JET Neutron Calibration 2013

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Calibrated JET Activation System and External Fission Chambers

- Using a $^{252}$Cf source of $2.62 \times 10^8$ s$^{-1}$
- Deployed in-torus by Remote Handling

Presentation

- Project preparations and execution
- Raw results and first data analyses only
3 pairs of **fission chambers** - $^{235}\text{U}$ & $^{238}\text{U}$

- Located around JET (on the limbs in Oct. 2, 8 and 6).
- Response ~ insensitive to neutron energy - by design
- Both pulse counting and current modes used
- Wide Range of neutron yields: $10^{10}$ to $10^{20}$ n/s
- Absolutely calibrated to <10%, periodic verification
  (originally *in-situ* using $^{252}\text{Cf}$ source, then cross calibrated by activation technique)
JET Octant 3 Cross-section

(Octant 3 Upper) Irradiation End – I.E

JET Mechanical Support Structure
Vaccum Vessel (Double-walled)
Iter-Like Wall (Plasma-facing)

JET Activation System

- **8 Irradiation ends** located in 5 octants: Octant 3 Upper here

- **Capsules** containing sample foils are delivered and retrieved pneumatically Indium Foils here

- **Conventional gamma-radiation measurements**
  Range: $10^{14}$ to $>10^{20}$ n/s
  most widely used reactions at JET:
  \[ \text{DD} - ^{115}\text{In}(n,n')^{115m}\text{In}, \ (4.5 \text{ h half-life}) \]
  \[ \text{DT} - ^{28}\text{Si} (n,p)^{28}\text{Al}, \ ^{63}\text{Cu}(n,2n)^{62}\text{Cu}, \ ^{56}\text{Fe}(n,p)^{56}\text{Mn} \]
  detectors: 3 NaI, HpGe (absolutely calibrated)

- Counting of delayed neutrons - Range $10^{14}$ to $>10^{20}$ n/s
  After N,fission reactions in $(^{235}\text{U},^{238}\text{U},^{232}\text{Th})$ foils
  Gives DD neutron yield, when $Y(\text{DD})>> Y(\text{DT})$
  detector system: 2 stations with six $^{3}$He counters

- **Accuracy typically ~ 8-10%**
  for both DD and DT neutron yields
  delayed neutron measurements can give 7%
The JET Experiment - Changing since 1985

JET 1985
1985, Calibration in JET
Clean, metal-walled JET, Easy man access

JET 1991
Inside JET 1994
T, Be in V.V. walls & air

March 2010 - During Shutdown
>2011, JET ITER-Like Wall
T, Be in V.V. walls & air
Delicate divertor
-> Difficult man access
• Early decisions
  – Calibrate for (D,D) operations as the priority
  – $^{252}$Cf neutron source only (confirms old calibration)
  – Remote Handling deployment of neutron source (Mascot)
  – Preparation for 2016 DT generator calibration (< JET D,T)

• ITER has a similar task to come & a strong interest

• Project
  – Physics Preparations
  – $^{252}$Cf Neutron Source Issues
  – Health Physics & Safety - Formal safety case - permission to proceed
  – Engineering and RH developments

These 4 strands interacted iteratively throughout the project
R-H Deployment Environment

Safe source storage
- TCTF tent
- Operational Shield
- Auxiliary Shield in ISO container

Source loading & deployment
- Transport Flask in Loading bay
- Transport Flask in Loading bay
- Mascot
- Oct 5 Boom tent

11 m Port to Port

Contingency Provisions
Normal Operations
Calibration Tooling

- Designed from key needs in Physics, RH & Safety
  - Separate Source from massive Mascot-Boom System
  - RH transfers of NS on JET site & failsafe connections

- Build -
  1. Batons & related RH items
  2. Shields, ie OS, AS, Support Frames & Loading Methods
  3. Dummy versions: Source, Batons, TF & OS
  4. Procedures: loading, testing, operations

- 3-Level Test System
  1. Individual components
  2. Assembled sub-systems
  3. Full system (dummy source) tests
    (in IVTF &/or in-vessel)

- Examples follow
RH compatible baton

2-part baton

Source baton -
Contains N Source
Fits in transport flask
Connects to MB

Mascot Baton -
Failsafe SB Connection
2 grips for Mascot
Tether to Mascot Chest

Mascot Grips
Winch Hook tether point
Bolt Runner drive point
Neutron Source Handling interface
Neutron Source

