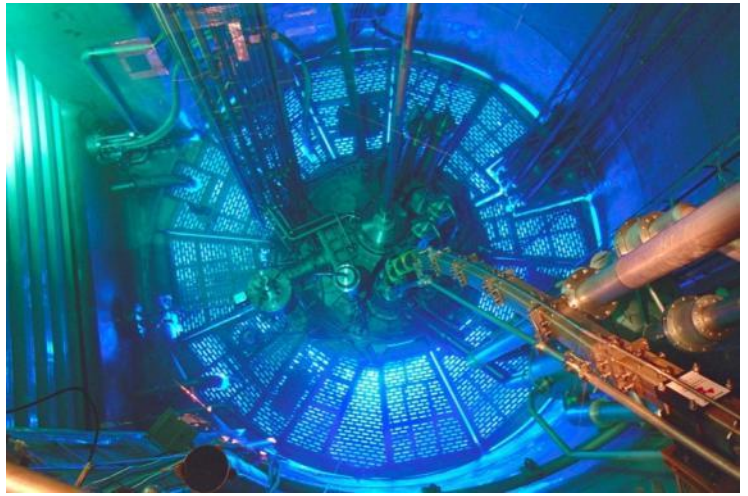
The ILL Reactor

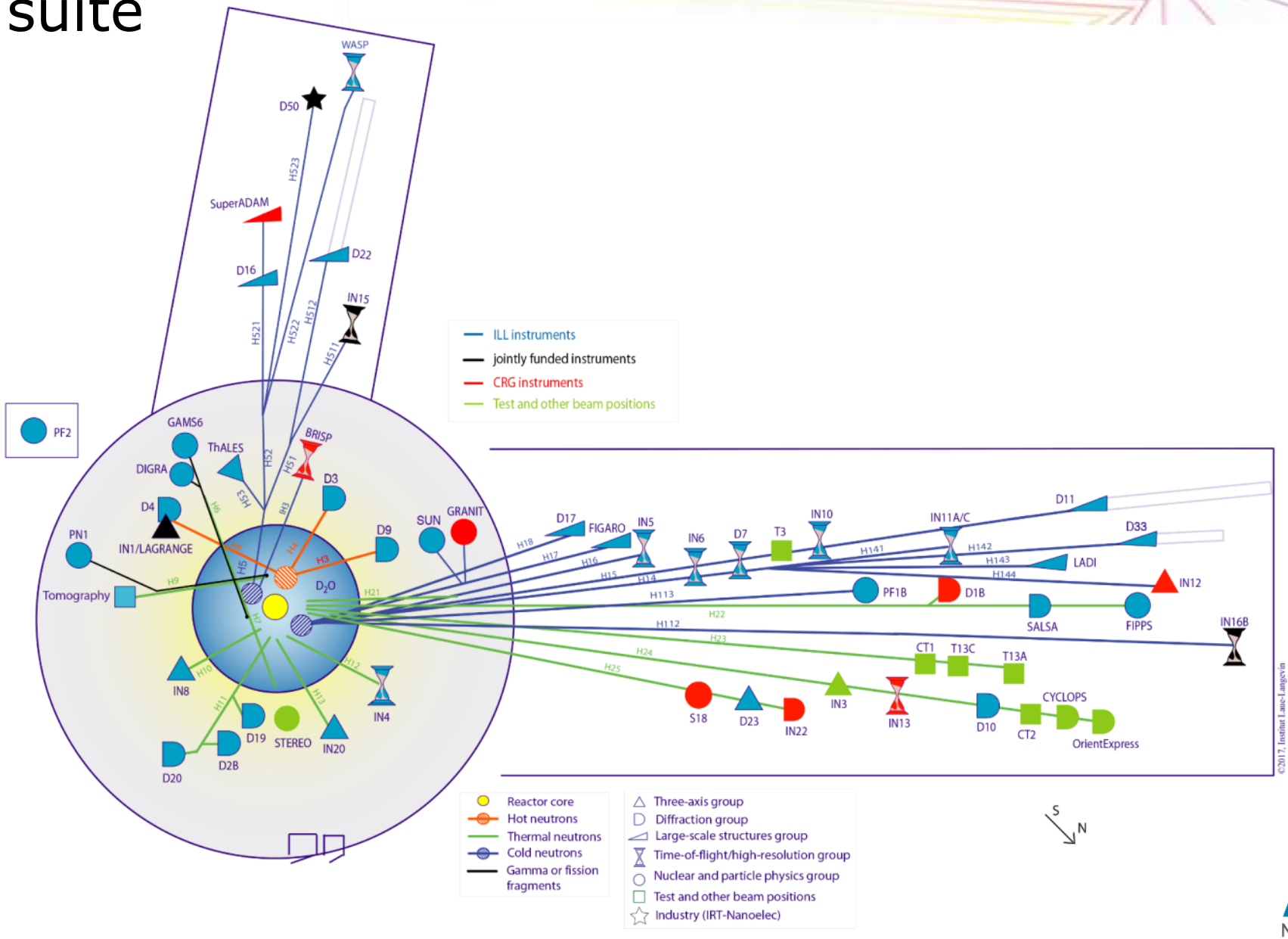




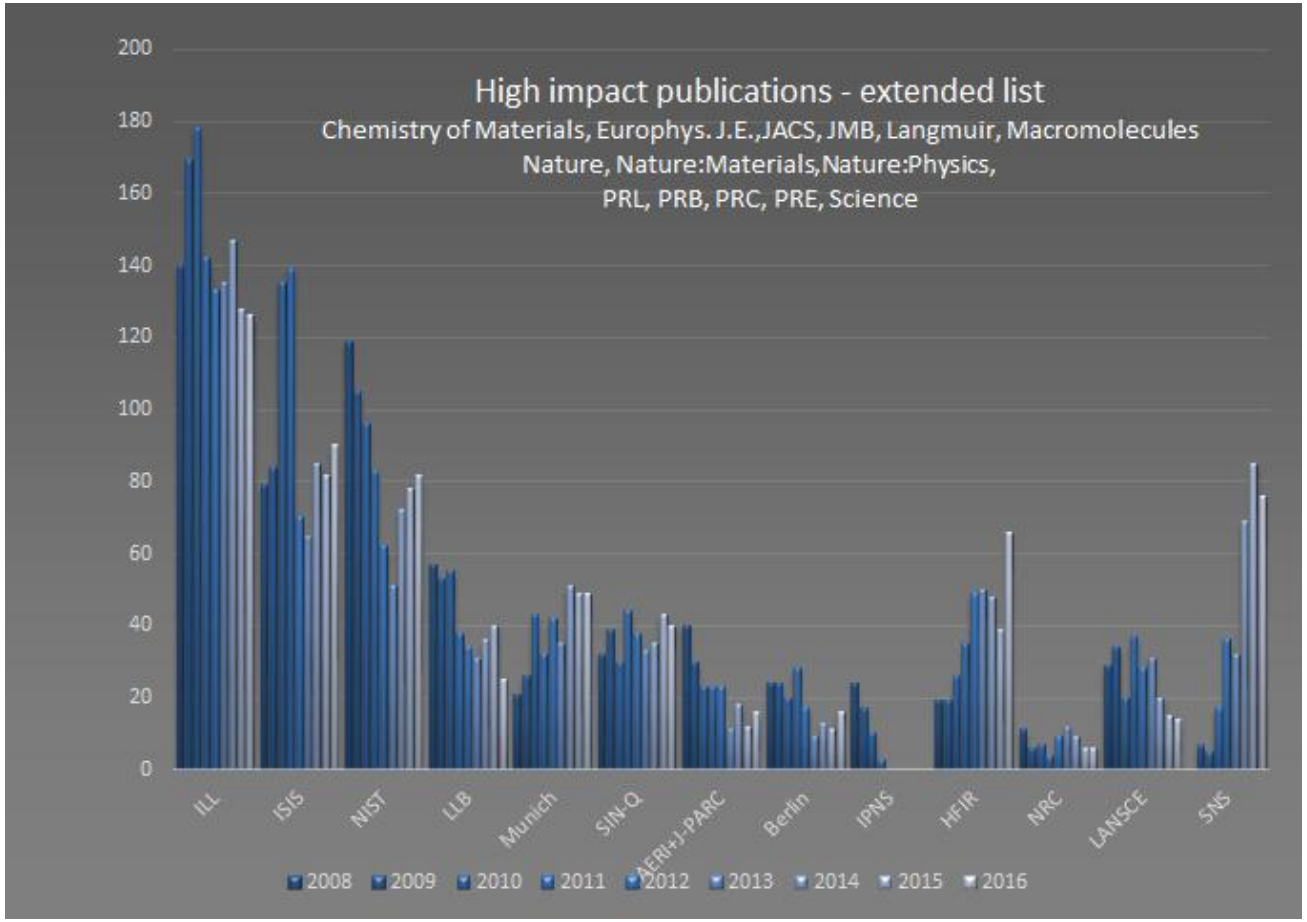


