# Procurement and Quality Assurance issues for the ITER Magnets

**The ultimate aim of the QA**

**The game of high spec and non-conformity**

**When is a strand good (enough)…**

**Cost and value of conductor test**

**Coil test:**

what we need to know

what we better ignore

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*Quality Assurance Issues for ITER Magnets*
*CERN Academic Training, June 3rd 2005*

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# What is *Quality* ?

## From the perspective of the supplier,

1. ….” to deliver according to the specification ”
2. ….” to earn a good reputation ”
3. ….” to make the customer happy ”

## From the perspective of the customer

Quality is ***“no trouble”*** (schedule, performance, reliability, safety, price)

## **Misunderstanding between *Quality Assurance* and *Acceptance Tests***

Actually, ***QA is strictly a business of the supplier***, e.g. including

- Technical definition of internal procedures,
- Certification of tooling
- Safety of handling and processes
- Formation of personnel
- Documentation and reporting of manufacturing steps
- Inspection of intermediate and final products

The customer should only care about definition and results of ***Acceptance Tests***

***The self-involvement of the customer in the industrial QA is popular in research projects, with fatal misunderstandings about the roles and the competences, leading to mix the technical and financial responsibilities***

## The dark conscience of the customer

- **An exaggerated worry about QA frequently reflects a lack of confidence from the customer in his own specification and acceptance test, rather than a lack of confidence in the supplier**

- **Neither extensive QA definition nor repeated acceptance tests on components will ever detect a misconception in the design**

- **The targets and range of the acceptance test for industrial supplies must be carefully defined.**
  - The test of the industrial supplies cannot turn into a ***design verification***, for which the contractor has no responsibility
  - On the other hand, performance responsibility can and must be separated from ***acceptance of components*** and individual procedures

## Performance specification vs. "blue print"

*If a component, e.g. a NMR magnet, already exists on the market, at least as a prototype, it is easy to specify it in terms of performance, leaving the design and manufacturing methods to the supplier. Final commissioning will be the only milestone.*

*New, complex research devices are (in most countries) designed by the research institutions, with the industry executing the blue print of the drawings. Acceptance test cannot be based on absolute performance, as the supplier does not carry design responsibility.*

*Even when the concept design is provided by the customer, leaving "only" the engineering design to the supplier, a performance test cannot be used as a commercially binding acceptance test.*

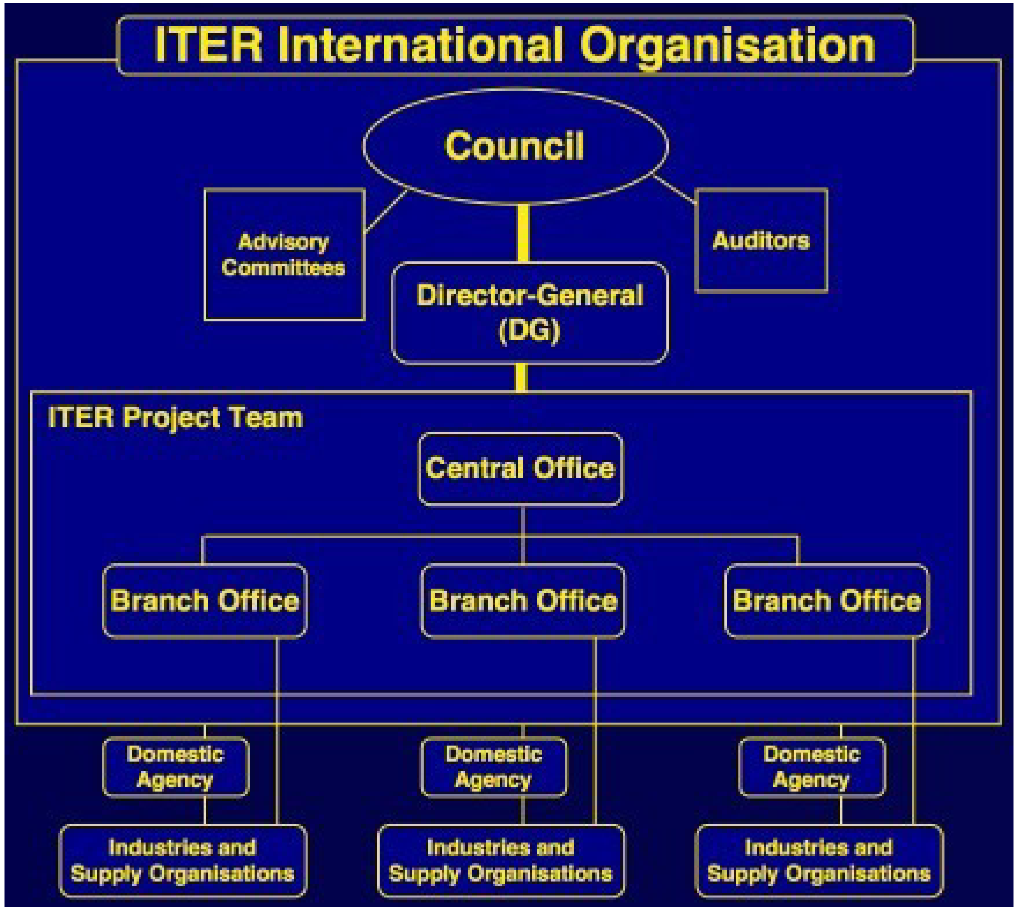
*The ITER coils are procured under design responsibility of ITER. Any QA test on industrial items is aimed to prove the proper execution, not the performance*

