Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Parallel computations for the auto-converted MCNP5 models of the ITER ECRH launcher

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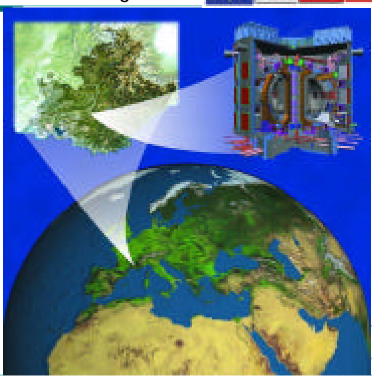
The UK forum for users of Monte Carlo Neutron, Electron and Gamma radiation transport codes (MCNEG-2008) Sellafield Ltd, Risley, Cheshire, UK, 3rd-6th March, 2008

Talk Outline

1. **Neutronics analyses of the ITER upper port ECRH launcher**
2. **Benchmarks of the advanced auto-generated MCNP 3D model of ITER**
3. **Computation performance assessments for parallel MCNP tasks**

ITER Background



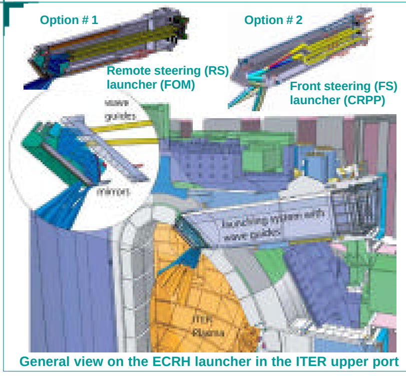
ITER site is chosen in Europe, at Cadarache, near Aix-en-Provence, France

ITER first plasma operation is expected in **2016**

- Steady state operation as ultimate goal with non-inductive current drive
- Operating modes should have sufficient reliability for **nuclear testing**.
- The device is anticipated to operate for ~ 20 years, using externally supplied tritium.

- Average neutron load on First Wall ≥ 0.5 MW/m^2
- Av. fluence ≥ 0.3 MWa/m^2

Introduction to ITER ECRH launcher design



ITER Parameter	Units
Plasma Major Radius	6.2 m
Plasma Minor Radius	2.0 m
Plasma Volume	840 m^3
Plasma Current	15.0 MA
Toroidal Field on Axis	5.3 T
Fusion Power	500 MW
Burn Flat Top	>400 s
Power Amplification	>10
Upper port ECRH power	20 MW

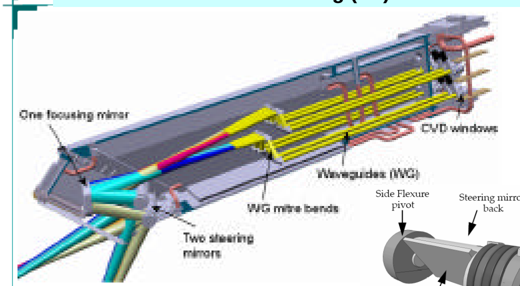
General view on the ECRH launcher in the ITER upper port

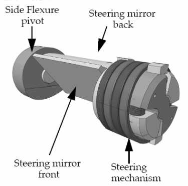
1. Neutronics analyses of the ITER upper port ECRH launcher

- **The aim of radiation shielding analysis** is to prove the correspondence of the ECRH launcher design to all range of nuclear criteria specified for ITER project:
- **Radiation shielding requirements** for reliable operation of the mm-wave elements, for launcher structure, and for neighbour ITER components (VV, TFC)
- **The aim was reached by means of:**

1. **Streaming assessment:**
   - Neutron streaming analyses for fast neutron fluence estimate on torus diamond windows on the launcher rear (5 m deep) side
2. **Shielding assessment:**
   - Analyses for shield arrangement
   - Helium production in steel of vacuum vessel.
   - Volumetric nuclear heating distribution

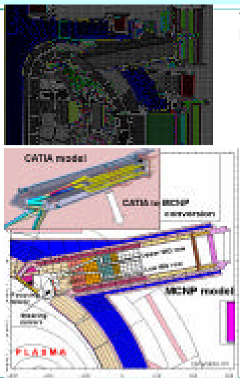
Outline for the Front Steering (FS) launcher design



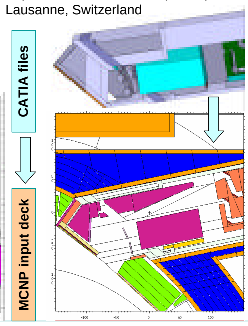


CAD to MCNP automated interface use is inevitable !!!