58 MW reactor, operates ~200 days/year,
4 cycles of 50 days / year
(when fuel available and authorities agree!)

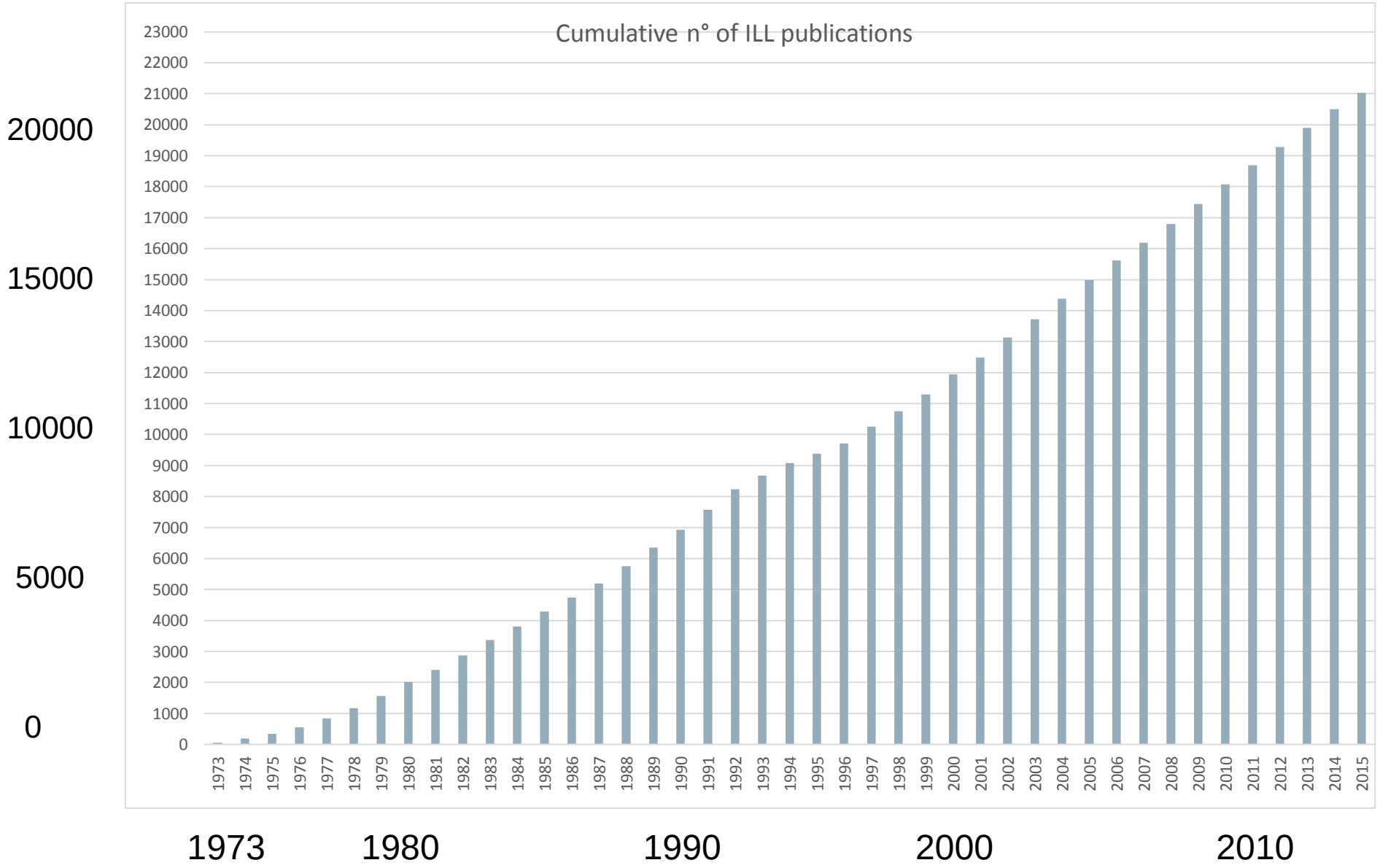
The instrument suite



Record figures for publications in high-impact scientific journals (2008-2016)



