

Federal Republic of Germany

Nuclear Weaponisation Related Technical Capabilities Assessment (WTCA)

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1. Executive Summary

This report assesses the current technical capabilities of the Federal Republic of Germany (hereinafter Germany) across seven representative non-nuclear science and technology topic areas that are considered to be critical to the potential development of a nuclear weapons programme based on a comprehensive collection and review of available open source information by subject matter experts (SMEs).

This assessment is conducted to determine whether Germany can develop, acquire, and utilize these non-nuclear science and technologies to fulfil relevant State functions and achieve strategic objectives related to nuclear weaponisation.

Key findings:

- No evidence of any direct nuclear weaponisation links has been observed in the open source which could indicate a State level nuclear weapons programme in Germany.
- Germany has extensive technical capabilities in seven science and technology topic areas critical to the development of a nuclear weapon programme.
- Germany has a number of universities and technical institutes which have historically investigated and generated publications on nuclear weaponisation related topics.

Nuclear Weaponization and Current Technical Capability: Definition

For the purpose of this WTCA,

Nuclear Weaponisation is defined as a State sponsored, complex aggregation of disparate science and technology (S&T), manufacturing and engineering disciplines and activities, integrating, in particular; high explosives, hydrodynamics, neutronics, exotic materials, numerical modelling, fast diagnostics, military delivery systems and nuclear material* in order to enable the design, and production of nuclear weapons.

**NB: Such a programme can be developed to an advanced level without the introduction of NM.*

The current nuclear weaponisation (NW) related technical capability describes the level of a State's technical maturity in seven representative NW critical science and technology topic areas relevant to a nuclear weapons programme based on the State's past and present activities in research and development (R&D) and manufacturing, and existing relevant infrastructure.

Summary Table 1: Weaponisation-Related Technical Capabilities Category

Topic Areas	Related Topics/Areas	NW Related Activities Past/Ongoing/None Identified	Rationale	Development Level Extensive/Restricted/ Minimal
1. Hydrodynamics (Shock Physics)	Implosion & Shock Physics, Detonation	Past	<ul style="list-style-type: none"> Historical research activity directly related to nuclear weapons. Publications on the fundamentals of shock wave and detonation physics. On-going hydrodynamics driven research. Extra-large, light-gas gun of the Fraunhofer EMI. 	Extensive
	Diagnostics (HVP registration)	Past Ongoing	<ul style="list-style-type: none"> Historical explosion experiments with PIN-DOME measurements. State of the art visualization techniques, developed for high-velocity processes. 	Extensive
	Facilities	Ongoing	<ul style="list-style-type: none"> Broad technical capabilities to conduct small-scale explosion experiments and to develop the process of full-scale blasting. Light-gas guns, shock tubes and shock tunnels with comprehensive diagnostics available. 	Extensive
2. Energetic Materials (Explosives Technology)	HE development, testing and production	Ongoing	<ul style="list-style-type: none"> Continued research, synthesis, development, modelling and testing on a wide range of HEs which could be utilised in nuclear explosives. Extensive experience in HE and ammunition production, as a basis for special HE development, production and testing. 	Extensive
	Detonation systems	Ongoing	<ul style="list-style-type: none"> Institutions, and industrial producers developing detonation systems. Companies developing special fuzing systems. Historical publications on multipoint initiation of high explosives. Articles demonstrating extensive experience in HE detonation technology. 	Extensive
	Special production and storage facilities	Ongoing	<ul style="list-style-type: none"> A considerable number of organisations possess special production and storage facilities. 	Extensive
3. Numerical Modelling	Hydro, neutronic, and coupled computer codes	Past Ongoing	<ul style="list-style-type: none"> Extensive historical publications on nuclear weapons physical package calculations. Wide application of hydrodynamic and radiation-transport codes. Coupling hydrodynamic and radiation transport calculations. Development of advanced techniques and codes modelling explosive detonation and radiative transfer. 	Extensive
	Data libraries (EOS, nuclear data)	Ongoing	<ul style="list-style-type: none"> Wide use of commercial, modified and self-developed nuclear data and nuclear data DBs. Publications on EOS related to shock compression numerical modelling. 	Extensive
	High Performance Computing (HPC)	Ongoing	<ul style="list-style-type: none"> Powerful personal computers sufficient for numerical modeling. A number of supercomputers. The 'most powerful quantum computer ever built. 	Extensive
4. Nuclear & Neutron Physics/Neutronics	Neutron initiators (NG)	Ongoing	<ul style="list-style-type: none"> Practical experience in neutron generator development since 1974. Commercially available NGs with required parameters. Numerous institutions use NGs. 	Extensive
	Experimental criticality studies	Past Ongoing	<ul style="list-style-type: none"> Practical experience in research reactors development since 1960s. Six research reactors under operation. Numerous institutions use NGs 	Extensive
	Radiation-matter interaction studies	Ongoing	<ul style="list-style-type: none"> In-depth research at numerous research institutes and universities. High quality university courses. Numerous institutions use NGs. 	Extensive
5. Materials (Non-fissile)	Be	Ongoing	<ul style="list-style-type: none"> Companies producing Be alloys and additive manufacturing of Be-alloy parts. The 4th largest exporter / importer of Be in the world. 	Extensive
	Li, tritium etc.	Ongoing	<ul style="list-style-type: none"> Strongly developed Li-isotope separation and tritium production for thermonuclear science. European Tritium Laboratory with the licence to handle up to 40 grams of tritium. 	Extensive
6. Fusing & firing technology	MPI systems, Fusing, Firing	Ongoing	<ul style="list-style-type: none"> Development, design and manufacture of arming, fuzing and firing devices for conventional arms. Development of conventional multi-point initiation systems. 	Extensive
7. Delivery System(s), Integration and Testing (Non-nuclear)	Missiles	Ongoing	<ul style="list-style-type: none"> The Taurus KEPD-350 air-launched cruise missile with an official range in excess of 500 km and warhead weight 480 kg. 	Extensive
	Aircraft	Ongoing	<ul style="list-style-type: none"> Panavia PA-200 Tornado IDS. Eurofighter Typhoon EF-2000. F-35 Lightning II in view. 	Extensive
	Submarine	Ongoing	<ul style="list-style-type: none"> To date, six Class 212A diesel-electric attack submarines not considered to be currently nuclear weapon capable. 	Restricted

