Project Management Lessons Learned from Building the Wendelstein 7-X Stellerator Fusion Research Reactor

M. Freire-Gormaly[1], A. Gittens[1] and L. Zhang[1]
[1] University of Toronto, Ontario, Canada
(m.freire.gormaly@utoronto.ca) (antonio.gittens@mail.utoronto.ca) (lavender.zhang@outlook.com)

Summary

Wendelstein 7-X (W7-X) is the world's largest "stellerator" nuclear fusion reactor being commissioned in Greifswald, Germany. It will inform the international fusion energy test device (ITER). The complexity of W7-X added challenges since industrial expertise to manufacture components did not exist. The construction was completed eight years behind schedule and almost 100% over budget. Key take-away lessons in project management were revealed from W7-X which can be applied to any nuclear project. These lessons are aligned with the project management knowledge areas of schedule, stakeholder, procurement, scope, schedule, cost, communication, risk, quality, human resources and procurement management.

1. Introduction

The Wendelstein 7-X (W7-X) is a "stellarator" nuclear fusion research reactor under commissioning in Greifswald, Germany [1]. The fundamental stellarator design was first proposed by Lyman Spitzer in the 1950s and working devices have been constructed previously [2]. The W7-X, however, is the world's largest stellerator type fusion reactor and has the longest steady-state plasma discharge time. It will help demonstration of continuous operation and resolve plasma physics [2]. These research facilities will contribute to the demonstration of energy-yielding fusion power and the eventual use of fusion energy for commercial power generation in approximately 2050 [2].

Stellarators have not been favoured for fusion energy generators for a number of reasons [3]. First, the complex twisted toroidal shape required to sustain and contain the plasma flow demands elaborate 3D design and modeling. Second, the complexity of the geometry requires manufacturing methods that are only available in modern times. Third, the assembly of the device requires innovative methods. Since the project is currently eight years behind schedule and almost twice the original budget [1], it provides a wealth of project management lessons learned.

2. Schedule Planning Project Management Lesson

May 2014 marked the start of commissioning for the W7-X project. This significant milestone was 8 years later than the schedule envisioned when the project was launched in 1996 [4]. To determine why this occurred, an assessment was performed, and hypotheses on what could have been done to prevent it are presented.

2.1 Schedules without Contingency are Impractical for Unproven Designs

Scheller et al. [5] identified several major design changes that occurred subsequent to the initial baselining of the schedule plan. One example, the structural supports designed for the magnetic coils were, upon further analyses, inadequate to withstand the expected loads during operation and required re-design and excessive reinforcement. The changes required to these structural support engineering drawings alone added one person-year of effort [5]. As a result, the first coil was delivered in 2002—about 4.5 years after contracts were signed [6] and a full year behind schedule. In addition, just the following year, in 2003, further reinforcement of the structural supports was needed after another round of simulations and re-calculations. Not only did this require more changes to the drawings, it also meant that the already completed coils had to be disassembled, modified, re-tested, and re-assembled. Further schedule delays were unavoidable.

Design changes are inevitable when producing innovative products and the lesson is not that changes should be avoided. Rather, while you develop a schedule for such a complex scientific project, however, project managers and engineers must ensure that the contingency reserves reflect the significant schedule risk associated with novel designs. Bosch [7] summarized this lesson quite well, noting that not only were the estimates unrealistically low at the start of the project, but they did not include a reasonable contingency given the nature of the design.

3. Stakeholder Management Project Management Lessons

A project as technically complex as W7-X understandably involves many stakeholders. Management of the consortia of suppliers and addressing the concerns of government funding agencies all while monitoring developments in the nuclear fusion research field can be an overwhelming endeavour.

3.1 Involve New Stakeholders to Provide Additional Resources

Well into the project timeline, the team recognized that additional magnetic coils were needed to control the plasma flow but there was no budget available to design and build the new coils [8]. Coincidentally, the U.S. government was narrowing the types of fusion energy projects it would fund, and their interest in projects such as the W7-X was increasing. Until this time, U.S. researchers had little interest and no power on the project but this confluence of events created an opportunity for the W7-X team to actively shift the Americans' engagement level from neutral to supportive. The team offered researchers at the Princeton Plasma Physical Laboratory and Oak Ridges National Laboratory the opportunity to participate in a novel fusion reactor project that was not available in the U.S. [9] and in exchange, the U.S. researchers designed and built the new coils at a cost of almost $9 million [8].

Project teams should regularly monitor stakeholder developments even if those stakeholders are low priority. Along with this, the team should have a plan, or at least an idea, of how they could promote the project to the stakeholders. Should an opportunity arise to shift a stakeholder to a more positive disposition, the team would be well placed to take advantage.

