Quality Management for WENDELSTEIN 7-X – Lessons Learned

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Abstract
The WENDELSTEIN 7-X stellarator is the next step device in the stellarator line of IPP Garching. It is being assembled in the branch institute of IPP at Greifswald. Start of plasma operation is scheduled for 2012. The WENDELSTEIN 7-X project is presently the largest scientific project in Germany. From the start of the planning up to the end of operation, the time span for this project will be almost 50 years. With the start of the construction phase of W7-X in 1996 a Quality Management System was established which is orientated on ISO 9001 and is used for design, procurement and assembly. With this Quality Management System now ten years of experience have been gathered, which are described in this paper
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1. Introduction

The WENDELSTEIN 7-X (W7-X) stellarator is the next step device in the stellarator line of IPP Garching. It is being assembled in the branch institute of IPP at Greifswald. Start of plasma operation is scheduled for 2012. For a technical description and further references see [1]. The W7-X project is at present the largest scientific project in Germany. From the start of the planning of the experiment up to the end of operation, the time span for this project will be almost 50 years. With the start of the construction phase of W7-X in 1996 a Quality Management System (QMS) was established which is used for the quality relevant regulation of all processes in the project, from the design to the procurement of all components and the assembly of the device including commissioning. The structure of the QMS is oriented on ISO 9000 ff but was specifically adapted to the environment of a scientific experiment.
With this QMS now ten years of experience have been gathered. This paper will first describe the structure of the QMS and the tasks of the QM-department. Then an analysis of the different steps of the components from design to commissioning under the special considerations of quality aspects are given together with the lessons learned. Of course, due to the variety of the many tasks, of different companies to deal with, working with an international team of colleagues, and the environment of a scientific institute being now committed to this project for more than 25 years, there is no single picture. The attitude to the "task" quality is different amongst the members of the project and the companies. Therefore the paper will focus on certain general aspects which should be considered in future projects e.g. in ITER. The main lesson is: Everybody involved has a strong intention and ambition to produce quality. But to obtain constant quality in such a large project a basic set of rules, a quality administration and a trustful collaboration with the members of the QM department is necessary. The sometimes contradictory objectives of quality, finances and time schedule must be carefully balanced. Quality is the responsibility of the top management and the task of the entire team.

2. Description of the Quality Management System

The original purpose behind the idea of Quality Management is to satisfy customer's expectation and to achieve a uniform level of quality throughout design and construction. Since a scientific project satisfies the demand of the engineers and scientists in charge with the construction, it is self evident that all members of the project want to work on the highest level of quality without the need for special regulations. However since the individual approach to quality is different and the cost and sched-

ule of the project is limited, it is necessary to have a set of regulations which have to be followed. The purpose of the QMS of W7-X is to establish general rules, to allow to trace back materials and processes and to benefit from the experiences of the different groups for the overall quality of the project.
The QMS of W7-X was described on another SOFT conference [2]. In the course of a large reorganisation of the project in 2004 the quality department now concentrates on quality planning and quality assurance only. The former tasks of documentation and technical system coordination have been put into independent departments. This turned out to be a good step forward to emphasise quality issues and separate them from other topics. The quality department of W7-X is part of the sub-division project coordination of W7-X which also deals with time schedule and finances. This ensures that the conflicts between these issues, which are fundamental for scientific projects, are being dealt within the same division. An open discussion of conflicts can always be carried out at the project board, which is the highest decision making body of W7-X. The QMS is based on the EN ISO 9001:1994 standard. The QMS was not certified, because there was no need. However certification would have perhaps strengthened the role of the quality department. The change to the version EN ISO 9001:2000 has so far not been implemented. The emphasis on process orientation of the new version instead on product orientation of the older, which is more appropriate for this project, will be considered during the next revision of the QMS. Since most of the process instructions and work procedures are already written in the spirit of process regulation, the revision will not change the spirit of the present QMS.
All documents of the QMS are made available to all heads of W7-X in a controlled way including revision control. The heads inform their team members about new versions. In addition all QM documents are accessible in the central electronic documentation system. Nevertheless in order to ensure common awareness of the quality standards for the project, personal information on the day to day working level between the colleagues and members of the QM department is necessary and practiced.
The main tasks of the QM department are:

- Implementing and maintaining the QMS: All documents of the QMS are adapted to the needs of the project. The application of standard formulations and guidelines from commercially available QMS turned out not to be helpful since the specialities of a scientific project are not covered by industrial type processes. However they may serve as a starter.
- Carrying out internal and external audits: Auditing is a central task of QM. However the term “Audit” and the formalized regulations for audits have led to the fact that real audits have been very seldom. It is more successful to have so called “Quality Meetings”. For these meetings - either with a company or internally - questions are compiled for special topics while keeping in mind the experience in the past and the future needs.
- Auditing of companies before placing the contract: Due to the work load in the project such audits have been very seldom. If a company is certified, then the “professional auditors” from the certification company have already done their best. If the company is not certified, they do not want to stick to a common standard or want to save money. In any case during the tender action detailed and real product and process orientated questions concerning the contract are recommended.
- Supplying up-to-date standards and technical regulation: For a project like W7-X the normal industrial type standards like DIN, ASME, KTA etc. are a sound but not always sufficient basis for the work. So some colleagues are tempted to define their own “standard requirements”. A part of work of QM department is to extract and combine, in special technical regulations, the most important requirement, which should be applied to the design and manufacture of the components. This concerns vacuum-, radiological-, safety, and control requirements, standards for welding, brazing and soldering, regulations for transportation, storage and handling. Since the technical knowledge is more within the technical departments, in future QM will only initiate that these departments document their guidelines (standards used, allowables, etc.) and will make sure that the technical demands of the different groups have the same quality standard.
- Support of the responsible officers (ROs) for the various contracts: From the very beginning on, at best starting at the design phase, one member of the QM-department (and one deputy) is assigned to each major component. These colleagues have to follow and contribute to all phases of the component (see below) up to the assembly.
- Maintaining proper test equipment and test procedures: The quality assurance for the assembly is organized by the QM-department in cooperation with the assembly division. The test equipment

of the project is controlled within a test resources data base. Every instrument and gauge is listed there with a number, the documentation, the necessity of calibration and so on.
- Controlling the flow of material: Only such materials which have certificates will be used for the assembly of the central machine. Each material gets its own identification number, their certificates are centrally stored and their use must be documented.
- Organizing the training of all internal inspectors: These inspectors are mainly involved in the assembly (see below).

3. QM at the various stages of the project

In principle for each component there is a standard path from the first idea to the final operation in the experiment. This path is as follows:
- from the specification of the global characteristics
- to the general technical design of the component
- to the detailed design of the component resulting in technical drawings (nowadays CAD models) and the detailed technical specification
- to the call for tender action, the choice of the contractor
- to the carrying out of the contract considering changes, unforeseen technical problems and non conformities up to the successful delivery of the component
- to the incoming inspection and detailed component preparation (those things which have not been included in the contract)
- to the assembly, and the commissioning phase.

All these steps have most of all their technical relevance, but also their relevance on quality issues. From experience one has to keep in mind that at earlier stages along this path quality is cheap and at later stages a lack of quality costs a lot of time and money. In the following some examples along this path will be outlined.

3.1. From design to procurement

The basic document at the start of the project was the system specification. This document contained a summary of the characteristic data and properties of all the components known at the start. It was based on the available documents from the approval phase of the project, which included more than 15 years of optimization from the basic ideas to rather detailed concepts. In retrospect the lesson learned from this phase is that such a document should have been the basis for a general design and status review and should have served as the starting point for the configuration management, in order to keep track of all changes. Due to schedule reasons and a lack of resources the document could only be finished when the detailed design of various components was already carried out.

From the system specification the design was derived. The control of the design and of the interfaces between the different components is a rather difficult task which sometimes is in conflict with the ongoing development and the scientific and engineering “phantasy” of the engineers. It is essential to organize a common data base for all CAD data together with a system for a clear assignment of the status of these data like “under work”, “data released”, “released data again under work” In addition the effort to perform critical design reviews and a proper design documentation should not be underestimated. Again due to schedule reasons, those long term items which have been finally designed, have been ordered occasionally without knowing the detailed design of neighbouring components. The lack of this information later caused a number of costly and time consuming changes in running contracts.