Table 1 Key and colour coding

Capability Qualifying term	Related Technical Capabilities
Minimal: The State has created and acquired none or little of the essential elements of the process.	Minimal or no industrial capacities or R&D activities or, some with a remote potential of use in a nuclear weapons programme
Restricted: The State has to develop or acquire significant part of the elements necessary the process.	Current or past production entities and research activities that require significant development for potential use in the nuclear weapons development.
Extensive: The State has indigenously developed or acquired almost all or all of the elements necessary for the process.	Current production facilities, past or ongoing relevant R&D that could be used with minor modifications for the development of nuclear weapons.

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2. Overview of Nuclear Weaponisation

2.1. Background

A nuclear weapons programme comprises a complex interplay of wide-ranging research and development, broad and specialised industrial capability and State support. Whereas the need for nuclear related technology is obvious, many of the other essential non-nuclear technologies may not be. For example, shock physics, chemistry, electronics, material science, numerical modelling etc.

All of these activities have legitimate, non-nuclear related applications and so have perfectly legitimate civilian applications in modern science and industry. However, a nuclear weapons programme is likely to contain elements from all these areas and could be developed to an advanced level well in advance of any nuclear material (NM) being introduced.

The existence of any or all of these elements could indicate a weaponisation relevant application, but is not de facto indicative of a nuclear weapons programme. Strong links between disparate elements, could however be a potential indicator and should warrant further investigation.

For the purpose of this assessment, seven representative science and technology topic areas have been chosen by SGIM weaponisation Subject Matter Experts (SMEs) as the critical topics for a potential nuclear weapons programme.

The fissile material requirement for the development of a nuclear explosive device is not explicitly considered here as this report focuses on the non-nuclear, but necessary technologies to support such an endeavour.

2.2. Seven Science and Technology Topic Areas

The following table lists the representative science and technology topic areas selected by the SMEs. Further discussion of these can be found in Annex A.

The table below provides the list of topic areas and their sub-sets

Topic areas	Sub-sets
1. Hydrodynamics (Shock Physics)	<ul style="list-style-type: none"> • Implosion & Shock Physics, Detonation • Diagnostics (HVP registration) • Facilities
2. Energetic Materials (Explosives Technology)	<ul style="list-style-type: none"> • HE development, testing and production • Detonation systems • Special production and storage facilities
3. Numerical Modelling	<ul style="list-style-type: none"> • Hydro, neutronic, and coupled computer codes • Data libraries (EOS, nuclear data) • High Performance Computing (HPC)
4. Nuclear & Neutron Physics / Neutronics	<ul style="list-style-type: none"> • Neutron initiators • Criticality studies • Radiation-matter interaction studies
5. Materials (Non-fissile)	<ul style="list-style-type: none"> • E.g. beryllium, lithium, tritium
6. Fuzing & Firing Technology	<ul style="list-style-type: none"> • Multipoint Initiation (MPI) systems • Arming, Fusing and Firing
7. Delivery System(s), Integration and Testing (Non-nuclear)	<ul style="list-style-type: none"> • Missiles, Aircraft, Submarines

For completeness, some topics which do not readily fit into the areas listed above, are dealt with in section 4 – ‘Other considerations’.

3. Assessment of Seven Critical Science and Technology Topic Areas

3.1. Hydrodynamics

3.1.1. Implosion & Shock Physics, Detonation

Although these areas of research may be pertinent to nuclear weapons, they all have conventional civilian and military applications and no evidence of any nuclear weaponisation links have been observed in the open source. However, the knowledge and expertise gained from this research would be of potential value in a nuclear weaponisation programme.