3.2 Offer Non-Monetary Incentives to Reluctant Suppliers to Share Project Risk

The W7-X team incentivized suppliers in two ways [3]. Firstly, there was a deliberate decision to design the device so as to maximize the use of standard components, thus reducing the risk to suppliers. Secondly, the tendering process was opened to suppliers who were not on the European Union's Approved Supplier's List due to lack of experience but who had the technical competence to complete the work. By the end of the project, the team would have these suppliers added to the Approved Supplier List.

4. Risk Management Project Management Lesson

The W7-X project team seemed to overlook some key risks when the project was launched. It could be argued that had this element of the project plan been more fully developed overall, the team might have been better prepared to deal with the schedule, cost, quality, and stakeholder issues that eventually arose.

4.1 Incomplete Risk Assessments Led to Events that Negatively Impact Cost and Schedule

The most striking risk for the W7-X was the bankruptcy of a key supplier. The specialized nature of the work meant that there were few competing firms in the market, which heightened the potential impact of bankruptcy of a supplier. This occurred in 2002 when Babcock Borsig, the parent company leading the consortium of manufacturers of the magnetic coils, declared bankruptcy [7].

The project manager has little control over the insolvency of a supplier but a complete risk assessment performed during project planning would have not only focused attention on this likelihood but led the team to develop suitable responses. Economic events in Germany in the late 1990s and the fact that Babcock Borsig had barely escaped insolvency in 1996 [4] demonstrated that the company's bankruptcy was highly probable. This would have been known in 1998 when the coil fabrication contracts were awarded [6] and should have been taken into account.

5. Cost Management Project Management Lesson

The W7-X project faced several cost overruns in the initial time-frame of the project resulting in a re-organization of the project team and a re-baselining of the remaining project in 2007 [1]. The initial cost of the project was estimated at €500 million [4]. However, the final cost of the project was over €1 billion to design, build and commission [2, 4]. Funding was 65% from the German federal government, 30% from the European Union and 5% from the Land of Mecklenburg [4]. The regional economy was supported with contracts worth over €80 million [1]. Formal project management tools were used in this large complex project to track progress, control the schedule, manage changes and ensure quality [10]. In particular, the use of a custom developed Earned Value Management (EVM) tool was crucial to the successful commissioning of the fusion reactor [11].

5.1 Use Earned Value Management Tools to Monitor and Control Project Schedule and Costs

As outlined in PMBOK 5th Edition, EVM is a well-established and effective tool for managing, measuring and controlling project progress. The unique challenges for the complex project required a distinct tool adapted for the needs of the precision assembly of the reactor and successful diagnostic engineering. To meet this need, the W-7X team developed a separate EVM tool for the Assembly, Diagnostic Engineering and In-Vessel Components Manufacturing [11, 12].

6. Communication Management Project Management Lesson

The W7-X project had stakeholders in Spain, France, Poland, Germany, USA and Japan [13]**.** This led to virtual teams that needed to be coordinated across time zones and cross-cultural awareness was crucial to ensuring successful project delivery [14]. When the members of the project team located in other geographic locations needed to visit the physical site, costs for flights, lodgings and food were incurred.

6.1 Use Effective Communication Between International Stakeholders and Project Participants

The W7-X team successfully managed over 600 suppliers from across Europe and the immediate project team in the Max Planck Institute of Plasma Physics was over 550 full-time employees. Some of the key international partners in the W7-X included [15, 16]: Los Alamos National Laboratory (USA), Princeton Plasma Physics Laboratory (USA), Oak Ridge National Laboratory (USA), Fantini Sud Spa (Italy), Karlsruhe Institute of Technology (Germany). Virtual monthly meetings were organized between managers from the various departments to review the progress of Diagnostic Engineering work packages [11, 12]. Progress monitoring was an important input to the EVM process discussed previously and these meetings ensured that all managers had a common understanding of what had been completed and what work was remaining.

7. Scope Project Management Lesson

7.1 Small Scope Creep can Lead to Significant Changes for Complex Integrated Projects

The W7-X is a complex structure made of intricately designed components backed up by complicated and advanced physics concepts. Each of these components requires high accuracy machining and welding among many other labour intensive, high precision works with minimal or no distortions [3, 17]. During assembly, it was crucial to precisely position the constituent parts and perfectly wind the coils around the fusion chamber [2]. This “domino effect” is not unique to the W7-X. The broader lesson is that creeping elegance and other forms of minor scope changes should be avoided because the end result is often unknown. Scope changes should go through a complete analysis to not only gauge the impact on cost and schedule, but also the impact on the operation of the final product or service, and potential impacts on stakeholders of the project. The Wendelstein 7-X project took 23 years from phase 1 approval by the European Atomic Energy Community in 1991 to the commissioning in mid-2014 [18]. There were over 600 companies involved in the project and more than 550 people were employed at the Max Planck Institute alone [13].