RH compatible baton
MCNP Model of NS in Source Baton
Below – close ups of either end

Source Baton (with dummy source) in Measurement jig at NPL

Anisotropy Results below

Source Anisotropy of 252Cf Neutron Source & Baton in Measurement jig at NPL

Anisotropy of Neutron Source in Baton: NPL measurements and Calculations
The Beginning: Source Baton Components in cell

The End: Tightening Cap on Source Baton
• Hire of NPL Neutron Source
• Source handling services
  (NS into baton in shielded cell facility with Manipulators)
• Absolute calibration of Neutron emission to < 2% (Mn bath)
• Calibration of n emission vs angle from the source-in-baton (anisotropy)
• Transport of NS to/from JET
Source Handling Sequence

(1) Transport Flask Receipt at JET

TF received at JET & transferred to Oct 5 boom tent (HP supervise)

(2) Oct 5 Boom Tent Operations

Remove TF entrance flange. Men exit. Warnings, J1T cleared, Shield doors & other doors closed. Locks, notices, etc.

3) R-H Operations

(Locked torus hall – no manned access)

Mascot removes shield plug, Then engages with NS baton and connects (failsafe confirmed) to Mascot baton

Withdraws unified baton – takes it into torus
RH Placed Source & Baton into Locations & Orientations as Specified by Physics
Contingency Arrangements
Operational Shield (OS)

The Operational Shield (OS) is a Contingency Arrangement in case of a Mascot or Boom fault.

Made of polythene & Lead (like TF)

OS on Oct 1Boom - can move round vessel to pick up the source baton.

Park Source in OS on Boom, Can withdraw to remote shield park (AS) if required = A safe shield location
Photos: RH loading/unloading of dummy NS baton into/from dummy OS & TF & retrieval of it from there.

All main locations, movements and operations successfully trialled under RH - Including contingency actions, eg pickup of dropped source baton
Physics Preparations

MCNP and other calculations for Physics: eg
- Next slide

MCNP N/G Dose rate evaluations for Safety Planning
- Next slide

Data Acquisition arrangements - for counting & backup

Samples and other activation preparations

Set up of key equipment, HpGe efficiencies, FC Thresholds
3 MCNP models used at different stages of project

Validity of calibration
- Estimates of Rates, statistics, dependencies
  - eg FC responses vs source position
  - eg Activation System response vs NS position
  (I. Lengar poster, ISFNT-11)

Corrections
- N Scattering: eg N Source structure, Baton, Mascot, Boom
- Practical Torus: eg Open ports, Missing items, etc
- Position dependencies & Error estimates
- Point to plasma corrections

N,G Dose rate estimates - for safety & operational planning
- Source in SB, source in SB in TF or OS, doses outside torus from SB inside
  (G. Stankunas poster, ISFNT-11)
• Activation: In samples

• Each sample ~ 9g (made of 4 foils)

• 12 sample runs (4 at each of the 3 heights (next slide))

• Time pattern: 3 hrs irradiation, 3 hrs (cooling + counting)
  – (for $^{115m}$In, 4.5 h half life)

• Activities: from 2 independent HpGe detectors from JET, IPPLM

• Activations were mixed with FC measurements
  – to optimise the total experimental output, vs time, given the RH shift pattern
Measurements:
- Distances down from end of I.E:
  - ~ 30, 93, 168 cm
- Radii: ~ 325, 300, 300 cm
  - R(plasma centre) ~ 300 cm
  - R (IE centre) ~ 325 cm

Logic:
- Upper: For model checking,
- Middle: ~ Mean of activation-biased plasma distribution
- Lower: ~ Plasma centre
Neutron Source Calibration
Spacer Tool for Top Position of NS under I.E.

~ 30 cm spacing to I.E. -> Know to < 3 mm

Designed accurate spacer tool for NS position

KN2 3Upper Irradiation end (in-vessel view)

RH tool to position NS Baton below KN2 IE
ie Vertically below.
Raw Activation Data & Calculations

JET and IPPLM data values are compatible

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<th>Item</th>
<th>Total Data</th>
<th>JET Detector</th>
<th>IPPLM Detector</th>
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<td>% S. Devn</td>
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Green line = MCNP value. Agrees with <data> - well within errors
### Uncertainty Analysis for Activation Data

#### JET HpGe

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<th>Combined Errors</th>
<th>Random</th>
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<td>Distance</td>
<td>Efficiency</td>
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#### IPPLM HpGe

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<td>Efficiency</td>
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<td>3.5</td>
<td>9.0</td>
<td>9.7</td>
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JET Counting geometry is 4 samples in one plane on top of the detector.