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Historical research activity directly related to nuclear weapons. • Publications on the fundamentals of shock wave and detonation physics. • On-going hydrodynamics driven research. • Extra-large light-gas gun of the Fraunhofer EMI.

Germany has had interest in hydrodynamics, ICF and high energy physics research involving experimentation and modelling of rapid, high shock, high temperature phenomena for many years. Historical research activity has provided a considerable amount of detailed theoretical, experimental and technological information which could be directly applied to nuclear weapon design. In particular, The Federal Ministry of Defence commissioned theoretical studies relating to fission induced by symmetrical compression in nuclear fission devices in the 1990s.

Hydrodynamics driven research is still very active. Germany has conducted research or taken part in collaborative research on topics involving shock physics including strongly shocked spherical solids for ICF relevant experiments, radiation hydrodynamics and numerical modelling and derivation of Equation of State data. Researchers have also worked with nuclear weapons laboratories on ICF related topics. Most of this research is aimed at ICF or understanding the properties of high energy density states of matter using lasers and particle beams and is of no safeguards or direct weaponisation concern. However, some of the knowledge and experience gained from these studies could be of potential value to a nuclear weaponisation programme.^{1 2 3 4}

¹ Kritcher, A. L. et al., Design of an inertial fusion experiment exceeding the Lawson criterion for ignition. In *Phys. Rev. E* 106 (2). DOI: 10.1103/PhysRevE.106.025201, <https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201>, 2022.

² Zylstra, A. B. et al., Burning plasma achieved in inertial fusion. In *Nature* 601 (7894), 542+. DOI: 10.1038/s41586-021-04281-w, <https://www.nature.com/articles/s41586-021-04281-w>, 2022.

³ Kritcher, A. L. et al., Experimental achievement and signatures of ignition at the National Ignition Facility. In *Phys. Rev. E* 106 (2). DOI: 10.1103/PhysRevE.106.025202, <https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025202>, 2022.

⁴ Nilsen, Jet al., Using neutrons and x rays to measure plasma conditions in a solid sphere of deuterated polyethylene compressed to densities of 35 g/cc at temperatures of 2 keV and pressures of 40 Gbar. In *Phys. Plasmas* 28 (12). DOI: 10.1063/5.0065236, https://www.researchgate.net/publication/356874171_Using_neutrons_and_x_rays_to_measure_plasma_conditions_in_a_solid_sphere_of_deuterated_polyethylene_compressed_to_densities_of_35_gcc_at_temperatures_of_2_keV_and_pressures_of_40_Gbar, 2021.

A number of publications (books) discuss the fundamentals of shock wave physics and detonation physics, with a considerable amount of detailed theoretical, experimental and technological information. Such information could be directly applied for NW – related activity.⁵

Entities:

- Freiburg, Institute of Physics, University of Rostock,
- Helmholtz-Zentrum Dresden-Rossendorf, Dresden.

3.1.2. Diagnostics (HVP registration)

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Historical explosion experiments with PIN–DOME measurements. • State of the art visualization techniques, developed for high-velocity processes.

In 1976, the experts of Battelle Institute (Frankfurt) published a paper on an explosion experiment of a spherical assembly with PIN–DOME measurements.⁶

Germany has utilised FXR and high-speed optical diagnostics such as streak cameras in a variety of fields such as optical spectroscopy and pyrometry of static targets under optical and x-ray laser heating, and radiative characterization of supersonic jets and shocks in laser-plasmas.

Fraunhofer EMI, within its Business Unit Defence, analyses modern concepts of protection and new materials for high-dynamic loading and develops sensor technology for ballistic applications, using measurement technology, some of which is unique in the world. It investigates issues from the fields of impact and shock wave physics, ballistics, laser effects, blast effects and blast physics. It has acceleration facilities for impact experiments, providing impact velocities ranging from 10 meters to 10,000 meters per second, with recording and modeling of the physical processes observed during impact, shock-wave and laser interactions.

EMI develops visualization techniques for high-velocity processes, namely: high-speed photography, high-speed videography, schlieren photography, flash X-ray photography, X-ray tomography and X-ray cinematography. Diagnostics developments include optical and laser-based techniques intended for temperature and velocity of (combustion) gases and high dynamic surfaces (VISAR and PDV). They also develop sensors and electronics engineering for very fast processes or robust environments.⁷

Entities:

⁵ Peter, O.K. Krehl, Shock wave physics and detonation physics – a stimulus for the emergence of numerous new branches in science and engineering, THE EUROPEAN PHYSICAL JOURNAL H, <https://link.springer.com/article/10.1140/epjh/e2011-10037-x>, 2021. (Dr. Krehl is a retired staff scientist from the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut (FhG-EMI) at Freiburg/Breisgau.

⁶ H.V. Freund, W. Geiger, and G. Honcia, Acceleration of Spherical Metal Shells by High Explosives: Detonation Velocity Along the Shell Surface and Efficiency of Energy Transfer, Battelle Institute, Frankfurt, Germany, PROCEEDINGS sixth Symposium (international) on DETONATION, August 24-27, 1976, Coronado, California, p. 521-527, <https://apps.dtic.mil/sti/tr/pdf/ADA059120.pdf>.

