Performance evaluation of OPAL’s neutron beams

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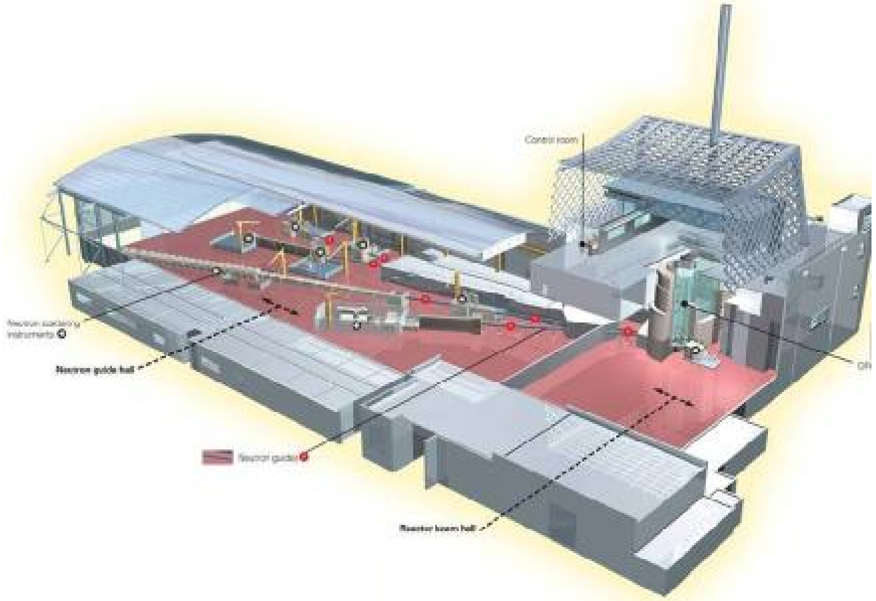
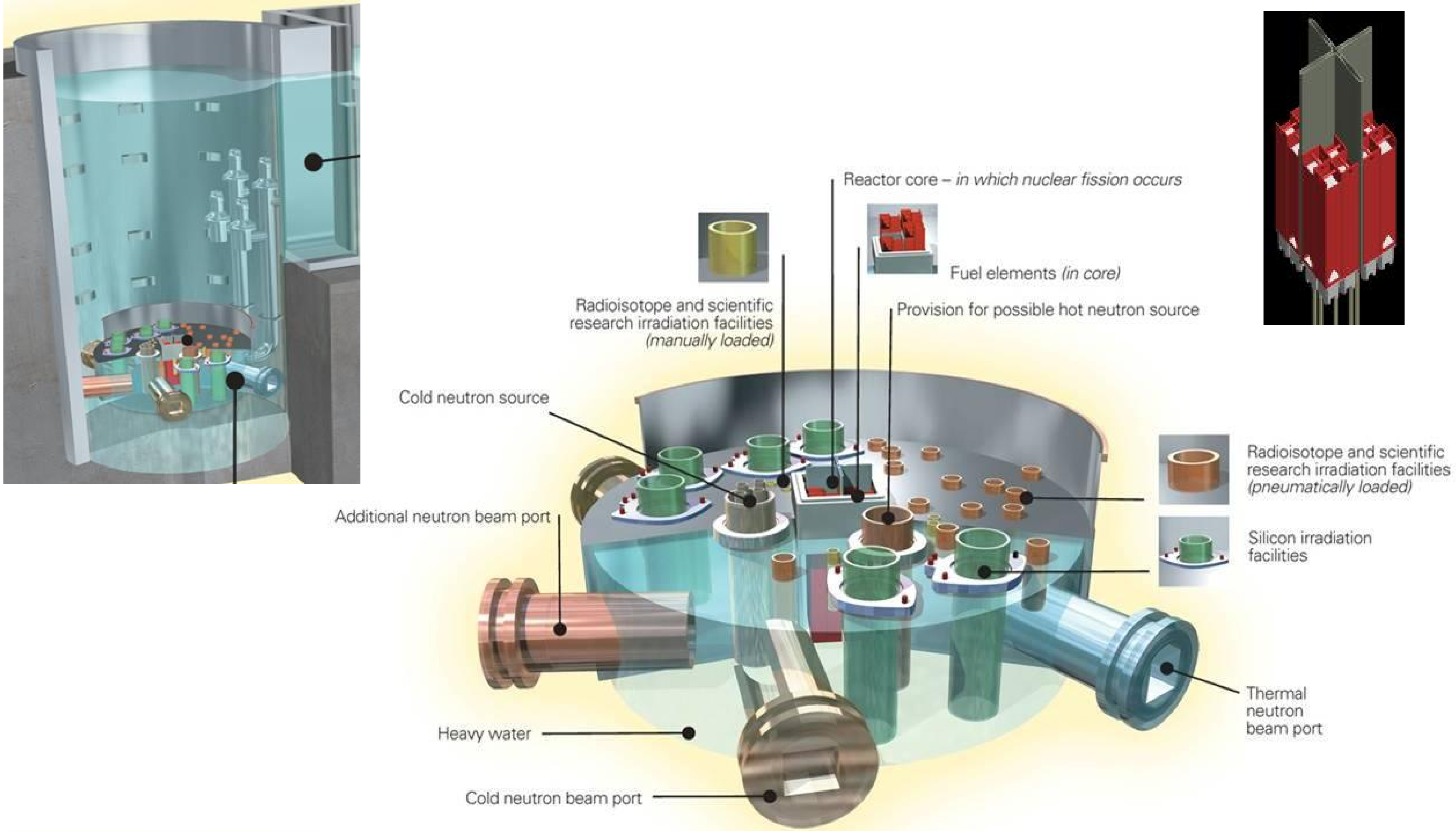
OPAL 2007 ~ 2050