IPPLM Counting geometry is 4 samples in a vertical stack on top of the detector → larger efficiency uncertainties.
Experiment Overview
(Fission Chambers)

• Prior set up of Thresholds with AmBe Neutron Source
• 1,000 sec runs of all 3 FC’s simultaneously,
  – recorded by scalers & by an automatic data store.
• Plus, 10,000 sec runs during 12 Activation Irradiations
• FC Runs were mixed with activation measurements to optimise total experimental output, versus shift pattern
• Sequence was:
  – Central Ring, Port scans,
  – Basket scan,
  – Overlap scans, ‘No Boom’ Oct 5 scans, Check scans
• Philosophy: Replicate old calibration,
  Extend it
  Check main correction values
Direct calibration of JET neutron monitors, using a standard $^{252}$Cf source in-Torus

Deployment plan:
Central ring Scans - plus Radial and Vertical Scans at Oct 7, 8
- plus Long Counts during activation runs

FC counts / 1000 s


UpperKN2/D1 vs. UpperKN2/D2 vs. UpperKN2/D3
MiddleKN2/D1 vs. MiddleKN2/D2 vs. MiddleKN2/D3
LowerKN2/D1 vs. LowerKN2/D2 vs. LowerKN2/D3
Pos6KN2/D1 vs. Pos6KN2/D2 vs. Pos6KN2/D3
Rad scan 8/D1 vs. Rad scan 8/D2 vs. Rad scan 8/D3
Vertical scan/D1 vs. Vertical scan/D2 vs. Vertical scan/D3
Rad scan 7/D1 vs. Rad scan 7/D2 vs. Rad scan/D3
Vert scan 7/D1 vs. Vert scan 7/D2 vs. Vert scan 7/D3

Toroidal position

FC D2 Oct 2
FC D3 Oct 6
FC D1 Oct 8
Long counting during Activation
R scan
Z scan
Radial scan: consistent with scattering from the outer regions of horizontal port.

(Inverse square law is allowed for here)

Inner rise is probably due to central column backscatter.

Vertical scan: also roughly consistent with scattering from the outer port regions.

(Inverse square law allowed for again)

Integrated Ring data + (R, Z) Dependence, -> 3D Response Function (Oct. 8 detector)
FC’s: Central Scan: Port Shape
Comparison – all ports are different

FC Oct 6 Counts: Historical Comparison
with 1984-9 data: x 2 reduction in 29 years

Reduction of Neutron Emission ‘Width’
due to Limiters & Other Additions
Recent (>2012) JET Wall layout

Reduction of Neutron Emission “Width” & FC Response due to Limiters & Other Additions

Octant 2 has ILA attenuating the neutrons thro’ port exit
Octant 6 is a narrow port with closely aligned limiters
Octant 8 has wide limiters but port tailored by NBI water
FC Basket Scans: Central, Outer, Inner, Upper & Lower Rings

Main points:

Central rings reproduce and are close to Lower ring – similar geometry vs port.

Upper: less favoured (geometrically)

Outer: favoured (near port)

Oct 8: Central column region blocked

Inner sees port for longer (toroidally)
We have made a Successful JET Calibration whose analysis is still in progress.

- Activation data: 12 activation samples were analysed (3 different torus positions)
- Activation Data Analysis: First analysis is almost complete
  Uncertainties are now < ~ 6% (random) and ~ 8% (systematic)
- Our results indicate about 15% lower Activation coefficients for D,D plasma.
- Expect higher JET outputs by about 15%, after reprocessing.
  - Note that the effect of the boom and other corrections is rather small (< 2%) on the activation data.

- Fission Chamber data: Extensive Central, Basket and port scans data (>350 points)
- Fission Chamber data: Analysis is still in progress.
  - Analytical: Ring analysis for 3 different port types – now under way.
  - Digital: Now running MCNP models
    Target = correct relative responses in the 3 FC detectors,
    - so these can be properly normalised to activation measurements,
    - after cross-calibration measurements in plasmas.

- Now beginning the essential in-plasma cross-calibration measurements of the activation system and the Fission Chamber detectors