⁷ Fraunhofer Institute for High-Speed Dynamics, research into fast-moving processes through experiments and simulations, [Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institute, EMI](https://www.emi.fraunhofer.de/en/business-units/defense/service-offer.html); Business unit Defense, <https://www.emi.fraunhofer.de/en/business-units/defense/service-offer.html>.

- Battelle Institute, Frankfurt ⁸;
- Fraunhofer Institute for High-Speed Dynamics,
- Ernst-Mach-Institute (EMI).

3.1.3. Entities (experimental blast facilities)

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Broad technical capabilities to conduct small-scale explosion experiments and to develop the process of full-scale blasting • Light-gas guns, shock tubes and shock tunnels with comprehensive diagnostics available

The High Explosive institutions in Germany possess certain technical capabilities to conduct small-scale explosion experiments and to develop the process of full-scale blasting which could support a potential NW programme. ^{9 10}

A variety of experimental facilities, providing technical capability to study high-velocity processes with and without HE can be found at the RWTH Aachen University. These include a Hypersonic Shock Tunnel (TH2), Shock Tube (Q54) and Detonation Tube. ¹¹

The HE, armory and munition production facilities listed in Section 3.2.1. could make use of the dedicated test ranges to conduct a broad range of laboratory, small-scale and full-scale experiments. Experimental capabilities for full-scale blasting (tens of kilograms of HE) could be provided by a number of the German army test sites suitable for artillery exercises.

Entities:

- Fraunhofer Institute for High-Speed Dynamics,
- Ernst-Mach-Institute;
- Fraunhofer Institute for Chemical Technology (ICT),
- RWTH Aachen University - Rheinisch-Westfälische Technische Hochschule Aachen

3.2. Energetic materials

Well characterised high explosives (HE) and detonators are a key requirement of modern nuclear implosion weapon design. The types of HE generally used in nuclear weapons have many similarities to explosives used in various conventional armaments. It is therefore extremely difficult to

⁸ The Battelle Institute is a U.S. contract research organization. Founded in 1929 in Columbus, Ohio, it has a number of research facilities in the US and Geneva, <https://www.battelle.org/>. The research facility in Frankfurt am Main was founded in 1952 and closed in 1993, <https://dserver.bundestag.de/btd/13/054/1305496.pdf>, p. 19, 20.

⁹ Fraunhofer Institute for Chemical Technology ICT, Core expertise explosives technology, https://www.ict.fraunhofer.de/en/comp/explosives_technology.html

¹⁰ Fraunhofer Institute for Chemical Technology ICT, Energetic Materials, <https://www.ict.fraunhofer.de/en/comp/em.html>

¹¹ RWTH Aachen University, Chair of High Pressure Gas Dynamics, Experimental Facilities, <https://www.hgd.rwth-aachen.de/cms/HGD/Forschung/~kfm/dw/Experimentelle-Anlagen/lidx/1/>

differentiate whether a particular HE formulation is being developed for nuclear weapon intent, or for conventional purposes. However, a number of HEs which are relatively insensitive, stable and have high detonation velocities, are known to be potential candidates for nuclear weapons use.

3.2.1. HE development, testing and production

Capability	Rationale
Extensive	<ul style="list-style-type: none"> Continued research, synthesis, development, modelling and testing on a wide range of HE which could be utilised in nuclear explosives Extensive experience in HE and ammunition production, as a basis for special HE development, production and testing.

The Fraunhofer Institute for Chemical Technology (ICT) (see ref. 9 on p. 11) is a leading German research institute covering the entire development chain for propellants and explosives, with focused research for the Federal Ministry of Defence. The institute also supports numerous industrial customers. Its core research topics include:

- characterization of the reaction, performance and safety investigations of propellants, explosives and systems.
- experimental interior ballistic characterization of the reaction properties of propellants and explosives,
- characterization of explosives with regard to performance and sensitivity, in the detonation chamber / bunker or on open-air test sites, reaction control and quality management of energetic materials.

The German military and civil industry have considerable experience in HE technology, armory and ammunition production, which could serve as a basis for special HE development, production and testing. Those identified in open sources are: Rheinmetall AG ¹², Diehl Stiftung & Co. KG ¹³, KNDS Group ¹⁴ and Josef Meissner GmbH & Co. KG ¹⁵. The Rheinmetall Denel Munition's product portfolio includes artillery and mortar ammunition, missile subsystems (propulsion units, warheads, etc), ammunition for naval applications, rocket propellants and raw materials. ¹⁶

Entities:

- Fraunhofer Institute for High-Speed Dynamics,
- Ernst-Mach-Institute;
- Fraunhofer Institute for Chemical Technology (ICT),
- Rheinmetall AG,

¹² Rheinmetall AG, <https://www.rheinmetall.com/en/products/propellants/propulsion/nc-rm-pvk>.

¹³ Diehl Stiftung & Co. KG, <https://www.diehl.com/group/de/>.