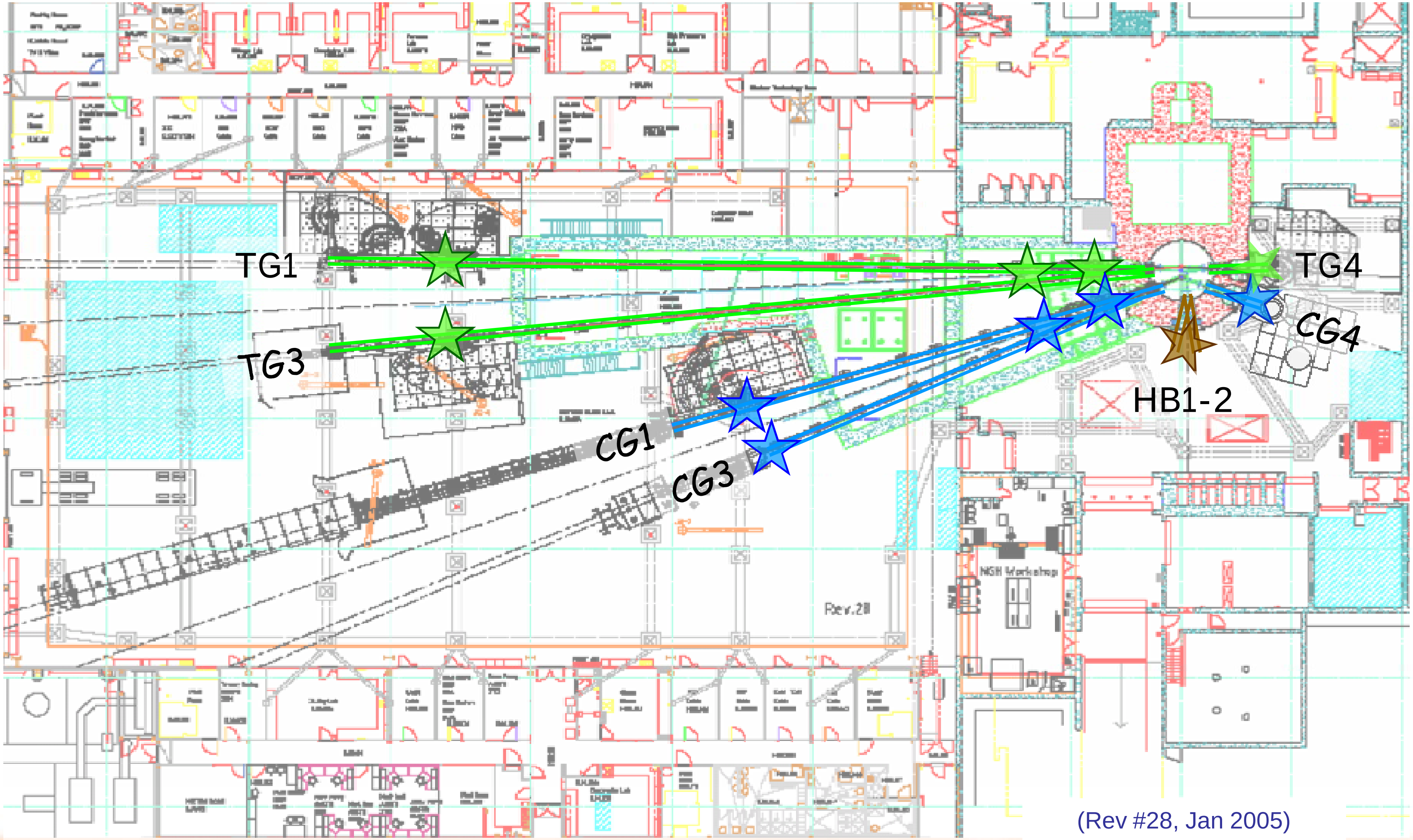


- Description of OPAL transport systems
- Performance simulation methods
- Neutron beam characterization results
- Some conclusions

OPAL’s core and reflector vessel



OPAL: Neutron beam facility: phase 1 (1998-2007)



(Rev #28, Jan 2005)

Neutron Beam Performance optimization (1998-2000)

Basic concepts developed, analytically & with acceptance diagrams

MCNP (LANL) models nuclear processes in Reactor core, moderator, cold neutron source and reflector.

Output (at n-guide inlet)

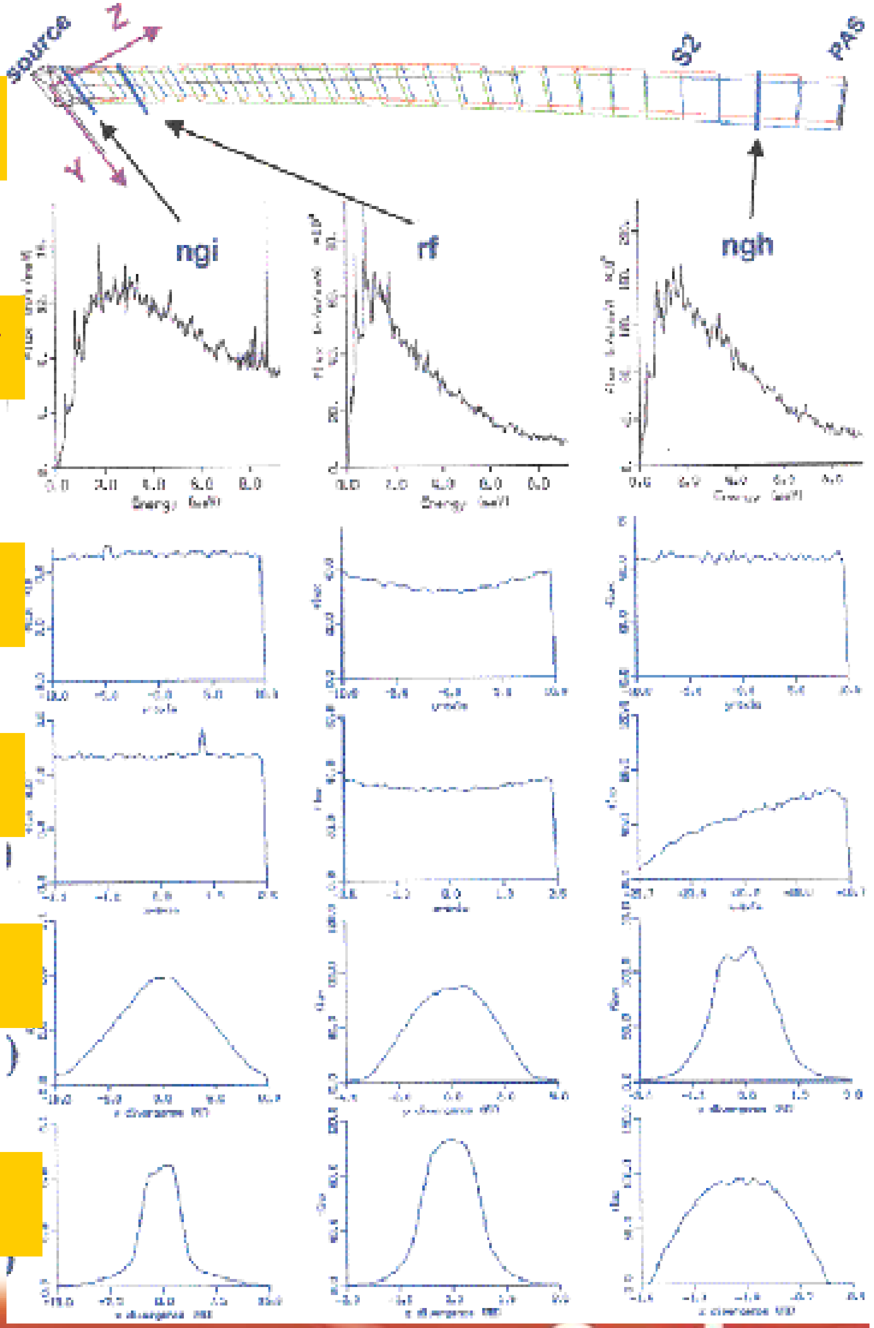
Neutrons (n_i) crossing surface (x) defined by Position, Trajectory, Energy & Probability

