ENGINEERING ANALYSIS AND CODES

Alfredo Portone
Fusion for Energy
OVERVIEW

1. Mission of the F4E Engineering Analysis Group
2. Core activities: Analysis, Codes & Standards
3. Modus operandi, contracts and grants
F4E requires a **whole range of engineering support** activities in the field of general mechanics, remote handling, plant systems, nuclear and safety engineering:

- Conceptual and detailed designs
- CAD support
- **FE analysis**
- Integration of systems
- Safety and nuclear engineering
- Cost assessment
- Welding and fabrication
- Standardization of components
- Risk analysis
- Quality assurance
Provide technical support in the area of Analysis, Codes & Standards to **F4E Procurement Groups**

**WHY?**

Support F4E Procurement Groups in handling of
- Design/Engineering Change Requests
- Non-Conformities Reports approval
- Backup Solutions investigations

...  

Remark: *Due to the large differences in procurement and commissioning schedule, the design maturity of the ITER components varies from quite detailed (magnets) to rather conceptual (blanket) ➔ some areas need a lot of design/analysis work to be carried out ➔ provide support to ITER IO*
Analysis and Codes needs

- Mechanical Analyses
- Thermo-hydraulic Analyses
- Electromagnetic Analyses

- Civil Engineering Analyses
- Neutronic Analyses
- Material expertise, …
Analyzing the engineering analysis codes:

- Electro-magnetic
- Seismic
- Mechanical
- Neutronic
Electro-mechanical analyses features

- Coupled electromagnetic-mechanical analysis through plasma (~mass-less) dynamics
- Computation of eddy currents (linear) and magnetization (nonlinear) to assess heating in cold structures, Lorentz forces, etc.
- Large & complex 3D models of vacuum vessel, blanket, FW, buildings (shell, solid,…)
- Wide range of mechanical analysis types (static, dynamic, linear, nonlinear, buckling, fatigue, cryogenics T, …)

Reference software

- ANSYS (ITER IO)
- Additional: ABAQUS, SAP 2000, Civil Fem

Choice impact on QA
Civil engineering analysis features

- Definition of equivalent static forces
- Floor response spectra computation
- Soil-structure interaction modeling
- Design of seismic isolators
- Airplane crash
- ...

Reference software
ANSYS/CIVIL FEM
SAP2000
Neutronic analysis features

- Complex 3D geometries & neutron sources!
- Transport calculations of neutron fluxes & spectra for high energy neutrons in presence of thick shields (large flux gradients), penetrations (streaming), multiple materials, sky shine in the Tokamak complex and other controlled buildings;
- Computation of gamma spectra, nuclear heat & damage, material activation, T production (TBM), inventories, doses & occupational exposure…;
- Parallel processing acceleration, MC/FE acceleration algorithms, automated processing software;
- Benchmarking, development of tools and models, improvement of calculation techniques.

Reference software

- MCNP5 v1.5, FISPACT 2007, FENDL 2.1 and EAF 2007 nuclear data libraries, mesh tallies techniques, rigorous-two-step (R2S) when possible
Nuclear database:

• **A fully qualified nuclear cross-section database** + validated computational tools are at the basis of any QA neutron & activation calculations as well as of their uncertainties assessment;

• F4E is driving a unique effort on the development of qualified nuclear data for fusion applications oriented to ITER, IFMIF and DEMO;

• This effort brings together recognized Experts and resources from EURATOM Associations and European industry

• This Nuclear Data R&D programme is part of the EU voluntary contribution (i.e. non credited) to ITER
Key features

- To qualify the ITER components, it is necessary to verify the analysis results according to different codes & standards. Suppliers must have proven experience;
  - ASME BPVC
  - RCC-MR
  - PED, ESPN
  - SDC-IC
  - SDC for Buildings
  - Eurocodes
  - EN...