¹⁴ KNDS Group, <https://www.knds.com/>

¹⁵ Josef Meissner GmbH & Co. KG, <https://www.josefmeissner.com/en/contact>

¹⁶ Rheinmetall Denel Munition, <https://www.rheinmetall.com/de/unternehmen/tochtergesellschaften/rheinmetall-denel-munition>

- Diehl Stiftung & Co. KG,
- KNDS Group,
- Josef Meissner GmbH & Co. KG.

3.2.2. Detonation systems

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Institutions, and industrial producers developing detonation systems. • Companies developing special fuzing systems. • Historical publication on multipoint initiation of high explosives. • Articles demonstrating extensive experience in HE detonation technology.

JUNGHANS Microtec GmbH, as a part of JUNGHANS Defence develops fuzes and fuze systems of all kinds – for mortars, infantry grenades, rockets, missiles and torpedoes, based on reliable mechanics and electronics. JUNGHANS Defence has been supplying large international armed forces and ammunition manufacturers with efficient, reliable fuzes and safety and arming devices for many years. ¹⁷

German research institutions, and industrial producers of HE and ammunition, cover the entire development chain for propellants and explosives, including detonation systems, which could serve as a basis for special application of the technologies available.

In 2011 the co-authors from TDW Gesellschaft für verteidigungstechnische Wirksysteme GmbH (TDW Society for Defense Technology Systems GmbH ¹⁸, subsidiary of MBDA Deutschland ¹⁹) and Numerics GmbH ²⁰, presented a conference report concerning professional study of conventional multi-point initiation systems (MPI) with numerous initiation spots, causing detonation waves²¹.

A 2019 article, reviewing the detonative properties of low bulk density, high bulk density explosive component Nitroguanidine and 82 explosive formulations, compared with 15 reference compositions containing both standard high explosives, ²² represents enormous experience in HE detonation technology.

¹⁷ JUNGHANS Defence, [Home - Junghans defence](#).

¹⁸ TDW (Gesellschaft für verteidigungstechnische Wirksysteme mbH) is a European company that develops and manufactures warheads for guided weapons, <https://www.mbda-deutschland.de/das-unternehmen/tdw-gmbh/>

¹⁹ MBDA Germany, [The Company | Official press website of MBDA-Germany](#).

²⁰ NUMERICS GmbH is a consulting engineering company that offers a variety of engineering services and software products for defense and safety-related tasks, <https://numerics.de/products/>.

²¹ W. Arnold, et al., A Novel Technology for Multi-Point Initiation of High Explosives, [\(PDF\) A Novel Technology for Multi-Point Initiation of High Explosives](#).

²² Ernst-Christian Koch, Insensitive high explosives: IV. Nitroguanidine e Initiation & detonation, Lutradyn - Energetic Materials, Kaiserslautern, <https://www.sciencedirect.com/science/article/pii/S2214914719302168>; Lutradyn provides scientific and technological support in the field of Energetic Materials with an emphasis on insensitive & high explosives.

These articles provide thorough theoretical and experimental expertise, directly applicable for special detonating packages design and development.

Entities:

- Lutradyn - Energetic Materials,
- JUNGHANS Microtec GmbH,
- Fraunhofer Institute for High-Speed Dynamics,
- Ernst-Mach-Institute;
- Fraunhofer Institute for Chemical Technology (ICT),
- Rheinmetall AG,
- Diehl Stiftung & Co. KG,
- KNDS Group,
- Josef Meissner GmbH & Co. KG.
- TDW Gesellschaft für verteidigungstechnische Wirksysteme GmbH

3.2.3. Special production and storage facilities

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • A considerable number of organisations possess special production and storage facilities

It's almost certain that all research and/or industrial facilities dealing with HE, as well as military arsenals, have specialized production and storage facilities that are well equipped with security, fire, and lightning protection systems.

Entities:

- Lutradyn - Energetic Materials,
- JUNGHANS Microtec GmbH,
- Fraunhofer Institute for High-Speed Dynamics,
- Ernst-Mach-Institute;
- Fraunhofer Institute for Chemical Technology (ICT),
- Rheinmetall AG,
- Diehl Stiftung & Co. KG;
- KNDS Group;
- Josef Meissner GmbH & Co. KG.

3.3. Numerical Modelling

3.3.1. Hydro, neutronic, and coupled computer codes

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Extensive historical publications on nuclear weapons physical package calculations. • Wide application of hydrodynamic and radiation-transport codes. • Coupling hydrodynamic and radiation transport calculations. • Development of advanced techniques and codes modelling explosive detonation and radiative transfer.

A theoretical model was developed by the Battelle Institute to explain the results of their explosion experiments with spherical geometry and PIN-DOME measurements. The results were subsequently validated by LLNL with 2-D Lagrange calculations, Frankfurt, 1988. ²³

In 1991, the Fraunhofer Institute for Technological Trend Analysis (INT) published Report No. 139 on the computer simulation of a nuclear explosive device. In particular, the report included calculations of gas dynamics, criticality, nuclear yield, and neutron initiation issues using the hydrodynamic STEALTH and Monte-Carlo ANISN computer codes. The report was commissioned by the Federal Ministry of Defense (Department Ru T I 3). The study concerns the fundamental physics of nuclear weapons.