$[(x, y_i, z_i),(a_{x}, a_{yi}, a_{zi}),E_i,w_i]$

Input (sequential)

SMAC-3D (ANSTO) models neutron transport

- Three dimensional model
- Guide segmentation
- Detailed surface reflectivity curves



Cold Neutron Guide CG1

Energy Spectra 0 - 10 meV

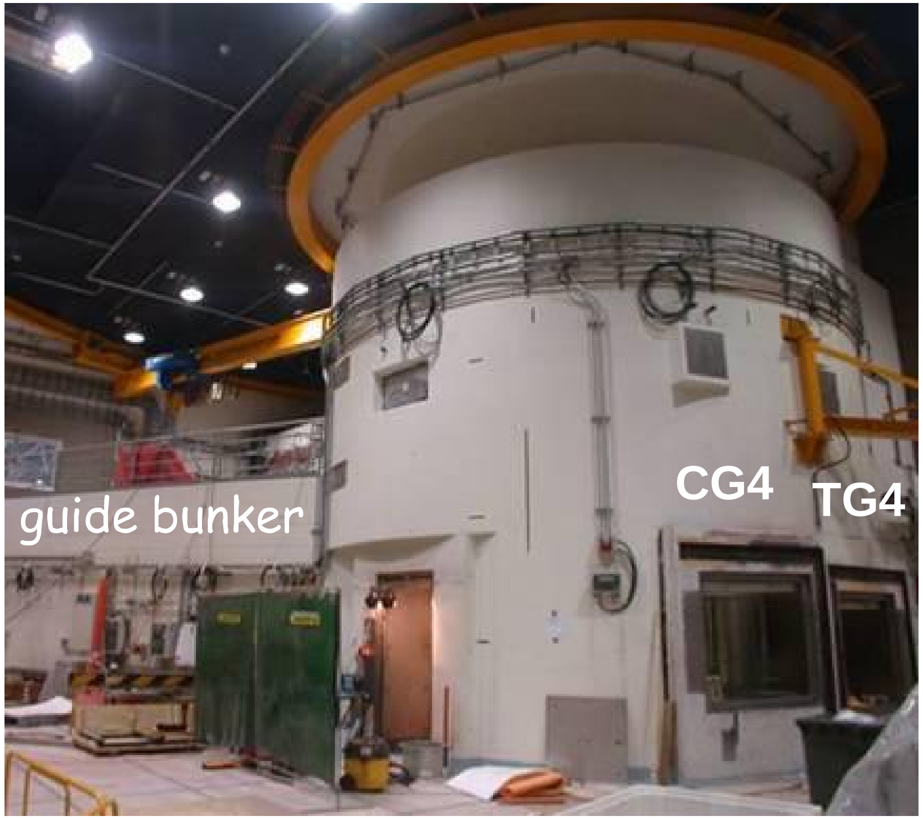
Y-axis distribution

Z-axis distribution

Y-axis trajectory

Z-axis trajectory

OPAL; beam characterization at reactor face

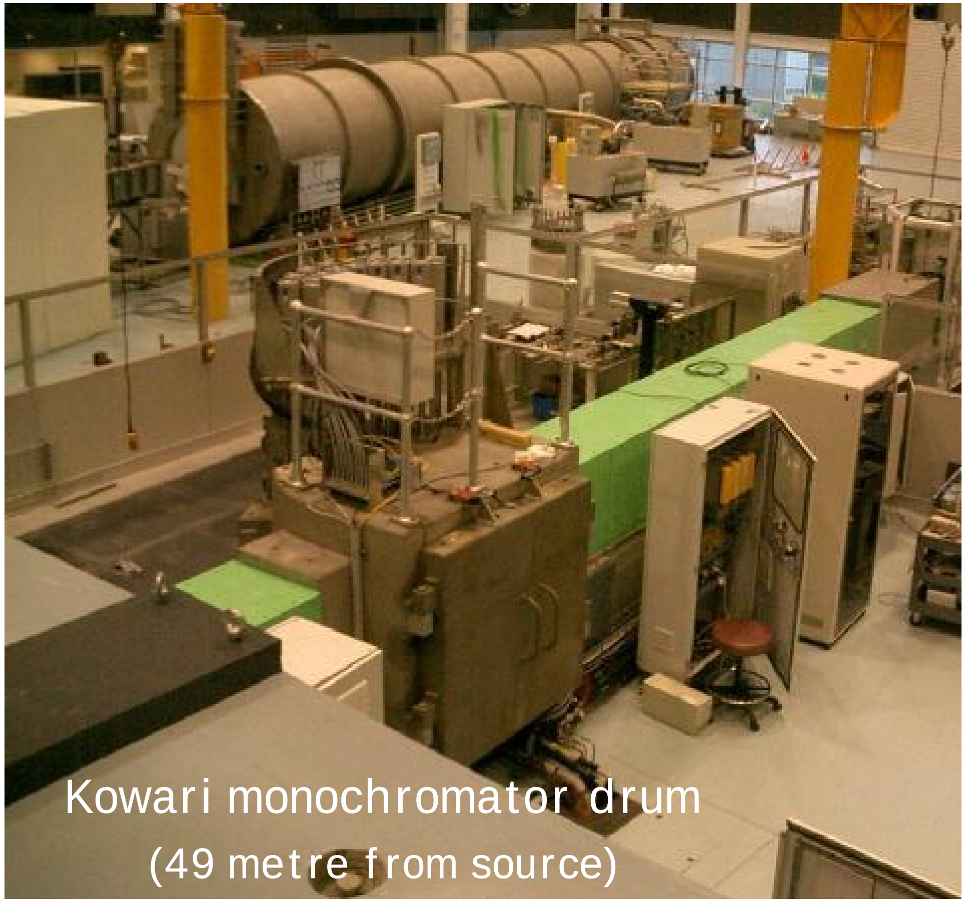


Temporary shielding at TG4
(~4.5 metre from source)