Multi-code approach for the ITER components

- No single industrial code covers the variety of ITER components & loads;
- Specific existing codes cover some particular operational requirements;
- Some components (magnet, in-vessels) need special codes developments.
<table>
<thead>
<tr>
<th>Component</th>
<th>PED Category or ESPN category &amp; level</th>
<th>Selected Codes</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manifolds and piping → PED</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blanket System</td>
<td>Blanket Modules – Cat. IV Piping and manifold – Cat. I, Level N3 + TBD</td>
<td>Design – <strong>Structural Design Criteria – In-Vessel Components</strong> Manufacturing, inspection: ASME or EN standards (conventional parts) and TechSPecs</td>
<td>Agreed Notified Body shall check design, manufacturing and conformity. Divertor case to be considered</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tritium Plant and Detritiation</td>
<td>Categories I-IV, Level N2, N3 or non-nuclear</td>
<td>Design and Manufacturing: - Vessels ASME Section VIII, Div. 2 - Piping ASME B 31.3, Category M - Valves ASME B16.34 - And Technical Specifications</td>
<td>Conformity with PED/ESPN required, Agreed notified Body required. Use of EN standards under consideration.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Complete table in “Codes and Standards for ITER Mechanical Components”
RCC-MR 2002

Generic - Integrated in the base Code
- Rules for bolts (RB 3280 +A6)
- Materials
- Electron Beam and Laser welding
- Pressure test
- Rules for box structures (RC3800+RC4000)

Specific - Appendix A19
- Categorization of welded joints
- Special rules for permanent attachments sealing welds and Cu coating
- Use of alternative NDE methods (Ultrasonic Testing and Photo Thermal Camera)
- Low Co materials

ITER needs - box type structure -
Requirements of ESP and ESPN
Introduction of European (Harmonized) Standards

RCC-MR 2007

EFDA - F4E Active involvement
Use of international electrical standards (IEC) and adoption of French Standards + European Directives for (1) installation & operation rule, (2) design, manufacturing & testing of components affecting safety (nuclear and personnel) and fire protection

→ ITER Electrical Design Handbook, Part 3: Codes and Standards

<table>
<thead>
<tr>
<th>SSEN EQUIPMENT</th>
<th>Manufacturing Standard</th>
<th>Indoor / Outdoor Facilities</th>
<th>Site Installation Standard</th>
<th>Nuclear Safety</th>
<th>Personal Safety</th>
<th>Tokamak Complex</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV / LV DISTRIBUTION TRANSFORMERS</td>
<td>IEC 60076-1</td>
<td></td>
<td>IEC 60076-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60076-2</td>
<td></td>
<td>IEC 60076-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60296</td>
<td></td>
<td>IEC 60364</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60664-1</td>
<td></td>
<td>IEC 60905</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 61000-5</td>
<td></td>
<td>IEC 61000-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 61000-6-2</td>
<td></td>
<td>IEC 61140</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 61000-6-4</td>
<td></td>
<td>NF C 15-100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HD 538-2 S1</td>
<td></td>
<td>IEC 60780</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NF C 52-112 / NF EN 50464</td>
<td></td>
<td>IEC 60980 (SR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60068-3-3</td>
<td></td>
<td>IEC 60364-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60754</td>
<td></td>
<td>IEC 61249-2-21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIRCUIT BREAKER</td>
<td>IEC 60664-1</td>
<td></td>
<td>IEC 60068-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60947-1</td>
<td></td>
<td>IEC 60364</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60947-2</td>
<td></td>
<td>IEC 60947-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 61000-5</td>
<td></td>
<td>IEC 60947-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 61000-6-2</td>
<td></td>
<td>IEC 61000-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 61000-6-4</td>
<td></td>
<td>IEC 61140</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60068-3-3</td>
<td></td>
<td>IEC 60364-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEC 60754</td>
<td></td>
<td>IEC 61249-2-21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Safety Related Buildings** - ITER Structural Design Code for Buildings

- Adaptation of state-of-the-art structural design criteria for civil works
- Specificities of the configurations and loads of a fusion nuclear plant
- Based on the concept of the limit state design used jointly with the method of the partial factors, as stipulated in Eurocode EN 1990
- First part devoted to the design specifications of the safety important buildings of ITER
- Construction rules defined in second part (topography, tolerances, earthworks, concrete works, formwork, reinforcement, base isolation and elastomeric bearings, leak-tight metal parts on containment, etc.).