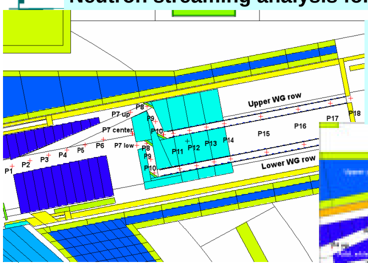
McCad interface is used for MCNP models generation from CATIA files



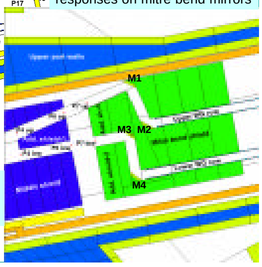
The recent Front Steering (FS) ECRH launcher design developed by Plasma Physics Research Centre (CRPP), EPFL, Lausanne, Switzerland



Neutron streaming analysis for the FS launcher

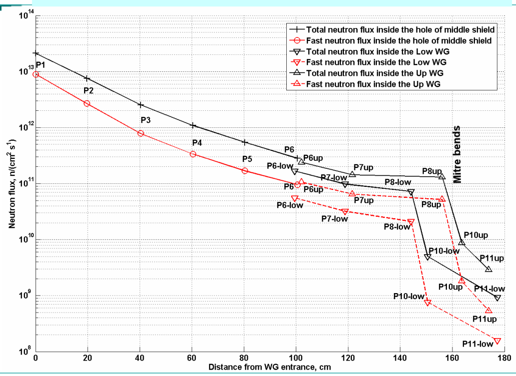


Effect of the Additional Shield Blocks-1-2-3 in the launcher internal shield was estimated by neutron streaming (point detectors) and by nuclear responses on mitre bend mirrors



MCNP point detectors (P1-P20) technique applied for neutron flux calculations inside the Middle Shield hole and along the WGs

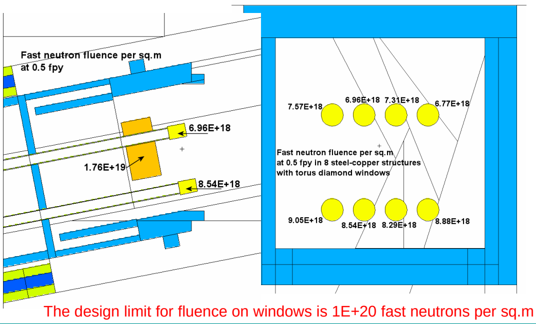
FS launcher with additional shield blocks-1-2-3



Fast neutron fluence at the CVD diamond windows

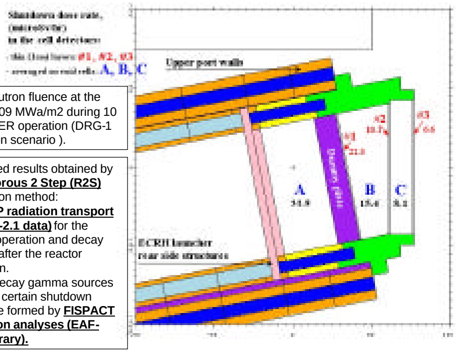
Vertical radial-poloidal cut through the dummy valves and torus windows

Vertical toroidal-poloidal cut through the torus window blocks



The design limit for fluence on windows is 1E+20 fast neutrons per sq.m

Shutdown dose rate map after 10 days decay time



Total neutron fluence at the FW is 0.09 MWa/m2 during 10 years ITER operation (DRG-1 irradiation scenario).

Presented results obtained by the **Rigorous 2 Step (R2S)** calculation method:
1) **MCNP radiation transport (FENDL-2.1 data)** for the reactor operation and decay gamma after the reactor shutdown.
2) The decay gamma sources after the certain shutdown times are formed by **FISPACT activation analyses (EAF-2005 library).**