OPAL beam characterization in bunker & neutron guides

Mirrotron engineers installing out-of-pile neutron guides

Thermal neutron guides run ~ 40m in bunker

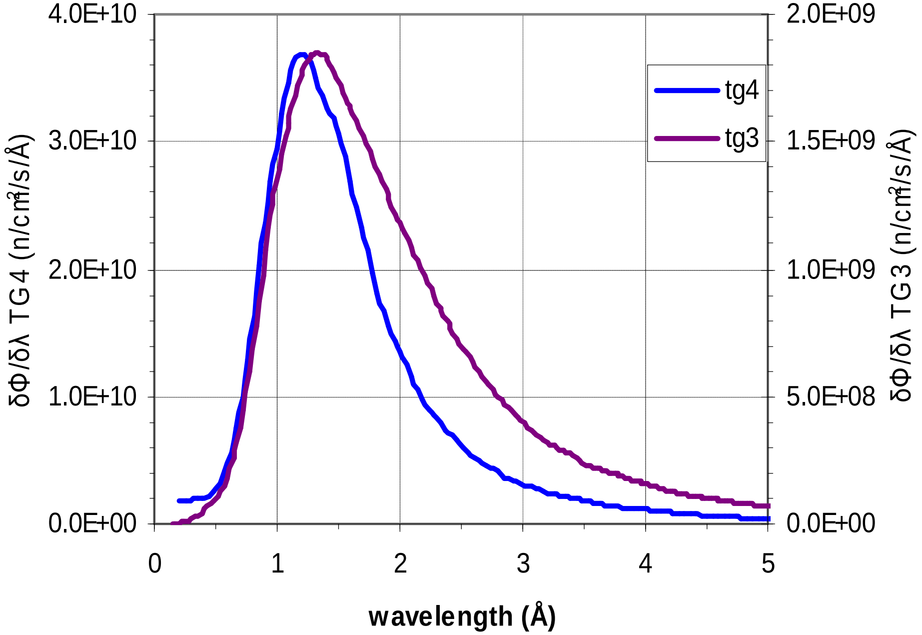


Kowari monochromator drum

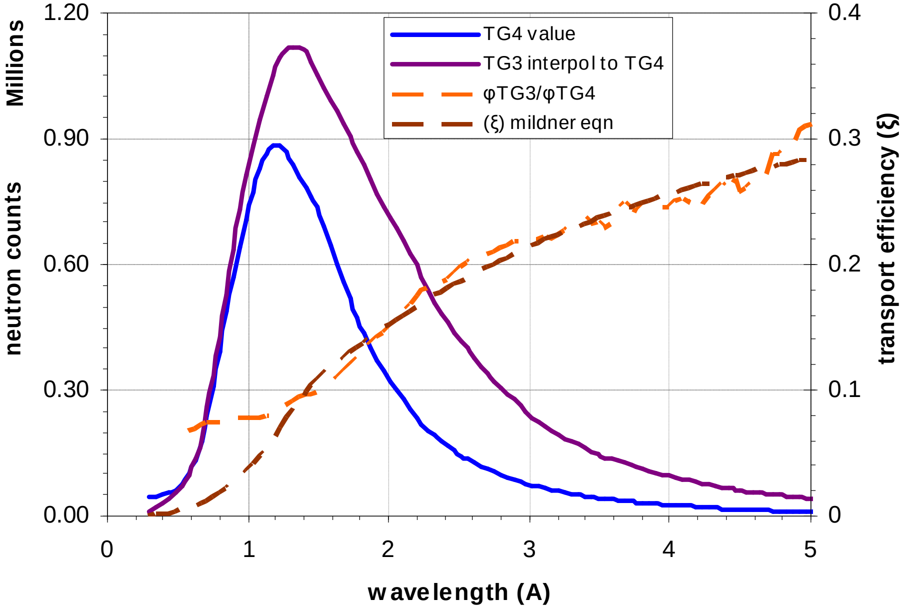
(49 metre from source)

OPAL thermal neutron beam spectra

compare TG3 & TG4 flux



TG3 flux transport efficiency



out-of-pile time-of-flight spectra –beam transport

TG4; $T_{M\text{-}B}$ = 310 K, TG3; λ_c = 1.29 Å, α = 0.093, R = 0.92

Out of pile transport efficiency

$\xi = \alpha.({}^{\lambda}/_{\lambda c})^3.R.n(\lambda); \quad \lambda\le\lambda c$

$\xi=\alpha.[({}^{\lambda}/_{\lambda c})^3-\{({}^{\lambda}/_{\lambda c})^2-1\}^{3/2}].R.n(\lambda);\ \lambda\ge\lambda c$

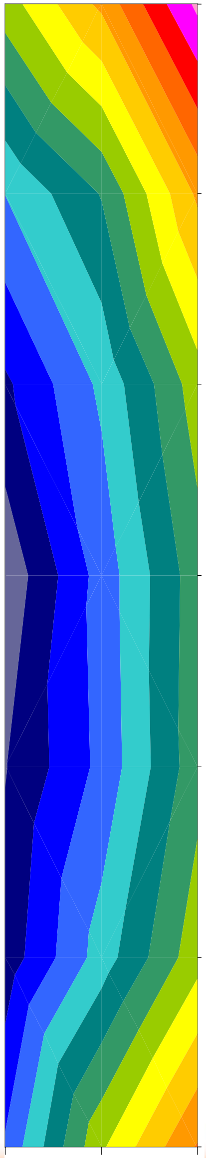
(Ref D. Mildner NIMA290,189-96 (1990))

With finite guide reflectivity (R)

where $n(\lambda) = {}^3/_2.{}^{\lambda c}/_{\lambda};\ \lambda\le\lambda c$ &

$n(\lambda) = {}^3/_2.[2.({}^{\lambda c}/_{\lambda})^2-1]/\{({}^{\lambda c}/_{\lambda})^3-[({}^{\lambda c}/_{\lambda})^2-1]^{3/2}\};\ \lambda\ge\lambda c$