The next step for a component is the technical specification. Technical specifications are prepared within the responsible department by the assigned RO. For the technical specifications of small and large contracts different templates have been set up by QM which prescribe a fixed structure and which have standard phrases for certain parts like obligations for carrying out the contract, project and quality management issues, documentation, acceptance tests and delivery. The use of these templates makes it easier to bundle the experiences which have been collected throughout the years from other contracts. Not every specification fits into this scheme, but this can be accommodated by changes and omitting/inclusion of other chapters. A clear technical specification specifying beside the drawings and CAD-models all required properties of the components (e.g. vacuum compatibility, quality of welds and soldered joints, materials to be used etc.) and all the tests, is of utmost importance for

launching a successful contract. All issues which must be clarified later during the manufacturing must be clearly indicated. It is very important that the final technical specification, before issuing the call for tender, is reviewed in a broader meeting so that all involved engineers can comment w.r.t. their interfaces with the component and agree with the specification. This is done during the regular Technical Coordination Meetings, where all heads of W7-X as well as all ROs are present.
The tender action phase depends on the legal regulations which have to be applied. Nevertheless it is quite helpful to have also this phase regulated within the QMS. For the sake of clarity it is advisable to separate the tender documents into what is required (e.g. technical specification, drawings, etc.) and what is only part of the tender process (e.g. administrative and commercial documents).
For large contracts it is advisable that during the tender phase at least one meeting is held with each bidder either at his premises or on site where also quality issues are discussed. After having received the offers it is necessary to set up a ranking. This is best done with a prepared list where each topic (technical information, commercial issues, management, quality) gets a certain weighting and ranking.

3.2. During the contract phase

Almost all contractors have an established quality system laid down in a QM-Handbook; most of them are also certified according to ISO 9001. However, many companies apply their system only to standard and series production, where they are using proven technologies which are based on a long lasting experience. Often the departments which manage innovative or development contracts are not actually followed by the internal quality system of the companies. In order to strengthen the awareness of the contractor's QM-department it is very helpful to have at the "Kick-Off" meeting a topic on QM requirements for the contract and to have regular quality meetings with the project leader and QM responsible at the contractors' site during the course of the contract. The demand from the customer often helps the QM responsible of the contractor to enforce quality issues since he also has to fight within his company between quality, time and money.
The follow-up of the contract is first of all the task of the RO. He is the person who is in contact with the contractor and who has defined the required quality of the component. He must be informed about any contact which takes place on the working or the upper managerial level. In order to have also the aspects of QA and time and financial control considered it is recommended to set up a project team, consisting of the RO, co-workers, and the assigned members from QM and project management. This team should meet every month to discuss the progress report of the contractor and to decide about the actions of the next month.
Since for the manufacture of special components most of the contractors enter "virgin soil" it is very important that the company performs a carefully coordinated preparatory phase before production starts. As far as possible all steps of the manufacture should be investigated and checked in detail by the RO and QM. Prototypes should be produced and tested extensively using non-destructive and destructive methods. It was found out that this even has to be applied for standard techniques like welding and soldering. The unique feature of W7-X with its long lifetime and very difficult possibilities of repair of the central components demands a technical quality which is well above the quality asked for in the standards. Of course this must be negotiated with the contractor and it must be laid down in the technical specification sufficiently in detail so that the associated costs can be considered in the offer. In order to control the quality of the manufacture it is advisable to prepare and examine working samples all along the route of the fabrication.
In spite of the fact that changes of agreed properties should be avoided it is in the nature of a scientific project that new insights demand changes. Such changes may be requested either by the contractor or by the customer. These changes may be the result from experiences during manufacturing or necessary changes in the specification due to new information. For these changes clear regulations were set up in W7-X which cover scientific, technical and commercial aspects. It must be guaranteed that both partners are always working on a clear and commonly agreed basis.
A similar subject is the handling of non conformities (NCs). There are different types of NCs, those which are due to deviations from agreed procedures and those where a specified property was not met. Since in general the manufacturer cannot judge the effect of these NCs on the functionality of W7-X he is asked to report each NC in a separate NC-Report (NCR) and to propose actions (leave as it is, repair, re-built) and propose measures how to prevent this NC for the future. Inside the project the NCRs are distributed to all those ROs who have interfaces with the components for judgement and

