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REGULATORY FRAMEWORK TOWARDS FUSION ENERGY IN GERMANY

[1]J.U. SCHMOLLACK, [1]K. COHRS, [2]C. HEITSCH , [2]J. HERB, [2]M. JOPEN, [2]M. KOWALIK, [2]I. PETERMANN [3]C. PISTNER, [3]A. KOPP , [3]M. ENGLERT, [4]P. SAUTER, [5]X. Z. JIN, [5]D. RADLOFF.

[1]TÜV Rheinland, Cologne, [2]Gesellschaft für Anlagen- und Reaktorsicherheit, Cologne, [3]Öko-Institut, Institute for Applied Ecology, Darmstadt, [4]Max-Planck-Institute for Comparative Public Law and International Law, Heidelberg, [5]Karlsruhe Institute of Technology, Karlsruhe, Germany

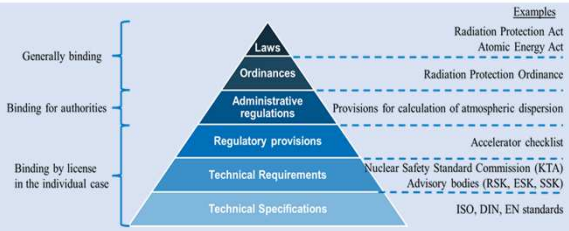
Corresponding author: jens-uwe.schmollack@de.tuv.com

ABSTRACT

- The pilot project was started in Jan. 2025 for 18 months.
- Evaluates the existing regulatory framework under which the stellarator Wendelstein 7-X (W7-X) was licensed.
- German Radiation Protection Law and its subsequent rules and regulations are generally applicable to fusion.
- Certain adaptations and clarifications will be required to speed up licensing process of fusion power plants.

THE GERMAN REGULATORY LANDSCAPE

The regulation of nuclear energy forms the foundation to protect life, health and real assets, ensure safety, environmental protection, and compliance with international and national standards. In Germany, the regulatory framework is governed by two primary instruments: the Atomic Energy Act and the Radiation Protection Act. A system of further regulations, recommendations and rules is arranged hierarchically beneath them. An overview on the principal structure, the binding levels and examples are given in the figure below. This regulatory framework forms the current basis for regulation of fusion facilities. However, it raises the question of whether it is fit for effectively licensing new fusion facilities up to future fusion power plants.

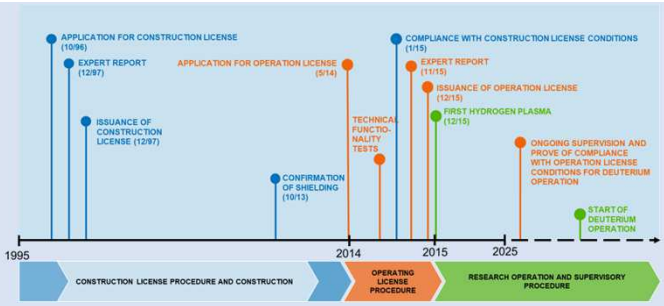


Basic scheme of existing German rules and regulations.

LICENSING OF WENDELSTEIN 7-X

Wendelstein 7-X, the world largest stellarator plasma facility, was built in Greifswald, Germany and has been operating since December 2015. The planned annual neutron production of $3{\cdot}10^{19}$ due to the deuterium-deuterium-fusion reaction results in a licensed maximum release of $2{\cdot}10^{11}$ Bq of Tritium.

A construction license was granted in December 1997. The construction of the first-of-a-kind facility took almost 18 years. Based on a safety assessment review report and an on-site inspection report of the independent reviewer as well as on considerations by the authority, the operation license was granted in 2015. Both licensing phases took roughly one year. The operation license defines a wide frame for W7-X operation and allows an ongoing process of subsequent upgrades.



FUSION TECHNOLOGIES IN FOCUS

Fusion research in Germany has long been focussed on magnetic confinement fusion (MCF). Only in the last few years research into inertial confinement fusion (ICF) has become more present.