In 2011, a group of retired authors associated with state research institutes and universities published detailed studies on the criticality and dynamic evolution of critical assemblies and nuclear explosive design yields involving reactor-grade and weapons-grade nuclear materials. These studies employed a variety of codes for neutron transport calculations, including Monte Carlo Codes MCNP 4C3 and TWODANT, and the ONEDANT code solving steady-state form of the Boltzmann transport equation. The publication provides a comprehensive scientific foundation for estimating nuclear explosive design yields, including a detailed exposition of the coupling of hydrodynamic and neutron transport computer codes and the numerical solution of the coupled system of equations. ²⁴

For different technical purposes, German institutes are using commercial and self-developed hydrodynamic, radiation-transport and coupled codes, such as SPEED (Shock Physics Explicit Eulerian/Lagrangian Dynamics) designed by NUMERICS ²⁵, coupled 3D neutron kinetic model DYN3D and computational fluid dynamics software ANSYS-CFX, both provided by the Helmholtz-Zentrum ²⁶, as well as numerous Monte-Carlo codes such as TRAMO ²⁷ and the commercially available MCNP, CTF, NEM and NJOY ²⁸.

²³ H.V. Freund, et al., Acceleration of Spherical Metal Shells by High Explosives: Detonation Velocity Along the Shell Surface and Efficiency of Energy Transfer, PROCEEDINGS, sixth Symposium (international) on DETONATION, August 24-27, 1976, Coronado, California, p. 521-527, <https://apps.dtic.mil/sti/tr/pdf/ADA059120.pdf>.

²⁴ G. Kessler, Proliferation-Proof Uranium/Plutonium Fuel Cycles: Safeguards and Non-Proliferation. Karlsruhe: KIT Scientific Publishing. DOI: <https://doi.org/10.5445/KSP/1000021572>, 2011, <https://www.ksp.kit.edu/site/books/m/10.5445/KSP/1000021572/>.

²⁵ NUMERICS GmbH, <https://numerics.de/products/speed/>.

²⁶ A. Grahn et al., Coupling of the 3D neutron kinetic core model DYN3D with the CFD software ANSYS-CFX, Helmholtz-Zentrum Dresden-Rossendorf, Institute of Resource Ecology, Department of Reactor Safety, Dresden, Germany, <https://www.sciencedirect.com/science/article/pii/S030645491400663X#b0065>, 2015.

²⁷ TRAMO is a Monte Carlo code developed at Helmholtz-Zentrum Dresden-Rossendorf for the calculation of gamma and neutron transportation, https://www.epj-conferences.org/articles/epjconf/pdf/2024/18/epjconf_isr-d-17_02005.pdf.

²⁸ Federico Puente Espel et al., New developments of the MCNP/CTF/NEM/NJOY code system – Monte Carlo based coupled code for high accuracy modelling, <https://www.sciencedirect.com/science/article/pii/S0306454912003052>, 2013.

The codes are mostly applied for conventional purposes such as HE simulation and nuclear reactor safety analysis, and are of no direct weaponisation concern. However, some of the knowledge and experience gained from this work could be of value to a nuclear weaponisation programme.

Entities:

- Battelle Institute, Frankfurt;
- Karlsruhe Institute of Technology,
- Fraunhofer Institute for Technological Trend Analysis,
- A number of institutes across Helmholtz-Zentrum,
- NUMERICS,
- Fraunhofer Institute for Chemical Technology (ICT),
- Fraunhofer Institute for High-Speed Dynamics,
- Ernst-Mach-Institute.

3.3.2. Data libraries (EOS (Equation of State), nuclear data)

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Wide use of commercial, modified and self-developed nuclear data and nuclear data DBs • Publications on EOS related to shock compression numerical modelling.

Germany is a member country of the Nuclear Energy Agency (NEA), and thus nuclear data libraries (BROND-3.1, CENDL-3.1, ENDF/B-VII.1, JEFF-3.2, JENDL-4.0, RUSFOND-2010, Standards 2006, TENDL, ENDF/B-IV,V,VI,VII.0 and others) are available to Germany via the NEA Nuclear Data Services and the Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library;²⁹ these are widely applied in calculations by the following leading institutions in Germany:

- Research Center Karlsruhe Institute of Neutron Physics and Reactor Engineering,
- Center for Radiation Protection and Radiation Oncology, University of Hannover,
- Department of Nuclear Chemistry, University of Cologne.

Several German research institutions are active in experimental measurements of neutron cross-section data and fundamental nuclear properties using radioactive ion beams:

- Helmholtz-Zentrum Dresden-Rossendorf;
- Forschungszentrum Jülich;
- Goethe University Frankfurt;
- Technical University Darmstadt,
- Technical University Dresden,

²⁹ Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library, https://www.oecd-nea.org/jcms/pl_27365/the-jeff-nuclear-data-library.

