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How to Develop Production-Level Software for the Fusion Energy Industry in Decentralised Research Environments

As a nuclear technology, fusion energy may be subjected to the stringent regulatory environments such as nuclear (fission) power plants. Software codes and standards need to be developed in acknowledgement of the uncertain regulatory environment, and to meet the Technology Readiness Level (TRL) required to deploy and operate a fusion power plant. Currently, the most mature fusion technologies are only at the small/medium scale demonstration (TRL < 4/5). As technologies develop from research through to deployment, the dependent software must be productionised to produce robust and licensable systems.

Across the diversity of the nuclear sector, there are countless examples of regulations and guidelines that contextualise the current international regulatory environment into which fusion energy is emerging. Examples include EURATOM Nuclear Safety Directive [Directive 2009/71/EURATOM and 2014/87/Euratom], the United States Nuclear Regulatory Commission's publication "Digital Systems Software Requirements Guidelines"[NUREG/CR-6734], and the IAEA publication "Digital Instrumentation and Control Systems for New and Existing Research Reactors"[STI/PUB/1914 ¦ 978-92-0-118320-0]. All three of these documents address the stringent regulations and criteria for operation and standards for software systems that are used to run nuclear facilities.

This work will focus on how fusion energy research can adopt standard approaches from other industries at the individual, group, and institutional levels to support the deployment of fusion energy in line with nuclear industry standards.

The software practices that the fusion industry needs to commercialise its digital products already exist across other industries, such as nuclear energy, finance, and "big tech". These practices include data and software lifecycles, continuous integration and continuous deployment workflows (CI/CD), automated packaging and documentation tools and more. Codes and standards for software can be developed by incorporating these practices.

To institutionalise coding and data best practices, the decentralised nature of the research environment must be acknowledged. Institutional policies to raise standards must support, not hinder, this style of work. Several key ways to support standards and development are:

- Repository templates (including package configurations and automation tools)
- A "Community of Practice"for data, software, and productionisation
- Including code and data practices in graduate training programmes
- Training on the responsible use of AI tools and copilots

This approach facilitates development and raises standards, without restricting the work practices of researchers.

Beyond this, more restrictive policies can be introduced to enforce change. For example, minimum software standards for presenting at conferences or requiring that software is open-sourced during the academic publication process. Such policy changes should only be made alongside the support needed to comply with the new policies.

Regarding the practical implementation of such policies, a long-term view is required. The development project should have a roadmap, with milestones and key performance indicators to measure progress. Raising the TRL of software in fusion is a long-term activity, requiring time and commitment. Through the adoption of practices and standards from other industries, software for fusion systems can be developed to a level that can be deployed in a power plant.

Technical Categories Addressed

Other Systems

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