Nuclear sufficiency criteria established for MCNP models

#	Definition of the nuclear sufficiency criterion	Value in FS design	Value in RS design	Value of general design limit	Type of criterion dependence on fusion power
1	Dose rate behind the CVD diamond window is below 100 microSv/hr after 10 days of shutdown	Less than 15 microSv/hr	Less than 15 microSv/hr	**100 microSv/hr**	Approaching to linear
2	Fast neutron fluence at the CVD diamond window kept below 10^{20} m^{-2} (0.5 fpy)	~10^{17} m^{-2}	Less than $2 \cdot 10^{19}$ m^{-2}	**10^{20} m^{-2}**	Linear
3	Helium production in the joining areas of the vacuum vessel is below 1.0 appm (0.5 fpy)	$1.2 \cdot 10^{-1}$ appm	$1.5 \cdot 10^{-1}$ appm	**1.0 appm**	Linear
4	Compatibility with conservative limit for nuclear heating of 10^{-3} MW/m^3 at the outer housing of the vacuum vessel	$2 \cdot 10^{-4}$ MW/m^3	$3 \cdot 10^{-4}$ MW/m^3	**10^{-3} MW/m^3**	Linear
5	Nuclear response in the structures of superconductive magnets of TFC near the launcher in accordance ITER requirements, in particular fast neutron fluence in isolator is below $5 \cdot 10^{21}$ n/m^2 (0.5 fpy)	$1 \cdot 10^{20}$ n/m^2	$1 \cdot 10^{20}$ n/m^2	**$5 \cdot 10^{21}$ n/m^2**	Linear
6	Nuclear heating density in the vacuum vessel kept below ~ 0.3 MW/m^3	$5 \cdot 10^{-2}$ MW/m^3	$5 \cdot 10^{-2}$ MW/m^3	**0.3 MW/m^3**	Linear

2. Benchmarks of the advanced auto-generated MCNP 3D model of ITER

- **Decades of human efforts** in previous reference ITER design in native MCNP
- **A lot of modification** have been implemented in CAD (CATIA) models
- MCNP model should be updated. **How?** To work again for modeling surface-by-surface for decades?
- **The solution is** MCNP calculations using automated models **conversion directly from CAD files**, or even perform MCNPX jobs with **CAD geometry engine**.

Translators (for MCNP made by FZK, ASIPP, JAEA)
Automatically convert CAD description of geometry into input description for standard radiation transport tool

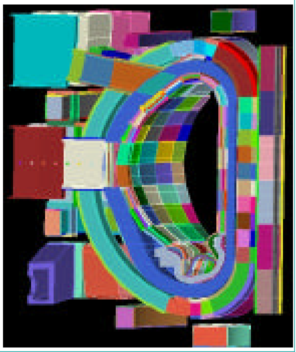
- limited geometric *richness*

Direct Geometry (in MCNPX code: UW-Madison)
Replace functionality of standard radiation transport tool with software library to directly use CAD geometry

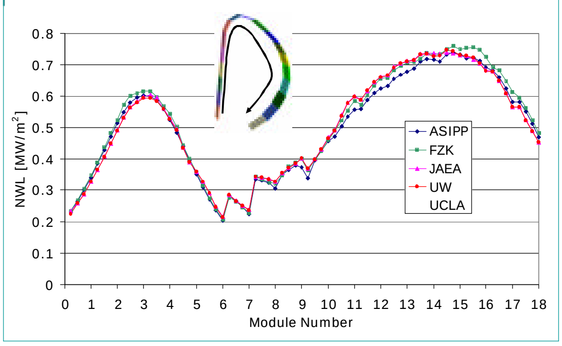
- performance penalty
- increased validation req'd

ITER Benchmark

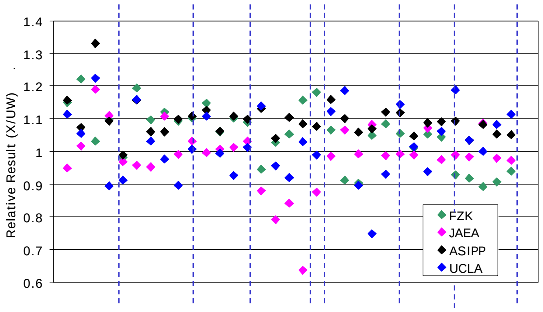
- Comparing 4 problems
  - Neutron wall loading
  - Divertor fluxes and heating
  - Magnet heating
  - Mid-plane port shielding/streaming
- Participants
  - UW, FZK, ASIPP, JAEA + ATTILA (UCLA/PPPL)