OPAL thermal neutron flux distributions



TG1 in bunker after removable section

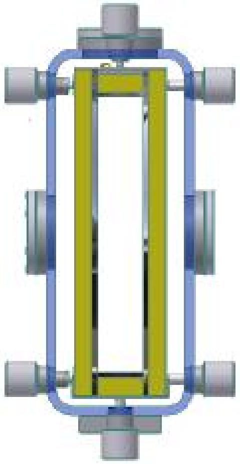
(~ 9 metres from source)

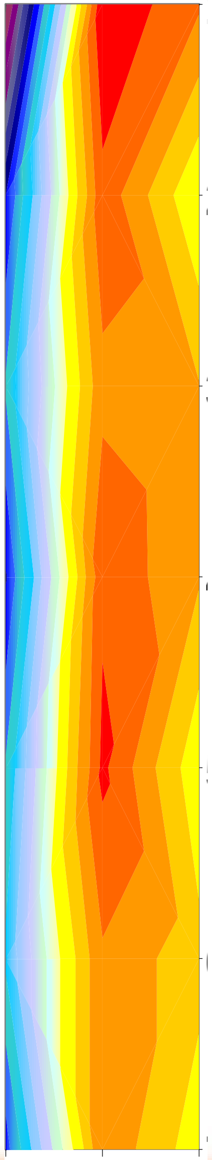
2% contours

variation:

15 % (h) x 11 % (v)

neutron guide cross-section





TG1 in neutron guide hall at Wombat monochromator

(~ 49 metres from source)

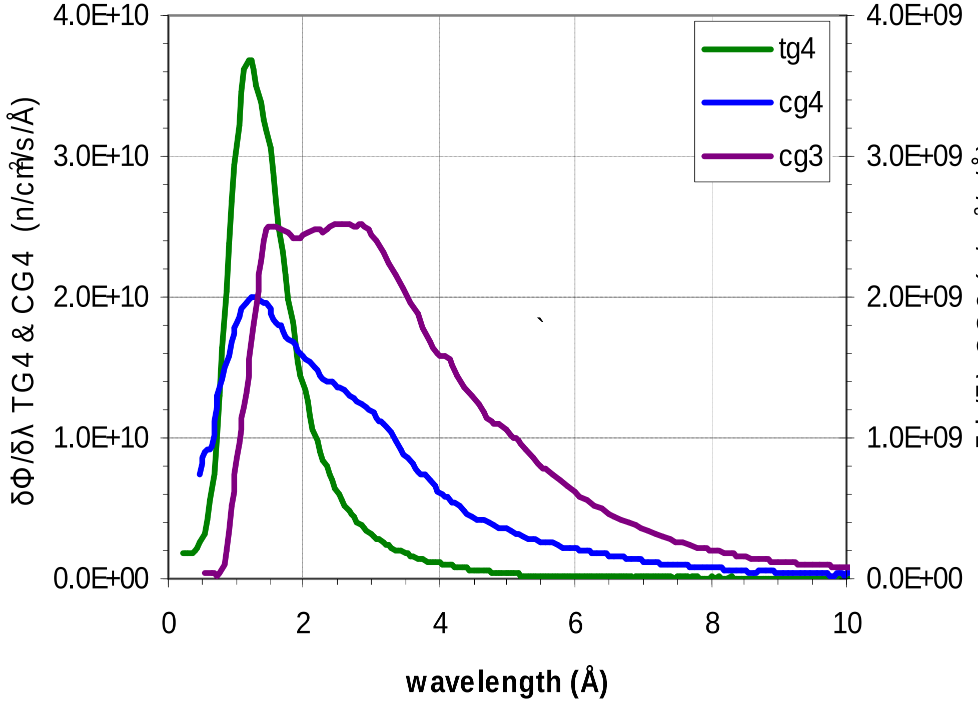
1% contours

variation:

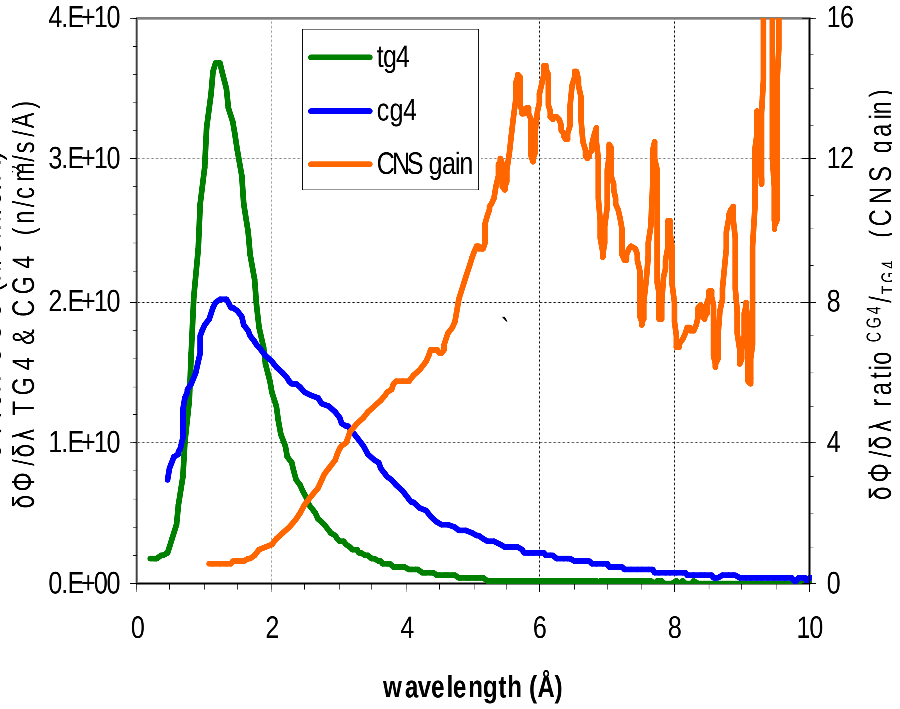
10 %(h) x 2 %(v)