***The component procurement in the ITER project is managed by the domestic agencies of the participating teams, who place (and pay) the industrial contracts. From the commercial point of view, the system is ill; "politically", it is a must***

*The specification and acceptance are agreed between the supplier and the domestic agency, who is the "contractual authority".*

*However, no acceptance criteria are defined between the domestic agency and the project team.*

*Conflicting interests will arise between the money holder (with clear constraints on expenses) and the final user (with highest priority on technical "quality")*



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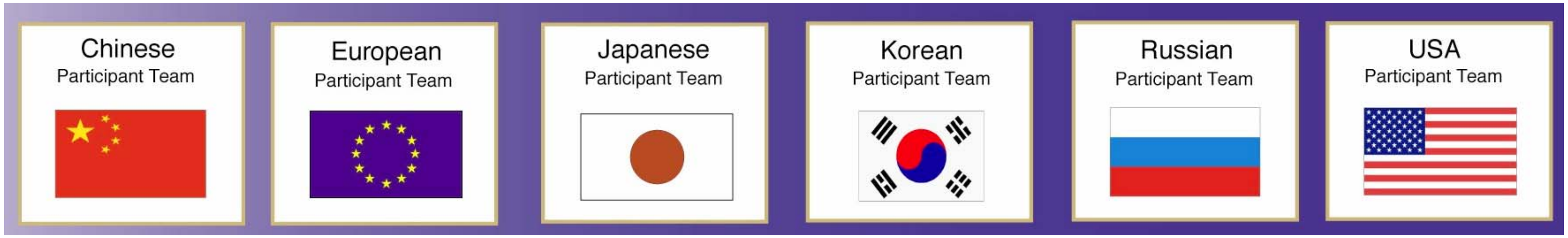
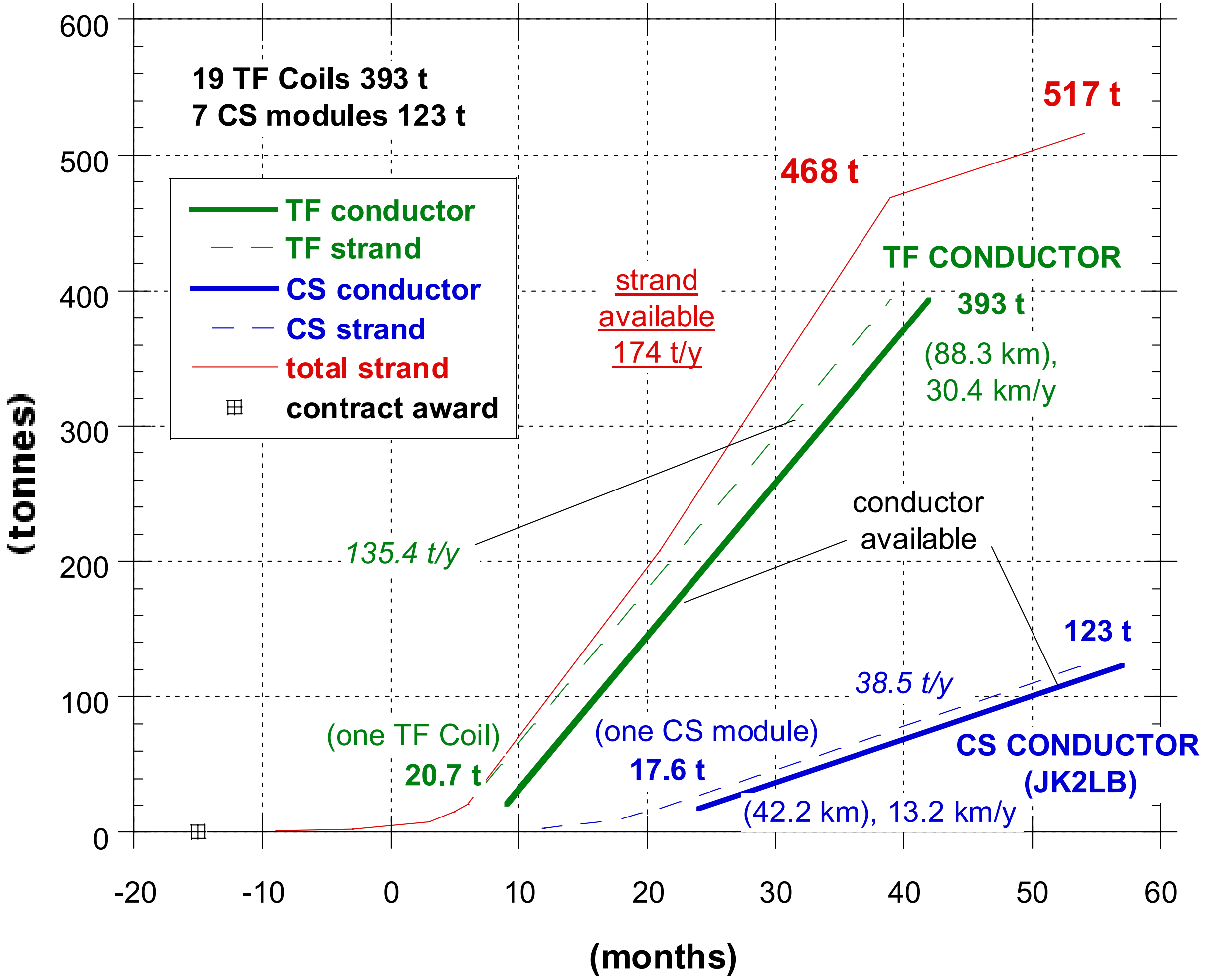
# (Likely) split of ITER magnet procurement