**No safety related buildings** - Application of Eurocode (mainly)
Internal analyses activity

- Analysis and Codes group (5 people) provides “in house”, light analysis capabilities + general computational expertise (brain-storming phase with “clients” from other groups, problem formulation, check interfaces, …)
- Medium/large (>1 month) design work orders carried out – typically - through industrial contracts of different types;

External contracts

- Large use of framework contracts, multiple lots, 3 cascade winners;
- Specific contracts are also issued for well specified work packages via single (<50 kEuro), restricted (<250 kEuro) or open tenders;
- Grants (40% F4E contribution) rarely used, mostly for University/Association R&D activities (e.g. nuclear data, code development, …)
- Yearly expenditure for analysis and codes activity ~ 1÷2 M€
Contract deliverables and IPR

• All MCNP/FE models, including input and result files, routines, and mesh quality summaries are asked to be given to F4E as part of the ADP (Acceptance Data Package) to allow F4E to repeat all the calculations performed by the Supplier.

• The intellectual property of all routines, input files, databases and result files developed by the Supplier under the contract will belong to F4E.

• If the Supplier needs to use any database or routine developed in the past under any contract (excluding past F4E and EFDA), it should declare this beforehand in the Background Declaration Form.
### REQUIREMENTS

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>RECOMMENDED SOFTWARE</th>
<th>ALTERNATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A unique CAD system (mechanical and networks)</td>
<td>CATIA v5 r19 SP 3 IGEXAO</td>
<td>Autocad (Buildings)</td>
</tr>
<tr>
<td>A unique analysis software</td>
<td>ANSYS (Civil FEM, LS-DYNA, FLUENT)</td>
<td>ABAQUS **</td>
</tr>
<tr>
<td>An efficient computer aided data management system</td>
<td>Enovia VPM (IO), Enovia Smarteam (f4e,associations, suppliers)</td>
<td></td>
</tr>
<tr>
<td>An efficient project management software</td>
<td>Primavera</td>
<td>Microsoft Project **</td>
</tr>
</tbody>
</table>

* Suppliers may use any CAD SW but F4E must receive everything in CATIA v5 format

** Upon approval by F4E on special cases
1. Nuclear Data Libraries
   - Improvement of European Fusion File (EFF) and European Activation File (EAF) as part of the nuclear data source for ITER (by means of the FENDL activities), TBM and broader approach activities and safety studies (IO requirement from French Nuclear Authority).
   - Benchmarking of updated and extended nuclear data evaluations

2. Nuclear Data Experiments
   - Development of measuring techniques for activation and T production
   - Integral benchmark experiments for data validation covering materials relevant to ITER and fusion in general, including neutronic and nuclear data analysis of specific impurities for fusion relevant neutron spectra
   - Design and implementation of experiments on fusion relevant mock-ups for evaluation and assessment of neutronic calculations

3. Nuclear Data Tools:
   - Development and validation of advanced numerical methods and computational tools, in the field of nuclear models and covariances and uncertainties
ITER CATIA V5 data: Exported by ITER to DA (incl. trace-ability): studied component + context

Native CATIA V5 r19 sp3 or:
Multi-CAD approach (Solidworks, Mechanical Desktop…)

Opportunity of CAD data exchanges (ITER + DA): when required

ITER DMU review
Saving into ENOVIA (Reconciliation)
ITER DIDO Meetings Approval process

CATIA V5 data only exported by F4E to ITER (incl. traceability, DET): studied component only

Process for Stable interfaces (frozen design)
Process dedicated to collaborative design tasks