OPAL cold neutron beam spectra

Wavelength spectra; CG4 & CG3



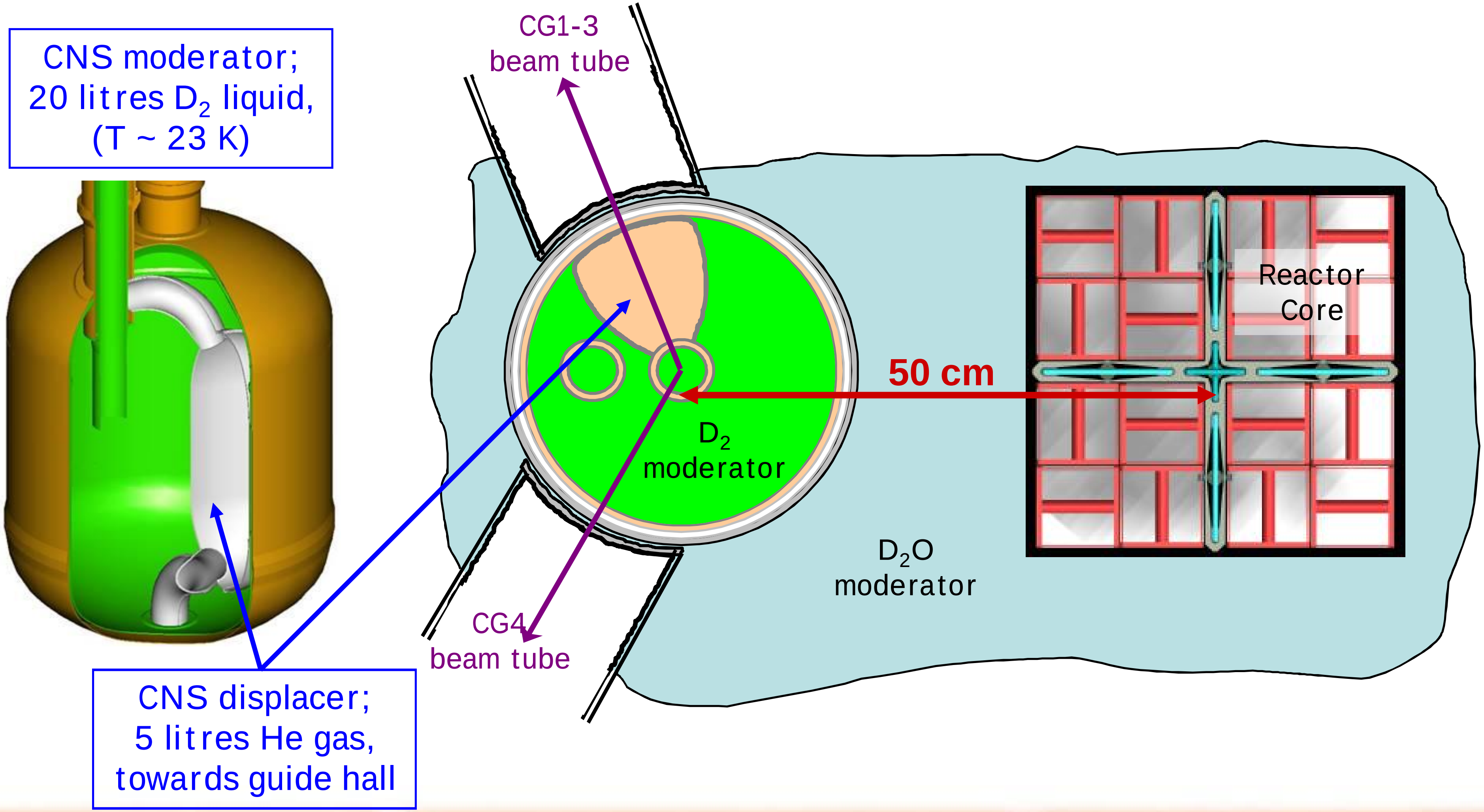
Cold neutron source gain



CG4 l spectrum; roughly two Maxwellians (with T_1 ~37 K & T_2 ~209 K)

OPAL cold neutron flux distributions

- CNS pinhole measurement on CG4 (May 2007)

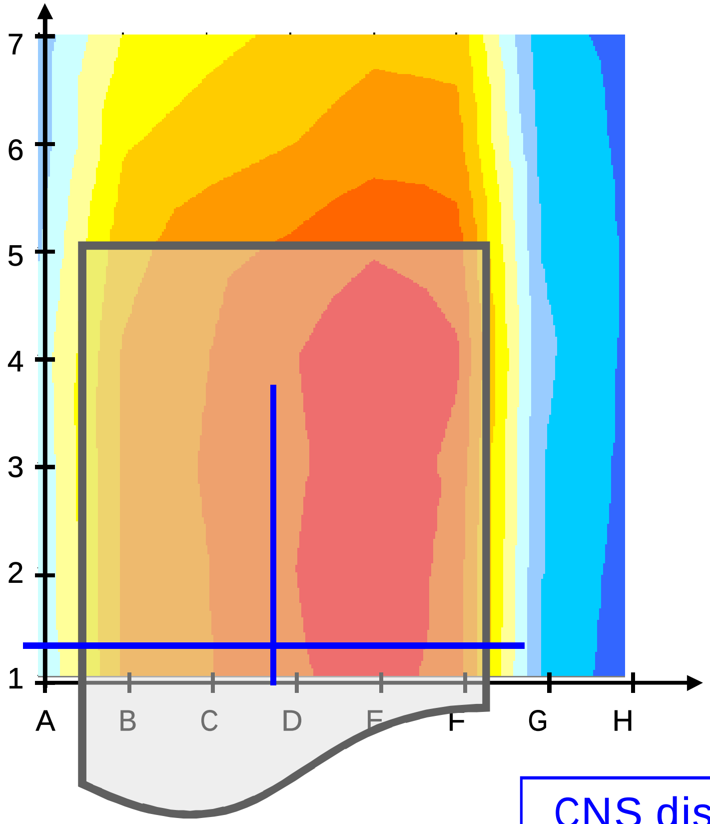


CNS moderator;
20 litres D_2 liquid,
(T ~ 23 K)

CNS displacer;
5 litres He gas,
towards guide hall

OPAL cold neutron flux distributions

- CNS pinhole measurement on CG4 (May 2007)