| | | | | | |
|---|---|---|---|---|---|
| NbTi strand<br>$Nb_3Sn$ strand | $Nb_3Sn$ strand | $Nb_3Sn$ strand | $Nb_3Sn$ strand | NbTi strand<br>$Nb_3Sn$ strand | $Nb_3Sn$ strand |
| Cabling<br>Jacketing | Cabling<br>Jacketing | Cabling<br>Jacketing | Cabling<br>Jacketing | Cabling<br>Jacketing | Cabling<br>Jacketing |
| Correction Coils<br>Feeders | 9 TF coils<br>4 PF coils | 9 TF coils 1/2 Central Solenoid | | 2 PF coils | 1/2 Central Solenoid |

## The $Nb_3Sn$ strand - ITER needs Present worldwide production rate is < 10 t/y

*All potential manufacturers (<10) must contribute for logistic and domestic reasons*



# The $Nb_3Sn$ strand specification - easiest or most difficult case?

- ***Main objective of strand specification is to get the CHEAPEST strand that allows conductor to be built***

- ***The specification gives (more or less) the minimum acceptable***

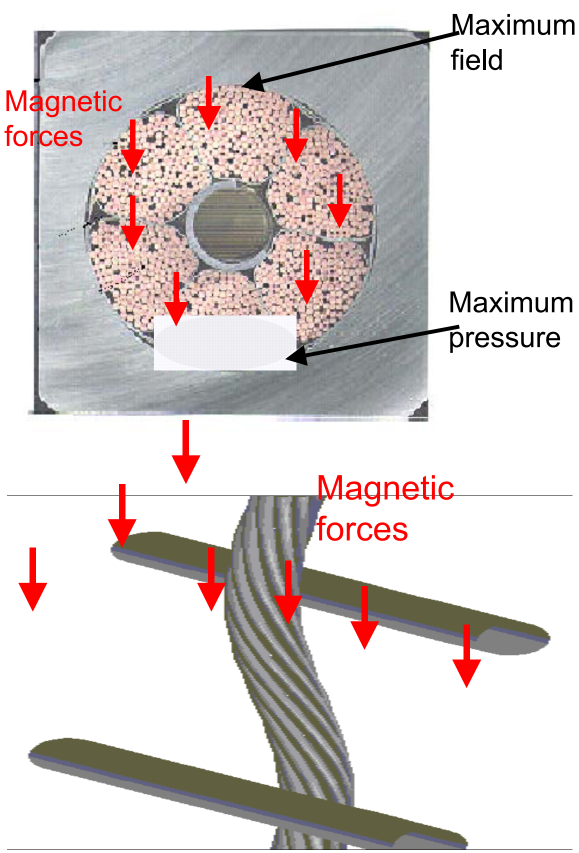
- ***Strand that exceeds specification gives extra margin BUT its higher performance can only give a cost saving IF THE CONDUCTOR IS REDESIGNED and REQUALIFIED***

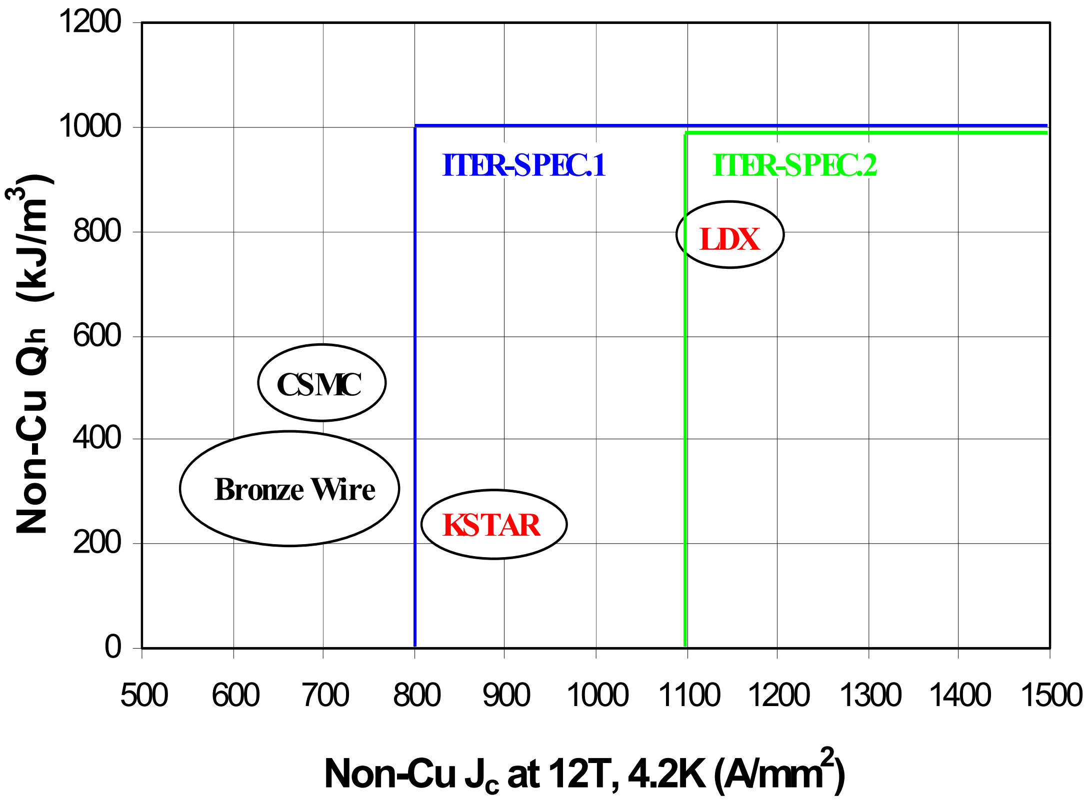
- ***ITER time schedule requires mixing of conductors from different suppliers to complete windings as quickly as possible, start downstream processes***

- ***Different cables (dimensions, build) in same coil NOT practical.***

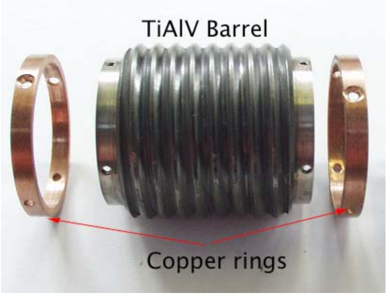
- ***Difficult to use effectively high performance strands with performance above 'other' strands***
- ***Prefer cheap strands that just meet the spec***