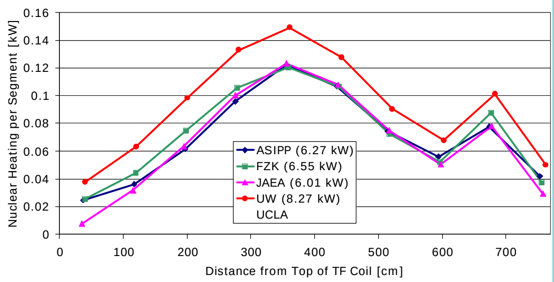
Neutron Wall Loading



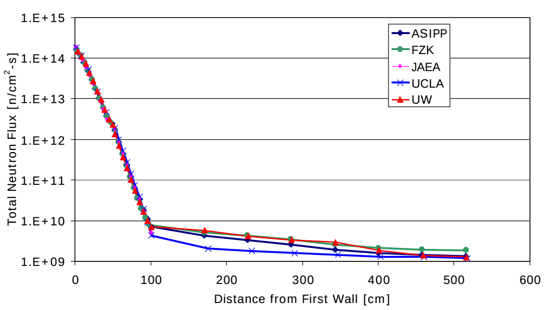
Divertor Fluxes & Heating



TF Coil Heating



Equatorial Port Results



3. Computation performance assessments for parallel MCNP tasks

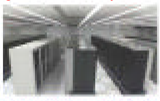
What do others have?

Cited from presentation of **Forrest B. Brown (LANL, USA)** made at the 2005 Frederic Joliot / Otto Hahn Summer School August 24 – September 2, 2005, Karlsruhe, Germany:

DOE Advanced Simulation & Computing – ASC

Three U.S. Defense Program laboratories (Los Alamos, Sandia, and Lawrence Livermore)

Red – 3 TeraOps



Blue Pacific – 3 TeraOps

Blue Mountain – 3 TeraOps (R.I.P.)

Lightning
Red Storm
Blue Gene/L

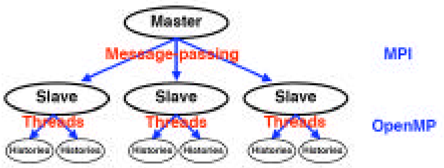
White – 12 TeraOps

Q – 20 TeraOps

MCNP performance assessments in U.S. DOE ASC project

Hierarchical Parallelism

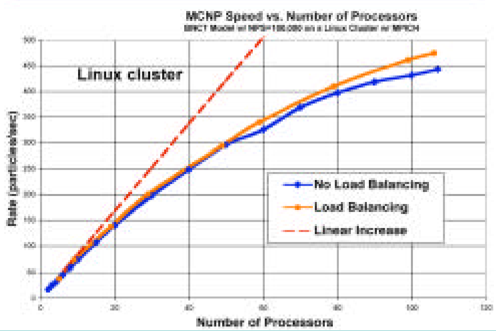
- Use **message-passing** to distribute work among slaves ("boxes")
- Use **threading** to distribute histories among individual cpus on box



- **We routinely test MCNP5 on:**
  - ASCI Bluemountain – SGI, 48 boxes x 128 cpus/box
  - ASCI White – IBM, 512 boxes x 16 cpus/box
  - ASCI Q – HP, 2 x 512 boxes x 4 cpus/box
  - Linux clusters
  - Windows PC cluster
- **1,000 processor jobs are "routine"**

MCNP performance assessments in U.S. DOE ASC project

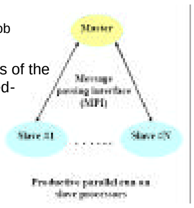
MCNP5 Parallel Calculations



In FZK the MCNP5 parallel computations have been performed on Opus[IB] InfiniBand Opteron Cluster:

- **Opus[IB]** is a cluster system based on the **x86_64** processor architecture, includes **CampusGrid** and D-Grid.
- Aggregated floating-point peak performance of the Opus[IB] cluster is about **1.1 Tflops.**
- **CampusGrid consists of 62 dual AMD Opteron-248** processors (62 nodes with 62*2=124 processors).
- OS is Scientific Linux 4.x. Resource management and job scheduling are achieved with PBS and LoadLeveler.

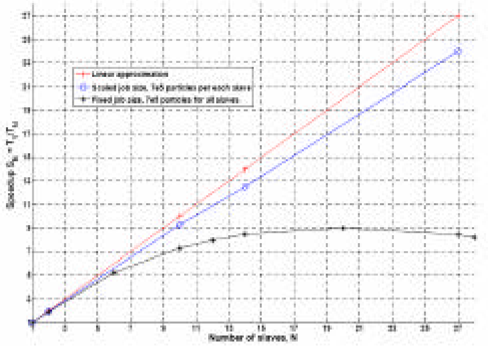
Parallelization of MCNP5 is achieved by means of the message-passing interface (**MPI**) with distributed-memory architecture of slave nodes.