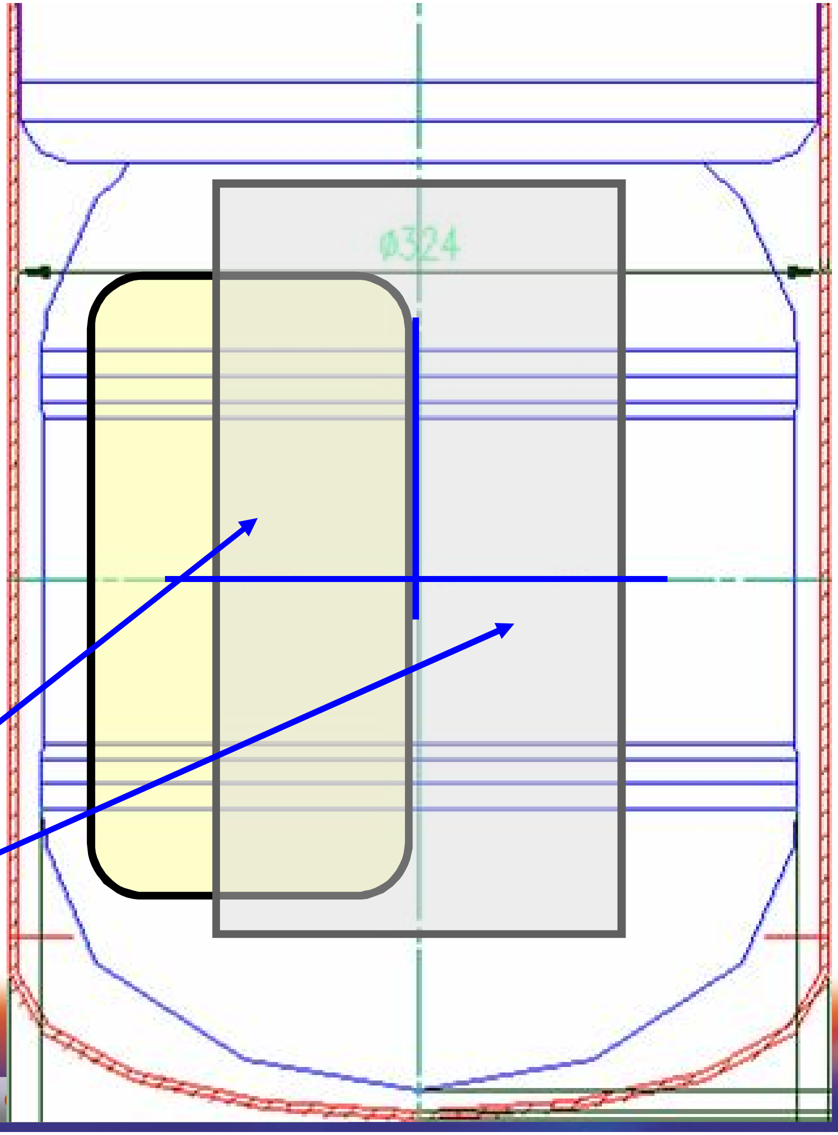
10 % contours

$\Phi_t \sim 6.3 \times 10^{10}$ n/cm^2/s

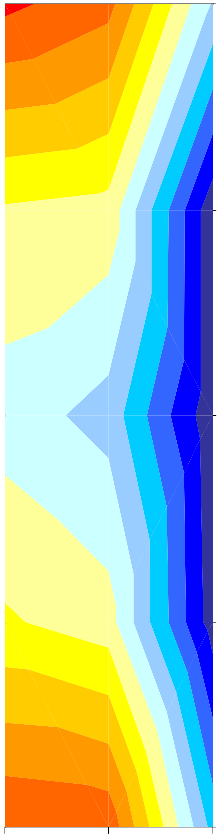
$\Phi_{(< 10\ \mathrm{meV})} = 2.5 \times 10^{10}$

CNS displacer

CG4 beam tube



OPAL cold neutron flux distributions



CG3 in bunker before removable section

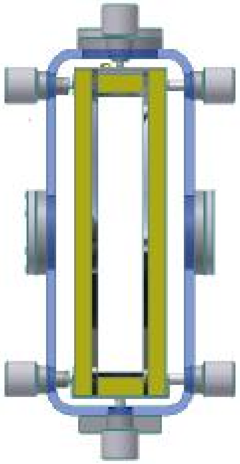
(~ 4.5 metres from source)

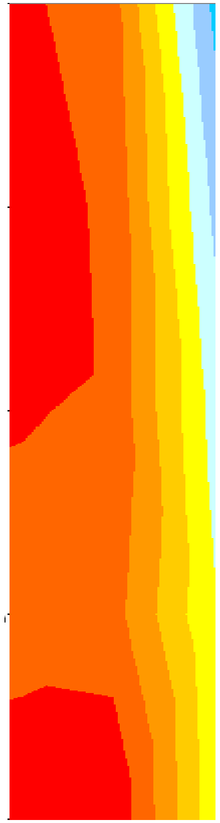
2.5 % contours

variation:

19 % (h) x 16 % (v)

neutron guide cross-section





CG3 in neutron guide hall before Platypus guide

(~ 30 metres from source)

1% contours

variation:

5 %(h) x 2 %(v)

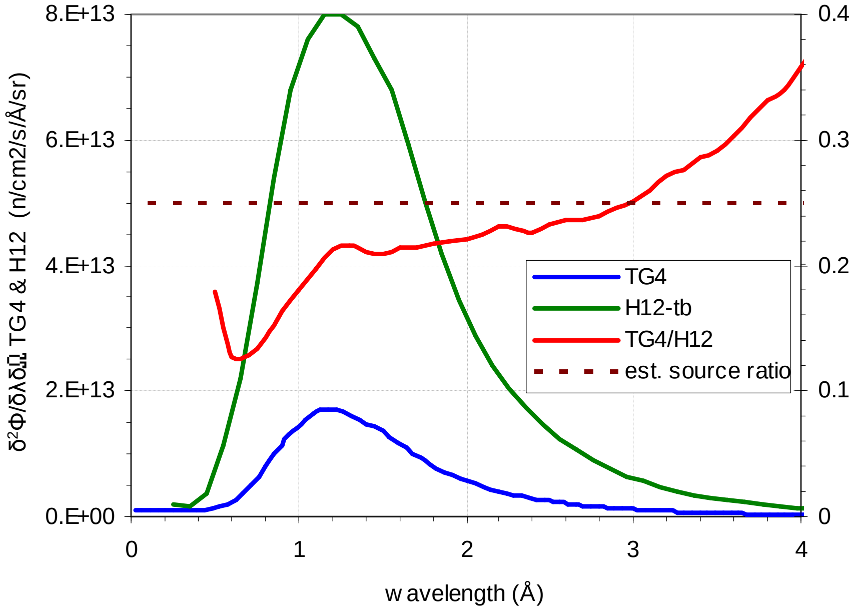
Summary of neutron beam performance tests