Evaluated Nuclear Data Library Descriptions, https://www.oecd-nea.org/jcms/pl_20505/evaluated-nuclear-data-library-descriptions.

- Johannes Gutenberg University, Mainz. ³⁰

There is a wide range of publications on EOS related to numerical modelling of shock compression. ^{31 32}

In a 2011 publication, a former Karlsruhe employee presented an equation of state for the compression of Pu and U metal, developed with data available in open sources (see Ref. 24 on p. 15), which could be directly applied to the development of nuclear weapons.

Entities:

- Research Center Karlsruhe Institute of Neutron Physics and Reactor Engineering,
- Center for Radiation Protection and Radiation Oncology, University of Hannover,
- Department of Nuclear Chemistry, University of Cologne.
- Helmholtz-Zentrum Dresden-Rossendorf;
- Forschungszentrum Jülich;
- Goethe University Frankfurt;
- Technical University Darmstadt,
- Technical University Dresden,
- Johannes Gutenberg University, Mainz. ³³

3.3.3. High Performance Computing (HPC)

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Powerful personal computers sufficient for numerical modeling • A number of supercomputers • The ‘most powerful quantum computer ever built’

Modern powerful personal computers, especially in PC clusters, are quite sufficient for numerical modeling with either commercial or in-house computer codes. In fact, very powerful computers are not necessary for robust hydrodynamic and neutronic calculations.

³⁰ PROGRESS REPORT ON NUCLEAR DATA RESEARCH IN THE FEDERAL REPUBLIC OF GERMANY for the Period 2018 – 2020, https://www-nds.iaea.org/indc/docs/working_papers/WP2021-06.pdf, 2021.

³¹ Wilfried B. Holzapfela, Equations of state for Cu, Ag, and Au and problems with shock wave reduced isotherms, Universität Paderborn, Paderborn, https://physik.uni-paderborn.de/fileadmin-nw/physik/Alumni/Holzapfel_LOP/ldv-249.pdf, 2010.

³² J.Lutgert et. al., Measuring the structure and equation of state of polyethylene terephthalate at megabar pressures, Helmholtz-Zentrum Dresden-Rossendorf, Institute for Solid State and Materials Physics, Technische Universität Dresden, (contains review of various EOS forms,) <https://www.nature.com/articles/s41598-021-91769-0#Sec3>, 2021.

³³ PROGRESS REPORT ON NUCLEAR DATA RESEARCH IN THE FEDERAL REPUBLIC OF GERMANY for the Period 2018 – 2020, https://www-nds.iaea.org/indc/docs/working_papers/WP2021-06.pdf, 2021.

For more demanding calculations, Germany has a number of supercomputers.

The Jülich Supercomputing Center operates two supercomputers, JUWELS and JURECA, while the new JUPITER is currently under construction. JUPITER will be Europe's first exa-scale computer, performing more than a quintillion (“1” followed by 18 zeros) arithmetic operations per second.³⁴ Other supercomputers of note are:

- High Performance Computing Center Stuttgart, at the University of Stuttgart, houses several supercomputers, including the "Hawk" system.³⁵
- The Leibniz Supercomputer Center in Garching operates the “SuperMUC” supercomputer.³⁶
- Center for Information Services and High Performance Computing, at the Technical University of Dresden, provides access to supercomputers like the "Cray XC40".³⁷

It should be noted that the ‘most powerful quantum computer ever built’ was launched in Eningen, Germany in 2021.³⁸

Entities:

- Jülich Supercomputing Center,
- High Performance Computing Center Stuttgart,
- Leibniz Supercomputer Center,
- Center for Information Services and High Performance Computing.

3.4. Nuclear & Neutron physics / Neutronics

3.4.1. Neutron initiators

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Practical experience in nuclear generators development since 1974. • Commercially available NGs with required parameters. • Numerous institutions use NGs.

³⁴ Jülich Supercomputing Center, <https://www.fz-juelich.de/en/research/research-fields/information/supercomputing#:~:text=INFRASTRUCTURE-Supercomputers,groups%20throughout%20Germany%20and%20Europe.>

³⁵ High Performance Computing Center Stuttgart, [HLRS High Performance Computing Center Stuttgart: Home.](https://www.hlr-stuttgart.de/)

³⁶ Leibniz Supercomputer Center, [LRZ: Leibniz-Rechenzentrum der Bayerischen Akademie der Wissenschaften.](https://www.lrz.de/)

³⁷ [Center for Information Services and High Performance Computing — Center for Information Services and High Performance Computing \(ZIH\) — TU Dresden](https://www.zih.tu-dresden.de/)

³⁸ Europe’s newest and most powerful quantum computer ever has just been unveiled in Germany (Euronews), <https://www.euronews.com/next/2021/06/16/europe-s-newest-and-most-powerful-quantum-computer-ever-has-just-been-unveiled-in-germany>, 2021.

Traditionally, compact neutron generators (NGs) have been used in the DT fusion reaction to produce high energy 14 MeV neutrons. Now compact NGs are widely used in a variety of research and industrial fields.