***The hesitation to accept high performance spec is not only due to the different supplier capability. The use of high non-Cu current density may conflict in CICC with the high bending degradation***



# $Nb_3Sn$ strand - Acceptance test




- As the strand is *specified on performance*, the customer does not care about QA, just acceptance test.
- The acceptance test belongs to the product certification and must be carried out by the supplier on each production length.
- After qualification and initial bench mark of the acceptance test procedure, there is no point to repeat the strand test at the customer's lab

*An issue of the $Nb_3Sn$ specification / acceptance is that the large series test must be done at easy, reproducible operating conditions, e.g. 4.2 K, 12 T, $\varepsilon = \varepsilon_0$. As the scaling laws for $Nb_3Sn$ strands depend on the specific strand layout, an issue arises between the (common) performance specified for acceptance test and the performance expected in operation, 11.3 T, 5.7 K, $\varepsilon = -0.77\%$*

# $Nb_3Sn$ strand - Acceptance options

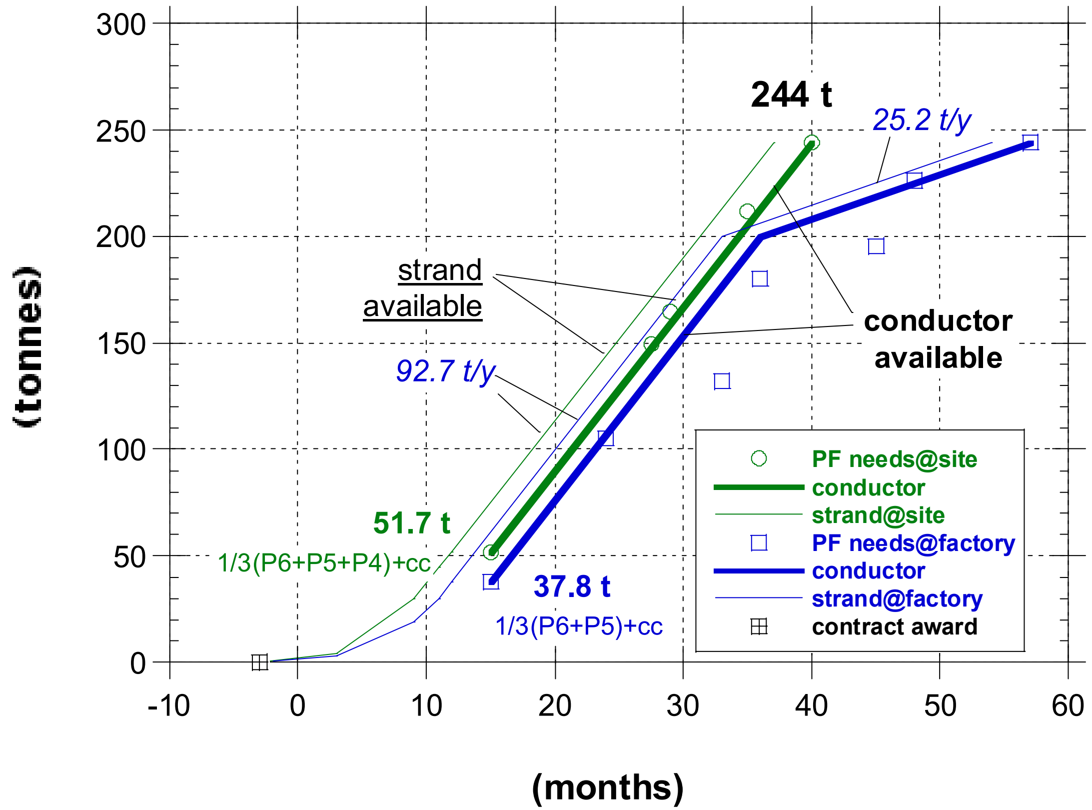
- ***In most cases, a manufacturing anomaly is detected by the company's QA procedures before the strand completion of the process. A "bad" strand seldom makes its way to the acceptance test***

- ***If the acceptance test result is below spec, the strand batch should be rejected. This is feasible in practice as one single batch is << 0.1% of the delivery scope for a single company, i.e. the financial impact is very small***

- ***The individual strand result, not the average of many batches, must be compared to the specified performance: the design aims to a balanced current distribution in the cable. A free, optimized current re-distribution is not granted.***