Beam line, location & energy (rf = reactor face) (ngh = neutron guide hall) *(flux in n/cm^2/sec)*	OPAL measured flux (20MW equiv, 2007-8)	OPAL calculated flux (ANSTO, 2000)	OPAL calculated flux (Mirrotron, 2003) (includes misalignment)
TG1: thermal neutron flux in ngh [1]	3.3×10^9	2.4×10^9	3.0×10^9 [3]
TG3: thermal neutron flux in ngh [1]	2.8×10^9		2.8×10^9 [3]
TG4: thermal neutron flux at rf [1]	4.0×10^{10}	1.9×10^{10}	1.7×10^{10} [3]
CG1: cold neutron flux in ngh [2]	5.9×10^9	7.1×10^9	5.7×10^9
CG3: cold neutron flux in ngh [2]	6.4×10^9		7.2×10^9
CG4: cold neutron flux at rf [2]	2.5×10^{10}	1.7×10^{10}	1.5×10^{10}
HB2: thermal neutron flux at rf [1]	3.6×10^{10}	1.7×10^{10}	*not calculated*

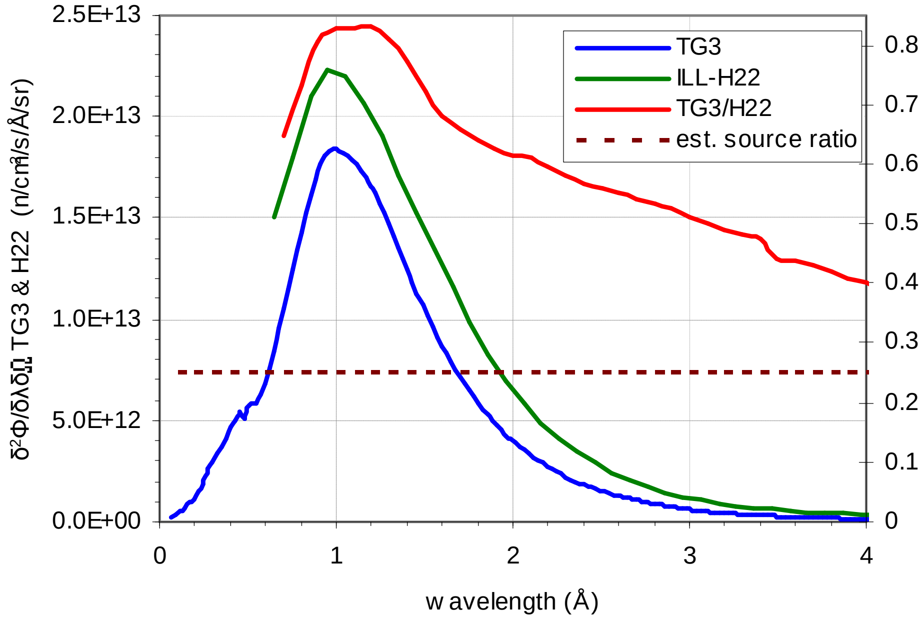
[1] E < 100 meV
[2] E < 10 meV
[3] corrected to E < 100 meV with observed spectral weights

Benchmarking OPAL thermal neutron beams
neutron brightness

TG4 (OPAL) and H12 (ILL)



TG3 (OPAL) and H22 (ILL)



Comparison of thermal beam brightness at reactor face is roughly in proportion to source design flux

Comparison of thermal beam brightness of guided neutrons illustrates high transport efficiency of OPALs m=3 supermirror guides

Neutron flux at sample position: (flux in n/cm^2/sec)

All measurements are all preliminary

OPAL n-beam Instrument	OPAL measured flux (2009) (20 MW equiv)	OPAL calculated flux (NBI Project 2000-2007)	Document reference & configuration information
Wombat [1]	5.2 x 10^6 –checking monochromator	~ 5 x 10^7	NBIP-SS-408-1002 [8]
Echidna [2]	3.7 x 10^6	2.5 x 10^6	NBIP-SS-401-1004 [9]
Kowari [3]	4.9 x 10^6	1 x 10^7	NBIP-SS-405-1003 [10]
Koala [4]	1.2 x 10^9	1.0 x 10^9	NBIP-SS-403-1006 [11]
Quokka [5]	7.9 x 10^6 –collimator misaligned	~ 10^8	NBIP-SS-404-1004 [12]
Platypus [6]	5.5 x 10^8	1 x 10^9	NBIP-SS-402-1002 [13]
Taipan [7]	3.6 x 10^7	~ 5 x 10^7	S. Danilkin, private communication [7]

[1] AZS-Ge(115), $2\theta_m$ = 90 , λ = 1.54 Å, m2s=2.1 m
[2] BNL-Ge(115), $2\theta_m$ = 90°, λ = 1.54 Å, α_1,α_2 open
[3] Si(400), $2\theta_m$ = 75°, λ = 1.67 Å
[4] white beam, no filter, aperture; ϕ = 3 mm (1/4 of Au foil)
[5] λ = 5 Å; T_{CNS} = 19.5 K
[6] white beam, T_{CNS} = 19.5 K
[7] HOPG, λ = 2.35 Å; no λ/n filter

[8] Ge(115), $2\theta_m$ = 99.7°, λ = 1.66 Å,
[9] Ge(115), λ = 1. 5 Å, ϕ_{kowari} = 2.6 x 10^9 n/cm^2/s
[10] Si(311), λ = 1.65 Å, ϕ_{kowari} = 2.6 x 10^9 n/cm^2/s
[11] ϕ_{kowari} = 2.6 x 10^9 n/cm^2/s, aperture; ϕ =3 mm (1/4 of Au foil)
[12] λ ~ 5 Å, $\phi_{pelican}$ = 5.7 x 10^9 n/cm^2/s (with MB T=40K spectrum)
[13] white beam, focusing guide in place

Conclusions from the OPAL experience

Performance of thermal beams

Measured fluxes are very high (in some cases even exceeding expectation).
Thermal beam brightness and λ distribution in guides are very good.

Performance of cold beams

Measured fluxes are very high (in some cases even exceeding expectation).
Cold beam λ distribution in guides is very good.
The CNS spectral distribution should be improved;
CNS brightness and spectral distribution measurements are still going

Beam delivery to sample position

Most fluxes are high and generally in line with expectation
Where measured flux is low we are working to identify causes and remedies

The design process for OPAL neutron sources and beams;

was robust, allowing us to ensure quality engineering and installation.
generally provided a solid basis for instrument selection and design.