Publications since the beginning



NEUTRONS FOR SOCIETY

2016 : science in numbers

Beam days and experiments	156 reactor days, 51 MW average power, 5580 instrument days, 73.6% for users, 595 experiments
Proposal and users	717 proposals for 4404 days requested - 538 proposals for 2815 days accepted. 1306 users, 227 new ILL users, 138 new neutron users
Instruments	Reviews of SALSA and GAMS instruments & Life Science Group
Training	38 PhD students, 14 graduations, 1 SFN prize, 48 trainees
Publications	534 peer-reviewed publications, 126 high-impact publications (with ILL data),
Scientific life	6 colloquia, 51 seminars, 10 workshops

~10% have ISIS & ILL co-authors

NEUTRONS FOR SOCIETY

The ILL modernisation programme

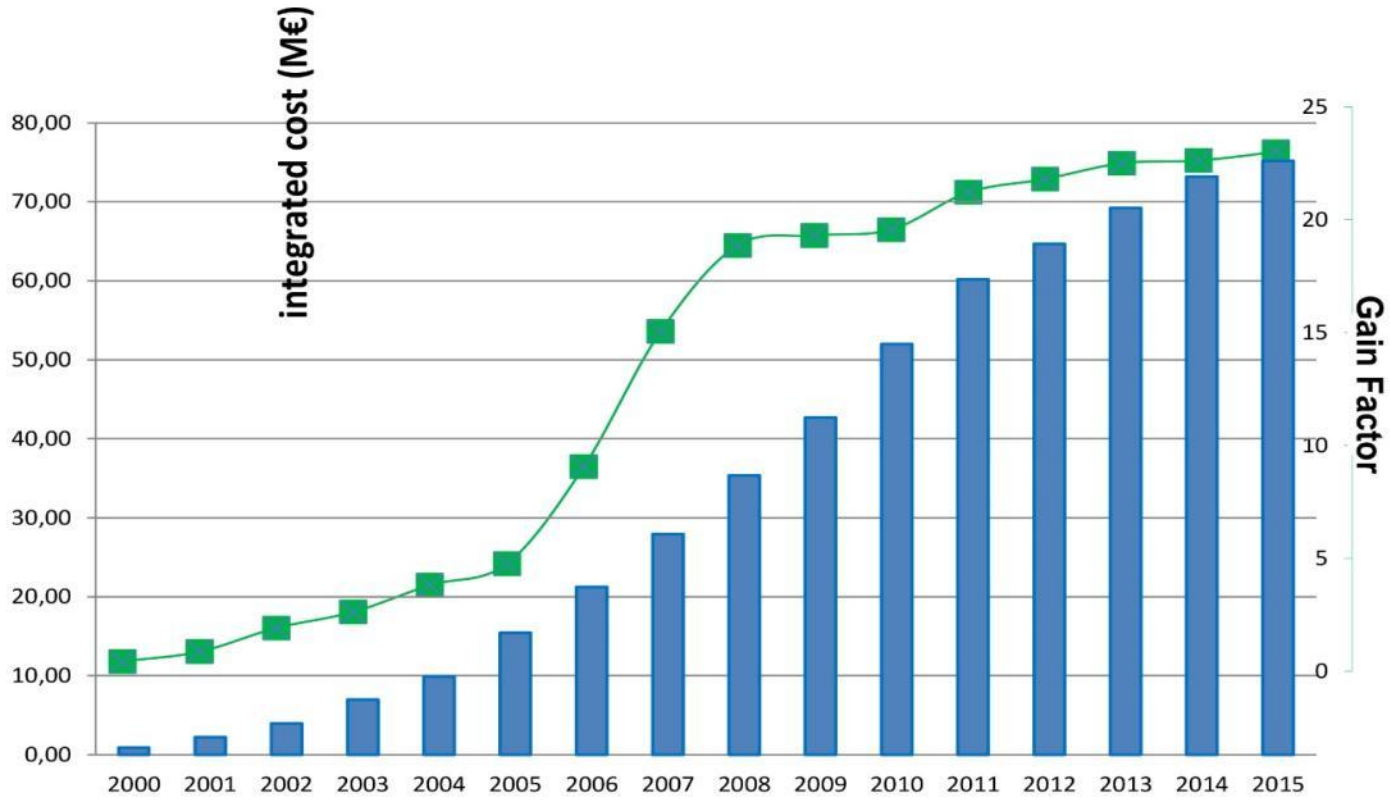
The Millenium Programme, 2001-2016

During this period ILL has:

- built or upgraded 28 instruments;
- replaced or renewed a great part of the neutron guides, making them ~ twice as bright;
- improved the technical devices, from cryostats to magnets, new polarised optics and a new electronic instrument control system…

The Millenium Programme

… as a result, the average neutron detection rate on the instruments has been improved by almost 25