Current research facilities include the stellarator W7-X and tokamak ASDEX upgrade, neither of which will use tritium as fuel. Various research groups are also contributing to ITER and EU-DEMO.

Four start-up companies based in Germany are working on a range of fusion technologies: two on MCF using stellarators, two on ICF. These companies are mostly focusing on deuterium-tritium fusion. Several other companies also from fusion supply chain are active in the German discussion on the regulatory framework regarding fusion.

HAZARD POTENTIAL AND RADIOACTIVE WASTE

SAFETY

- IAEA SF-1 safety principles apply to fusion research facilities/future power plants: 'People and the environment, present and future, must be protected against radiation risks'
- Fusion-specific fundamental safety functions (confinement of radioactive materials and radiation protection) need to be defined to ensure the applicable fundamental safety objective (SF-1)
- To apply a graded approach to safety assessments and requirements, we propose a metric to rank the hazard potentials of different facilities (currently under radiation protection/nuclear regulations and fusion facilities):
  The ratio of activities to the corresponding exemption levels.

RADIOACTIVE WASTE

- Significant volumes of radioactive materials will be produced in fusion power facilities due to the diffusion of tritium into structural materials and activation by neutrons
- Any radioactive material that cannot be reused and recycled will need to be disposed of as radioactive waste
- In Germany, all radioactive waste, including low- and intermediate-level waste, is currently planned to be disposed of in geologic facilities. Radwaste from fusion will need to be considered in future planning

NON-PROLIFERATION

Fusion energy poses three concerns regarding non-proliferation:

- Transmutation form U-238 into Pu-239 via fusion neutrons
- Increased availability of tritium, a crucial component for multi-stage thermonuclear weapons
- Military dimension of inertial confinement fusion research for validation of simulation codes for nuclear weapons
- Proliferation potential significantly lower than in fission, yet non-zero potential

Metric of radiological hazards

Type	Nuclide	Mass (kg)	Activity (Bq)	Exemption Level (Bq)	Ratio (-)	Sealed	Order of magnitude of exceedance of limit
Source	Cs-137	-	$4.4{\cdot}10^{16}$	$1{\cdot}10^{4}$	$4.4{\cdot}10^{12}$	yes	3
PWR	Xe-133	-	$7.3{\cdot}10^{18}$	$1{\cdot}10^{4}$	$7.3{\cdot}10^{14}$	no	8
	Cs-137	-	$3.0{\cdot}10^{13}$	$1{\cdot}10^{4}$	$3.0{\cdot}10^{9}$	no	6
	Total	-	$1.9{\cdot}10^{20}$	n.a.	$1.1{\cdot}10^{15}$	no	8
Fusion	H-3	4.0	$1.4{\cdot}10^{18}$	$1{\cdot}10^{9}$	$1.4{\cdot}10^{9}$	no	2
	Po-210	0.001	$1.7{\cdot}10^{14}$	$1{\cdot}10^{4}$	$1.7{\cdot}10^{10}$	no	3
	W-185	1000	$3.5{\cdot}10^{20}$	$1{\cdot}10^{7}$	$3.5{\cdot}10^{13}$	no	7

Selected licensed technical data of Wendelstein 7-X

Parameter	Limit
ECRH power, MW	10
ICRH power, MW	12
NBI power, MW	20
Neutron rate, n/s	$6{\cdot}10^{15}$
Neutron budget, n/a	$3{\cdot}10^{19}$
Tritium annual effluent with air, Bq/a	$2{\cdot}10^{11}$
Nobel gas annual effluent with air, Bq/a	$2{\cdot}10^{10}$
Further RN annual effluent with air, Bq/a	$4{\cdot}10^{07}$

CONCLUSION FOR DEVELOPMENT OF FUSION REGULATORY APPROACH IN GERMANY

- Radiation Protection Law appropriate for existing and future fusion research facilities as well as early demonstrators
- Suggestion to mention "fusion facility" in Radiation Protection Act for clarity
- Development of technical fusion regulatory framework necessary
- Possible long-term perspective: Adoption of a Fusion Energy Act

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