**The NbTi strand - ITER needs  Present worldwide production rate is > 150 t/y**

**Very similar performance is achieved by all manufacturers: *no problem***



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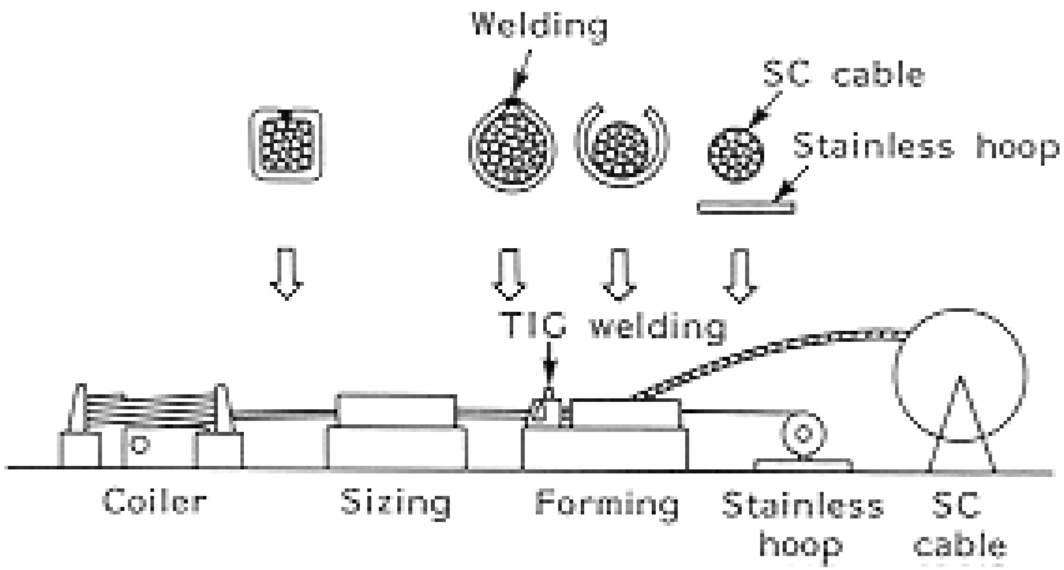
# Cabling

- The cabling is mostly carried out by companies not involved either in the strand production or in the conductor jacketing
- Opposite to the strand, the cable is designed by ITER, the spec is a "blue print"
- For the free standing cable, no performance test can be carried out
- Destructive tests on a short section may be done to verify the pitch lengths (spec available), the coating abrasion, the strand deformation (no spec available) and breakage
- Non-destructive tests have a very limited scope, e.g. visual check the outer cable surface for strand breakage…. However, no threshold for rejection is clear now