release of the proposed actions. It turned out that handling of the NCRs from specific components was a significant workload for the RO and the project. In order to have a timely follow up dedicated colleagues were put in charge to carry out the technical and organisational work.
For standard products, the interaction between the customer and the manufacturer is usually limited to the final acceptance since the process of production is well established. This is different for the manufacture of products for an experiment like W7-X. There exists no series production experience and in many cases, also after qualifying companies by building prototypes, the manufacture of the real part turns out to be different from what has been expected. Therefore in many cases it is necessary to have qualified inspectors on site during the course of the contract. The role of these inspectors must be very well defined. If they are too deeply involved in the fabrication process, they may no longer feel independent for an unbiased and critical quality assurance. On the other hand technical assistance from experienced inspectors is also appreciated by the companies to speed up the process and to save money. Therefore a good collaboration between the RO, QM and the inspectors together with the contractor is necessary to get the technically challenging product with the desired quality.
The documentation during the contract and especially for the final acceptance test and delivery must be clearly defined already in the technical specification. It is advisable to generate a detailed outline and a check-list for all the documents and to spend enough effort in agreeing with the manufacturer especially at the delivery of the first components of the contract.
The final step of the contract is usually the work acceptance test. For this test again it is advisable to have, beside the standard tests protocols for individual tests, a check list, where all items are listed, which have to be controlled during this test. Based on this completed list and the protocols the acceptance protocol can be signed.

3.3. From assembly to commissioning

The assembly of W7-X, which is a complicate technological challenge, needs a very close cooperation between the assembly department and QM. For the interaction a separate process instruction was written. The principle documents for the different steps of assembly are the QAAPs (Quality Assurance and Assembly Plans). The scheme of the QAAPs is based on the good experience which was gained with the QIPPs (Quality Inspection and Production Plans) used by many companies during manufacture. The QAAP is a list of the main assembly and test steps. For each step the numbers of the relevant documents are given (work instruction, test procedure, test protocol, non conformity report etc.). For each step it is defined who is doing it and who must be informed. After the step has been carried out the responsible persons have to sign. Each QAAP must be checked and released by a number of responsible persons; the same is true after finalisation of the QAAP. This instrument turns out to be very useful in keeping track of the assembly and it is flexible enough to leave sufficient freedom for changes, which can be included “on spot” but which will be immediately documented in the master QAAP. For the master QAAP during assembly the paper version is used, since this turns out to be more flexible than storing the information directly in the computer. For documentation purposes the finished QAAP will be scanned and put into the electronic documentation system.
Each assembly step in the QAAP is supported by work instructions. These instructions are prepared by the RO, are checked by all those who are involved (assembly, safety, QM, etc.) and are finally approved by the responsible head. A paper copy of each instruction must be readily available for the hands of the workers. This is the duty of the process planning department.
Tests can only be carried out according to written test specifications which are released by the responsible departments including QM. Each test procedure is accompanied by a standard test protocol containing all the parameters which have to be tested with their required values. By carrying out the tests only the fulfilment of the specified parameters is documented; the final decision to accept/discard a component is up to the RO.
Since the capacity of the central QM department is not sufficient to carry out all QA tasks, a system of internal inspectors has been set up. These inspectors get a two-fold training: The technical training for carrying out the tests and a QM instruction about the duties of the inspector to use proven and documented procedures only, to make sure that all test-equipment has its proper certification, and to evaluate the result of the test in an independent way without considering the consequences. If a test does not conform to the expected performance, a NCR must be issued. This NCR must be judged by the RO and not by the inspector.

The assembly of W7-X including the assembly of the supply- and diagnostics systems will last approx. 6 years. For the commissioning another year is planned for which a similar system of plans, instructions, checklists, confirming signatures and documentation is being set up in due time.

4. Summary

WENDELSTEIN 7-X is a very large and very complex project with challenging technical tasks and a very high quality standard. To fulfil the objectives both technical skills and organizational support are necessary. A QMS adapted to the special circumstances of a one product manufacture is used as a tool for success This QMS provides guidelines for all processes of the project from the design up to the commissioning. Different from a QMS for industrial series production, the QMS for W7-X is tailored to the special needs of the construction of a scientific experiment. A good balance between regulations and freedom has been found in order to ensure the technical quality and the necessary space for scientific improvements. Together with a proper documentation and an appropriate change management the overall construction process of W7-X is very well established.

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