8. Conclusion

The Wendelstein 7-X is a very complex technical project. It is a manifestation of the most advanced physics and material science to date. Although the project suffered greatly from cost overruns and immense schedule delays (in part due to the technical nature of the project), there are valuable lessons learned with regards to project management from which future projects could benefit. In summary, for complex projects adequate schedule and cost contingencies should be allocated in the project cost and schedule baselines. The use of Earned Value Management tool should be applied from the very beginning of a project to better control cost and schedule. Sound communication management was practiced in the W7-X project, and is recommended for future projects including nuclear refurbishment projects, nuclear new build projects, nuclear waste management projects and aging nuclear structure rehabilitation.

9. References

[1] I. Milch, "Preparations for operation of Wendelstein 7- X starting," 12 May 2014. [Online]. Available: http://www.ipp.mpg.de/3397401/03_14.
[2] A. Hellemans, "Fusion Stellarator Starts Up," 21 May 2014. [Online]. Available: http://spectrum.ieee.org/energy/nuclear/fusion-stellarator-starts-up.
[3] F. Wagner, "The Wendelstein 7-X project and its relation to ITER," Max-Planck-Institut für Plasmaphysik, 2006. [Online]. Available: http://bpe.epfl.ch/files/content/sites/lasen/files/shared/w7X%20report.pdf.
[4] R. Arnoux, "Iter the way to new energy," ITER , 15 April 2011. [Online]. Available: http://www.iter.org/newsline/singleprint/-/680.
[5] H. S. Bosch et. al., "The Production of Non-Planar Coils for the Wendelstein 7-X Experiment: A (Self-) Critical Review," IEEE Transactions on Applied Superconductivity, vol. 18, no. 2, pp. 451-454, 2008.
[6] J.-H. Feist, "Status of Wendelstein 7-X Construction," Fusion Science and Technology, vol. 46, no. 1, pp. 192-199, 2004.
[7] H.-S. Bosch, "Lessons learned in the construction of Wendelstein 7-X," Max-Planck-Institut fur Plasmaphysik, Chicago, 2011.
[8] T. Feder, "US narrows fusion research focus, joins German stellarator," Physics Today, vol. 64, no. 9, pp. 30-31, 2011.
[9] I. Milch, "First coil delivered from USA: USA participates in Wendelstein 7-X, million dollar investment in German fusion project," Max-Planck-Institut fur Plasmaphysik, July 2012. [Online]. Available: http://www.ipp.mpg.de/ippcms/eng/presse/pi/04_12_pi.
[10] T. Brauer, T. Klinger and B. H-S, "Progress, Challenges, and Lessons Learned in the Construction of Wendelstein 7-X," IEEE Transactions on Plasma Science, vol. 40, no. 3, pp. 577-583, 2012.
[11] A. Lorenz, H. Bosch and K. Kuttler, "Implementation of Earned Value Management Tools in the Wendelstein 7-X Project," IEEE Transactions on Plasma Science, vol. 40, no. 12, pp.3560 - 3565, 2012.
[12] A. Lorenz, H.-S. Bosch and K. Kuttler, "Implementation of earned value management tools in the Wendelstein 7-X project," in 2011 IEEE/NPSS 24th Symp. on Fusion Engineering (SOFE), Chicago, 2011.
[13] T. Klinger, "PlasTEP Plasma for Environment Protection," September 2010. [Online]. Available: http://www.plastep.eu/fileadmin/dateien/Events/100819_Presentation_of_the_voideship/Westpommern_2010.pdf.
[14] M. R. Lee, "Communicating across Cultures," IT Today, November 2013. [Online]. Available: http://www.ittoday.info/ITPerformanceImprovement/Articles/2013-11Lee.html.
[15] T. Klinger, "Wendelstein 7-X Construction and Future Research Plans," in 25th Symposium on Fusion Engineering, San Francisco, 2013.
[16] Fantini Sud S.P.A. , "Company Profile," 2012. [Online]. Available: http://www.fantinispa.it/filepdf/companyprofile2012_eng.pdf.
[17] Klinger, "Max-Planck-Institute-For-Plasma-Physics," IPP, 2014. [Online]. Available: http://www.ipp.mpg.de/16900/w7x.
[18] T. Klinger, Max-Planck Institute for Plasma Physics, 2011. [Online]. Available http://www.iter.org/doc/www/content/com/Lists/Stories/Attachments/680/ITER_W7X.pdf.