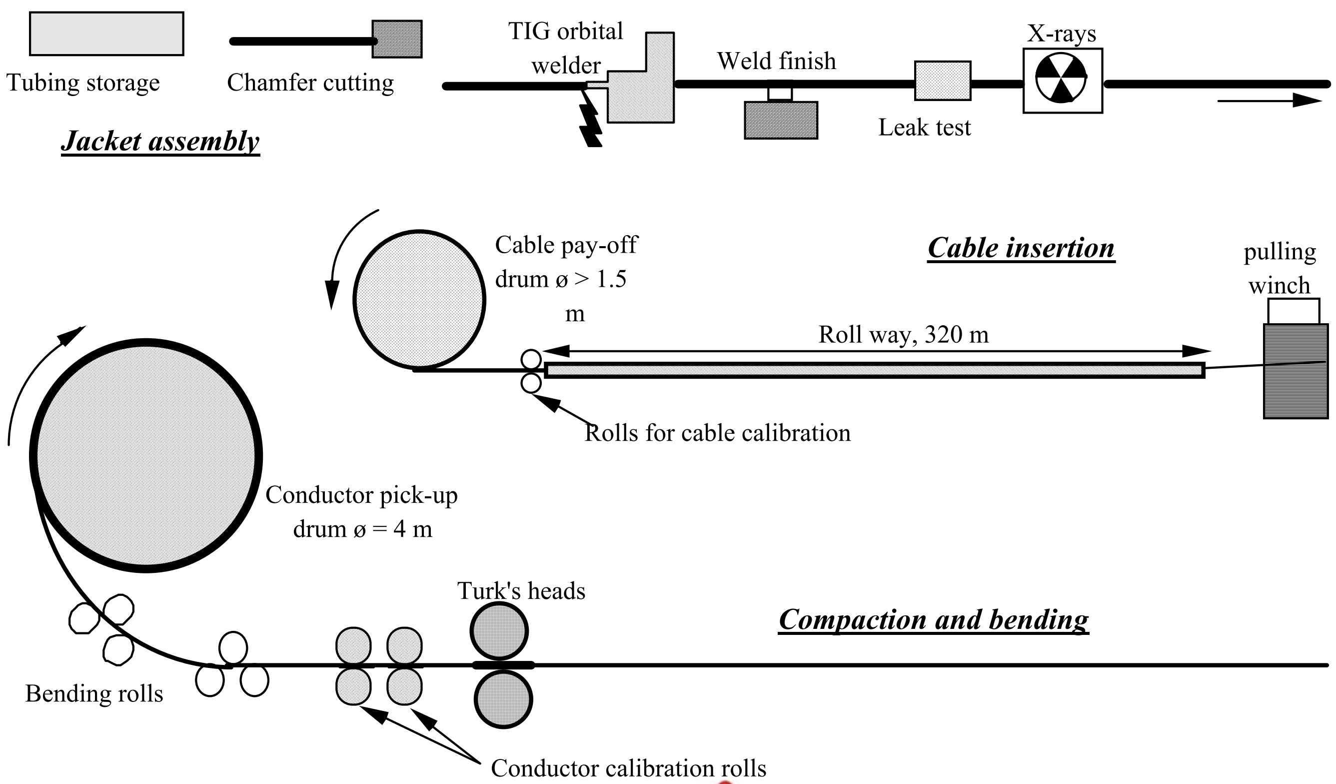
# Jacketing

- **For jacket and jacketing, the ITER specification must be "soft"**
  - Two method options are available: ***tube mill*** and ***pull through***
  - Geometric tolerance are specified (at the border of realistically achievable levels)
  - Metallurgic composition is hard to specify as each country has own standard alloys
  - On materials, "performance spec" prevails on "blue print"
  - Welding is also specified on "performance" rather than on "procedure"



# Jacketing

- **As the cable performance cannot be verified as "free standing", a "full" performance test as acceptance of the jacket/jacketing is ruled out by principle. Already at this level, the overall performance responsibility cannot be with supplier**



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# Finished Conductor: *to test or not to test…* - Liability issues

- **The conductor performance is not the object of an industrial specification**
- **Opposite to the strand, the acceptance/rejection is not in front of a company, who is liable for replacement/repair**
- **The performance liability of the domestic agencies,  supplying the conductor as in-kind contribution, is also questionable**
- **The financial liability of  ITER for conductor performance is out of question, as ITER "has no money"**
- **Before discussing the issue of rejection, the liable authority must be identified**

# Finished Conductor: *to test or not to test…* - Acceptance criteria

- **Even disregarding the liability issue, the acceptance criteria are not straightforward**
- **Compared to coil operation, a short sample test can reproduce the**
  - **Operating peak magnetic field, current, temperature and total mass flow rate**
  - **AC and transient field, energy disturbance (if required)**
- **Compared to coil operation, a short sample test cannot guarantee the identical**
  - **Joint resistance distribution (no joint is identical)**
  - **Distance between joint and high field (shorter in conductor test)**
  - **Self-field profile across the cable**
  - **Conductor length in high field (shorter in conductor test)**
  - **Mass flow rate distribution bundle/channel**