NEUTRONS FOR SOCIETY

The Millenium Programme: WASP

The Endurance Programme

Today ILL is setting its sights on the horizon of 2030; with the goals of:

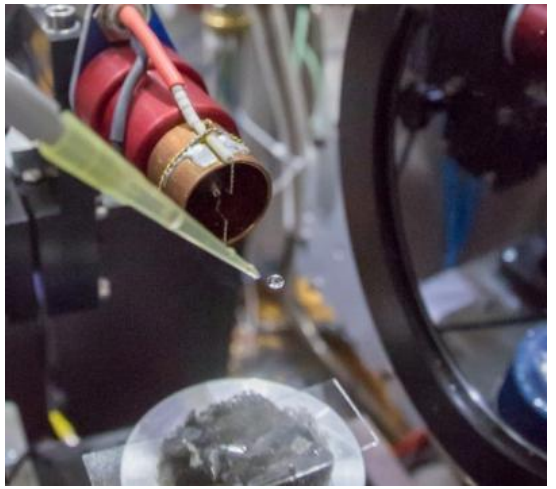
- preserving ILL's position of leadership by drawing on its strengths
- offering new possibilities in the fields of magnetism, materials science, soft matter, biology and particle physics

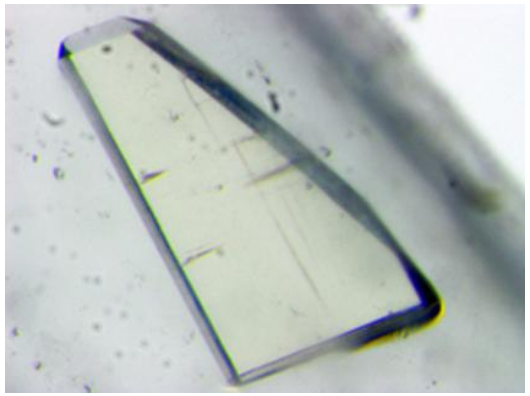
- Future developments for the instrument suite and scientific infrastructure:
  - 9 instrument projects
  - new or refurbished neutron guides
  - 2 infrastructure projects: sample environment and data analysis software

The Future of ILL

ILL is

- Preparing for the future, beyond 2023 (fewer neutron sources, ESS ramping-up): 10-year operating license, Endurance Phase 2, long-term procurement, …
- Building on its strengths: high intensity neutron beams → small samples, time-resolved measurements, polarisation analysis, …
- Enhancing scientific output with support for soft matter (PSCM), biology (LSG), magnetism (software), spectroscopy (simulations), …
- Providing capacity and capability to complement ISIS for the UK community