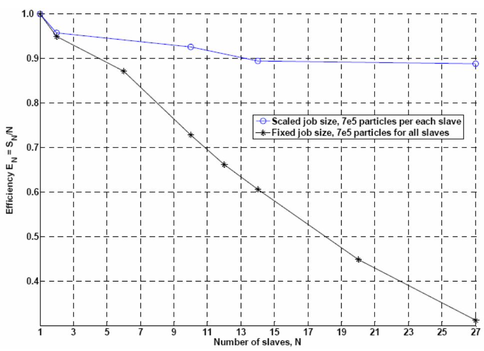
The MCNP5 parallel performance assessments include:

- Speedup of calculations $S_N = T_1 / T_N$
- Efficiency of parallel job $E_N = S_N / N$

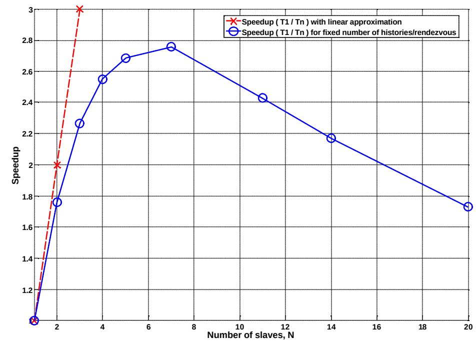
Parallel computation speedup for the MCNP5 run on the FZK CampusGrid Linux cluster



Efficiency for the parallel MCNP5 run on the FZK CampusGrid Linux cluster



Speedup of MCNP MPI parallel computations with 1 thread on each on each processor of Opus^{IB} Linux Cluster, IWR, FZK. Complicated ITER geometry with 3230 cells, using for ECRH launcher development,
fixed job for 70`000 particles sampling, fixed number of particles per rendezvous



Parameters of MCNP MPI parallel computations with 1 thread on each on each processor of Opus^{IB} Linux Cluster, IWR, FZK. Complicated ITER geometry with 3230 cells, using for ECRH launcher development,
fixed job for 70`000 particles sampling, fixed number of particles per rendezvous

# of processors (master + slave)	Job started, astronom. time, t1	Job finished, astronom. time, t2	Real time task used, astronom. (t2-t1), minutes	Total CPU time for the job, minutes	Total CPU time for computation (MCNP ctm), minutes	CPU time per each 7000 particles
1	18:40:09	20:22:10	102	102.02	98-99	10-11 min
2 (1m+1s)	23:10:56	00:52:24	102	101.47	99.15	10-11 min
3 (1m+2s)	23:10:30	00:08:46	58	170.60	98.34	10-11 min
4 (1m+3s)	19:14:54	19:59:43	45	172.95	98.94	10-11 min
5 (1m+4s)	18:37:34	19:17:27	40	191.20	99.21	10-11 min
6 (1m+5s)	19:36:02	20:13:58	38	217.20	100.48	10-11 min
8 (1m+7s)	18:37:53	19:14:37	37	279.86	99.99	10-11 min
12 (1m+11s)	18:38:16	19:20:03	42	478.48	102.21	10-11 min
15 (1m+14s)	19:20:20	20:06:53	47	670.62	101.99	10-11 min
21 (1m+20s)	20:07:19	21:06:38	59	1207.07	103.01	10-11 min

MCNP parallel performance: conclusions and recommendations (1)

- An extensive experience of neutronics analyses using MCNP5 parallel MPI-version on FZK CampusGrid Linux cluster provides proofs of order-of-magnitude speedup, which scales with the number of processors.
- An important issue for scaling is keeping or increasing the calculation load on each processor, the higher ratio of computation/communication, the closer speedup scaling to linear law.
- Short MCNP jobs assigned to parallel run have high overhead, hence use of many processors is inefficient. Such case has been demonstrated in a job with fixed size of particles per slave processor, while increasing number of slaves.

MCNP parallel performance: conclusions and recommendations (2)

• Parallel performance is sensitive to number of intermediate message exchanges between master and slaves (rendezvous).

• Rendezvous number should be reduced in compromise with fault tolerance, the best performance is for only one rendezvous at the end of the job.

• Using the outcomes of the parallel performance analysis, the MCNP 3D model of the ITER upper port ECRH launcher reaches results of 18.9e6 particle histories <u>24 times faster with 27 processor slaves, giving 88% of the estimated scaling efficiency.</u>