Nuclear fusion could give in the medium term a CO$_2$-free contribution to the increasing world energy needs. The International Thermonuclear Experimental Reactor (ITER) is going to be the major fusion project in the world, as soon as a choice on the site of the reactor is made between the two present candidates, Cadarache in France and Rokkasho in Japan. At present, EU, Russia, China, South Korea, Japan and the US participate to the negotiations. In ITER the plasma where the nuclear reactions occur is confined by means of low critical temperature superconducting coils, according to the tokamak configuration: Central Solenoid (CS), and Toroidal Field (TF) coils will be based on Nb$_3$Sn, whereas the Poloidal Field (PF) coils, located at lower field, will use NbTi. These coils will be wound with cable-in-conduit conductors (CICC) where the superconducting filaments are found inside a copper matrix in the strands, while the cable itself is made by about 1000 such strands twisted according to a predefined multi-stage structure. The complexity of this design is such that it is not obvious that the CICC behaves as a trivial superposition of single strands. Accordingly, a strong R&D program has been developed during the last decade or so, in order to assess the performance of these materials in ITER-relevant conditions. This program included the development of so-called Model and Insert coils, all of which have already been tested, except the insert coil for the PF coils, the so-called PFCI. The biggest Nb$_3$Sn coils so far, the CS and TF model coils, showed unexpected degradation compared to single-strand performance (lower current carrying capacity than the ensemble of strands times their current capacity). This is presently attributed to the strand bending inside the cable, in view of the critical current sensitivity to the strain in Nb$_3$Sn, but this explanation still has to be confirmed. This result led to the development of so-called advanced strands based on which short samples first and, possibly, a new insert coil will be tested during the next few years. Also the test of NbTi short samples showed unexpected degradation -- sudden quench at lower currents and/or temperatures than expected from the single-strand tests. This is presently attributed to non-uniformity of the current on the cable cross section, but it still has to be confirmed in the case of a long conductor as in the PFCI. In all cases, adequate computational tools had to be developed ad-hoc and applied to the analysis of the performance of these complex systems, as the latter cannot be directly assessed by the experiment because of the insufficient number of diagnostics inside the coil.

The proponent group has been active since 1995 in the development and application of state-of-the-art computational tools for CICC analysis (Mithrandir, M&M, THELMA), including hybrid/multi-physics models (thermal-hydraulic, electromagnetic, mechanical fields). Since 2000 the proponent group also had increasing responsibilities in the testing of samples, insert and model coils for ITER, going from the simple attendance to the CS Model and Insert Coil tests, through the contribution to the definition of the test program of the TF Model Coil and of several short samples, to the test group leadership of the PFCI. The proponent group collaborates on these topics with many institutions all over the world (see author list of publications below). These activities are funded by EURATOM and MIUR.

### Research program objectives (intermediate and final) and expected results

#### Intermediate objectives on NbTi
- Definition of the test program of the PFCI by means of 1) predictive analysis, 2) analysis of short sample tests (2006)
- Participation to the PFCI test at JAERI Naka, Japan (2006)
- Analysis of the test results with particular reference to 1) CICC performance, 2) stability and quench propagation, 3) AC losses, and resulting validation of the computational tools (2007)

#### Intermediate objectives on Nb$_3$Sn
- Contribution to the definition of the test program of short samples based on different advanced strands (2006)
- Participation to the sample test at CRPP Villigen, Switzerland (2006)
- Analysis of the test results with particular reference to 1) CICC performance, 2) current distribution on the CICC cross section, and resulting validation of the computational tools (2007)

#### Final expected results: Clarification of NbTi and Nb$_3$Sn CICC degradation. Feedback of the validation on model and code: improvement and implementation of the required new items, with particular reference to the hybrid thermal-hydraulic/electromagnetic models (NbTi) and mechanical/electromagnetic models (Nb$_3$Sn). (2008)