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The EPN Science Campus

Coda:
my time at ILL …

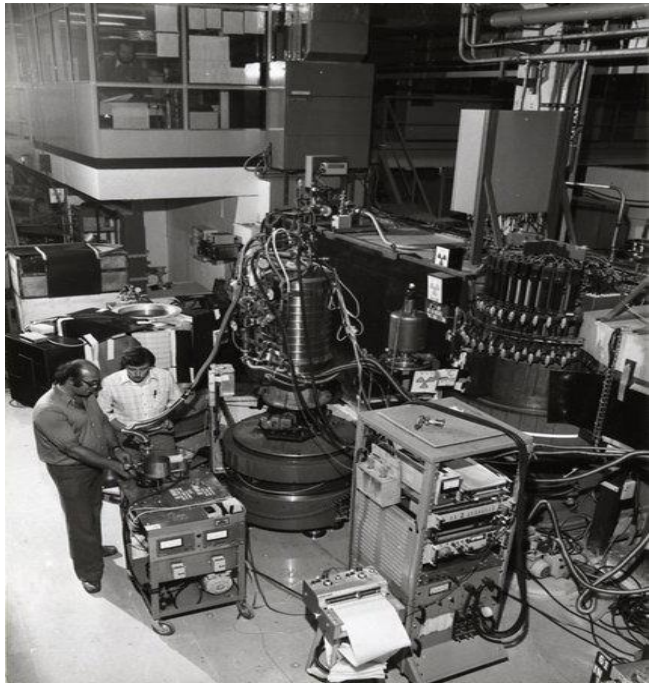
My time at ILL … …

- I arrived at ILL in the Summer of 1973
- I was appointed responsible for the second arm of IN2 (cf CRNL)
- But it was never built (a great opportunity to fit into ILL)

Bruno Dorner

My time at ILL … …

- In the mid 1970s → Responsible for the new cold neutron TAS IN12
- Vertically curved PG mono, lifting-block mono shielding, large sample table with heavy gonio, analyser-detector system on one table, central drive systems with tanzboden, polarised neutrons, independent computer (SOLAR 1640?) …