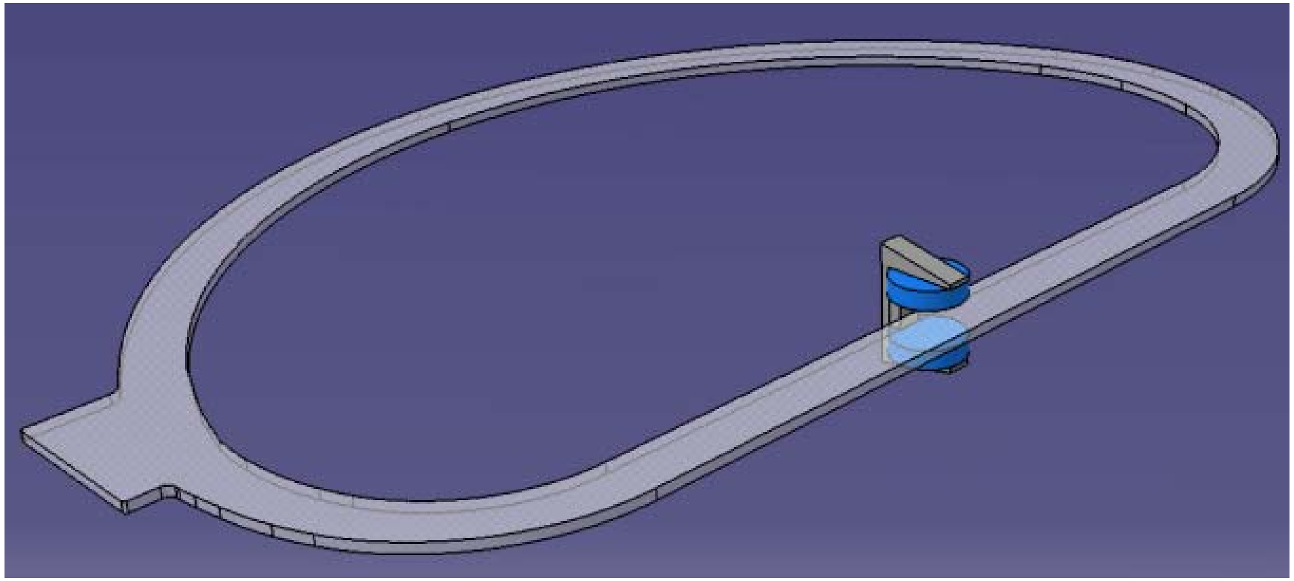
- **It is a matter of fact that, whenever a short sample did not achieved the expected/specified performance, the "supplier/customer" always claimed that *<< in a coil, the performance will be much better>>***

## **Finished Conductor:** ***to test or not to test… -*** **Rationale**

- **Intensive, short length conductor test of large scale production makes no sense**
  - –The achievement (or not) of target performance is an endless argument
  - –The financial liability for rejection ***(>4M€ /conductor length)*** remains an open question
  - –There is no reason to suspect performance scattering through the production
  - –Systematic "acceptance" test would introduce ≈ 9 months delay between conductor delivery and start of winding
  - –The cost of sample preparation/testing for the whole production (head and tail of each length) would be a non-negligible fraction of the overall conductor cost
- **Qualification tests before starting the large scale conductor production are essential and mandatory**
  - –Demonstration (to full satisfaction) of an "exact" ITER final layout prototype, to freeze the design phase
  - –Qualification (to full satisfaction) of each supplier for each type of delivered conductor, prior to start the series production
  - –Random (e.g. one sample/coil) test during production, for monitoring of stability

## Coil test: *a big issue*

- **Opposite to accelerators magnet, a full performance test of an ITER magnet cannot be done as free standing (forces, field, radiation)**
- **A proposal for full testing of each individual pancake by a split solenoid travelling all along the winding is (almost) self-consistent, but not viable in terms of cost and time**



## Coil test: *an even bigger issue*

**Although the infrastructure for a cold test of a free standing coil is very expensive and the test is not "decisive", a test should be done for**

- HV insulation test
- Cold leak tightness test
- Pressure drop by supercritical helium of individual channels (flow balance may be applied)
- Monitoring of joint resistance, max 1kA (no feed back)

**Insulation defects and cold leaks would be 100% fatal in operation, but can be easily fixed at low cost. The investment of a cold test would pay back**

**No coil will be rejected based on cold test.**

**Only repair is considered**

# Assume that…

- **Disregarding the feasibility of a "full performance coil test" and the reliability of the test results, just assume that the coil performance is below design…**
  - ***reject the coil ?***
    - *Cost is in the range of 100 M€… who pays?*
    - *To re-do the coil takes at least 2-3 years… delay the ITER construction ?*
    - *If you re-do it identical, you should also expect an identical behavior…*
    - *If you change design, what about the other coils? When is the new design qualified?*
  - ***accept the coil ?***
    - *If you can accept performance below design, why do you test?*
    - *To know one year in advance that the performance is lower, does not help much*

## Lesson and Conclusion

**The design of a large machine must be proved before starting construction**

**Trust in the qualification procedures is essential**

**For industrial components, Quality Assurance is industrial business**

**The extent of liability must be clarified through the procurement path**

**Performance tests cannot be the basis for acceptance on blue print items**

**Hold points before assembly are important and should be applied to all repairable items**

**It does not help to test whatever cannot be either repaired or replaced**



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