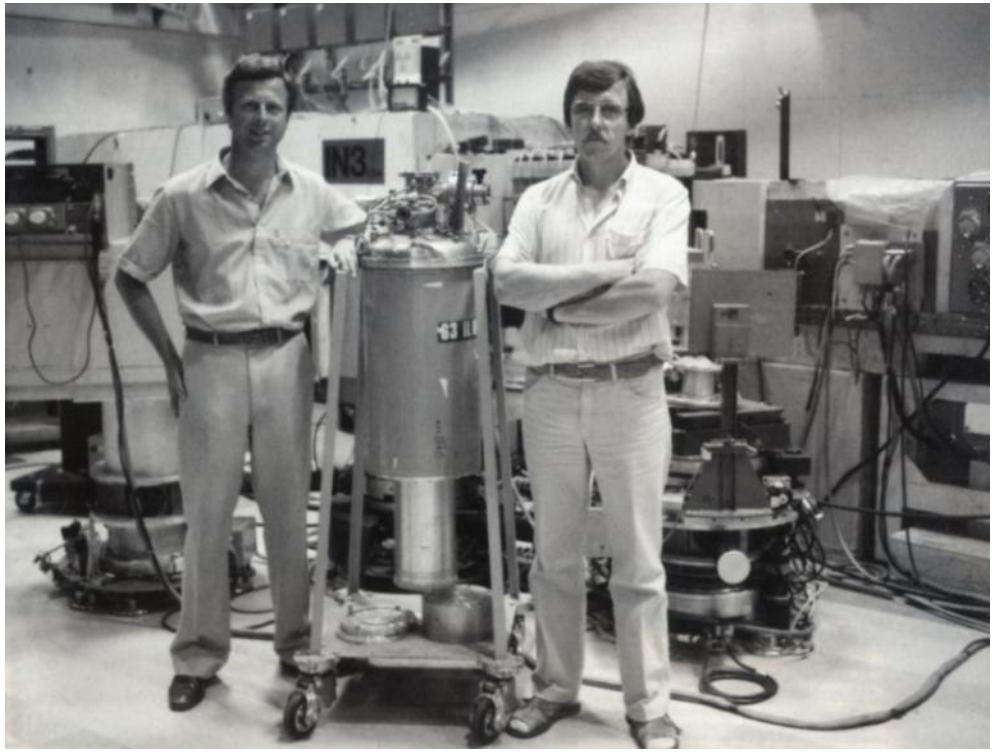
My time at ILL … …

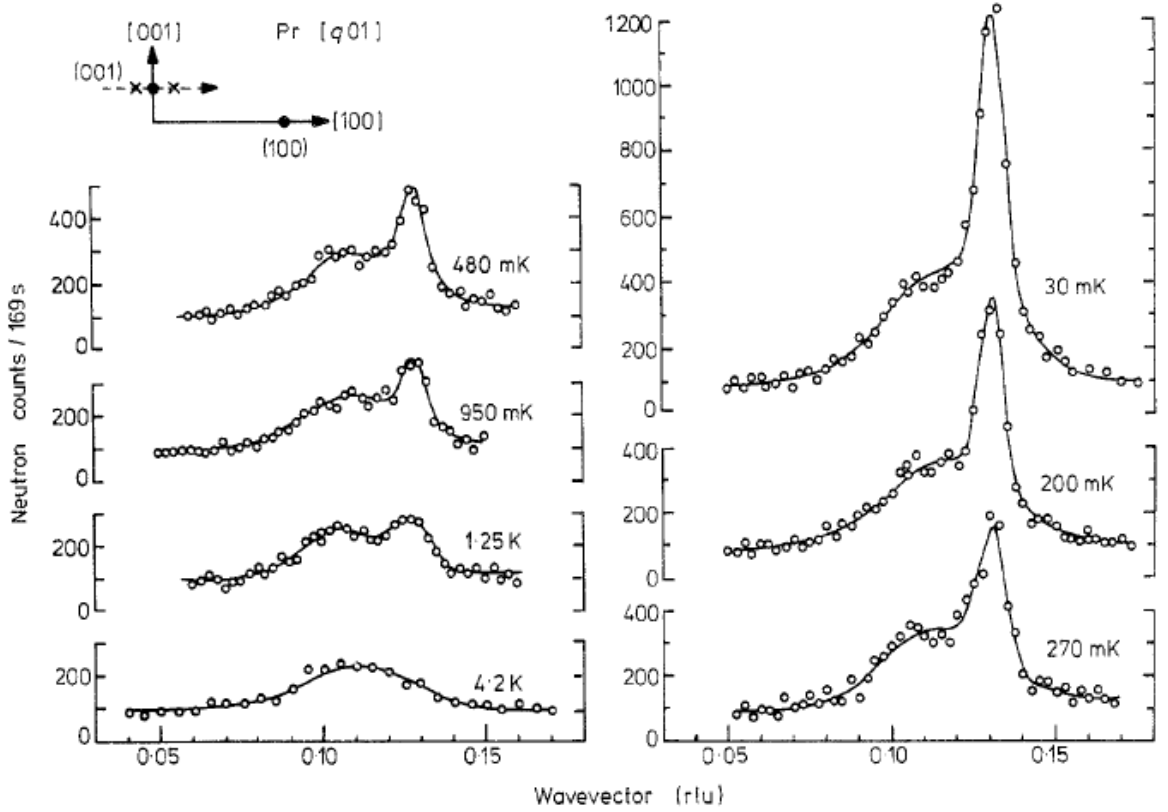
- In the mid 1980s, after the long shut-down, Roger Pynn and I suggested placing a cold TAS in the reactor hall, but on a guide to the 2nd guide hall
- IN14 was almost ready when I left ILL in 1987 (IN14 → ThALES)

Different hats … …

- Physicist, ILL (1973-87); Staff Scientist, 1975
- Member, Instrument Subcommittee (1988 – 91)
- Member, Scientific Council (1992 – 93); Chairman (1994 - 97)
- Member, U.K. delegation, Steering Committee (1997 - 2000)
- Member Steering Committee, DG ESRF (2001-2008)
- Director (2013-2016) – and long-term user

Early science: low-temperature and uniaxial stress-induced phase transitions in praseodymium
Prof K.A. McEwen, Birkbeck/UCL





Reasons for ILL's success (personal opinion)…

- The reactor – cold and hot sources, guide halls, modular concept …
- User programme – with T&S support (so no need for major grants) and good peer review
- International staff – complementary expertise/experience, turn-over of scientists
- Long-term governmental support – adequate financing (at least in early years); several countries providing funding above that possible by a single country
- Governance (Associates) – control without micro-management (usually)
- Opening to European (and international) partners – consortia, CRGs …
- Technical developments – in-house and with international partners
- Instrument and source renewal programmes
- Local academic/scientific environment (CEA, CNRS, UJF, EMBL, ESRF, IBS …)

A motley crew … …

50th Anniversary Celebration: 19 January 2017
ILL Directors and Associate Directors

NEUTRONS FOR SOCIETY