Currently the NGs generating DT neutron yield in the range of 10^8 to 10^{11} n/s are commercially available. The main manufacturers compact NGs are Thermo Electron, Sodern EADS and Schlumberger. There are yet others, which are made by universities or national laboratories, like VNIIA (Moscow, Russia) and Lawrence Berkeley National Laboratory.³⁹

Germany has used neutron generators with outputs exceeding the INFCIRC/254 dual-use limit of 3×10^9 n/s, which could potentially be used for neutron initiation in a nuclear weapon. As early as 1974, the Institute for Applied Nuclear Physics at the Gesellschaft für Kernforschung (GFK), Karlsruhe, invented a sealed high power neutron tube known as KARIN (Karlsruhe Intense Neutron Generator). It produces 6.5×10^{12} neutrons per second.⁴⁰

Some German facilities that are known to either use compact neutron generators and/or have capabilities related to neutron generation include:

- Fraunhofer Institute for Ceramic Technologies and Systems⁴¹,
- Bundesanstalt für Materialforschung und -prüfung⁴²,
- Hahn-Meitner Institute (now part of Helmholtz-Zentrum Berlin)⁴³,
- Helmholtz-Zentrum Dresden-Rossendorf⁴⁴,
- Neutron Radiography Laboratory, University of Applied Sciences, Lübeck⁴⁵,
- Institut für Neutronenphysik und Reaktortechnik – Karlsruhe Institute of Technology⁴⁶,
- Jülich Research Centre (Forschungszentrum Jülich)⁴⁷.

These facilities either use compact neutron generators directly and/or are involved in neutron-based research and applications where such devices are employed in specific testing, imaging or scientific investigations.

Entities:

- Fraunhofer Institute for Ceramic Technologies and Systems,
- Bundesanstalt für Materialforschung und -prüfung,
- Helmholtz-Zentrum Berlin,
- Helmholtz-Zentrum Dresden-Rossendorf,

³⁹ IAEA Radiation Technology Reports Series No. 1, NEUTRON GENERATORS FOR ANALYTICAL PURPOSES https://www-pub.iaea.org/MTCD/Publications/PDF/P1535_web.pdf, 2012.

⁴⁰ HAEFELY/KARLSRUHE Fast neutron generator, <https://cds.cern.ch/record/1730181/files/vol17-issue3-p064-e.pdf>, [HAEFELY/KARLSRUHE: Fast neutron generator - CERN Document Server](https://cds.cern.ch/record/1730181/files/vol17-issue3-p064-e.pdf); Karl Albrecht Schmidt, The haefely-gfk fast-neutron generator, <https://www.sciencedirect.com/science/article/abs/pii/0360301677902802?via%3Dihub>, Institut für Angewandte Kernphysik, Gesellschaft für Kernforschung, Karlsruhe, 1977.

⁴¹ Fraunhofer Institute for Ceramic Technologies and Systems, <https://www.ikts.fraunhofer.de/>.

⁴² Bundesanstalt für Materialforschung und – prüfung, <https://www.bam.de/Navigation/EN/About-us/about-us.html>.

⁴³ Helmholtz-Zentrum Berlin, [Helmholtz-Zentrum Berlin \(HZB\) - Mainpage](https://www.hzberlin.de/).

⁴⁴ Helmholtz-Zentrum Dresden-Rossendorf, [HZDR – Helmholtz-Zentrum Dresden-Rossendorf](https://www.hzdr.de/). [HZDR – Helmholtz-Zentrum Dresden-Rossendorf](https://www.hzdr.de/).

⁴⁵ Neutron Radiography Laboratory, University of Applied Sciences, Lübeck, [Technische Hochschule Lübeck](https://www.tu-luebeck.de/).

⁴⁶ Institut für Neutronenphysik und Reaktortechnik – Karlsruhe Institute of Technology, [KIT - Karlsruhe Institute of Technology](https://www.kit.edu/).

⁴⁷ Jülich Research Centre, [Forschungszentrum Jülich](https://www.fzjuelich.de/).

- University of Applied Sciences, Lübeck,
- Institut für Neutronenphysik und Reaktortechnik - Karlsruhe Institute of Technology,
- Jülich Research Centre.

3.4.2. Experimental criticality studies

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Practical experience in research reactors development since 1960s. • Six research reactors under operation. • Numerous institutions use NGs

Experimental criticality studies are being conducted with special research facilities such as research reactors, subcritical/critical assemblies, zero-power reactors and “neutron sources”.

The first German, SIEMENS type SUR-100 zero-power reactor was developed in West Germany in the 1960s, both for educational purposes and as a demonstration object for an engineering discipline.⁴⁸

Germany currently has six operating research reactors:⁴⁹

- the FRM II research neutron source at the Technical University of Munich⁵⁰,
- the TRIGA Mark II research reactor at the University of Mainz⁵¹
- the four teaching reactors:
 - SUR Stuttgart⁵²,
 - SUR Ulm⁵³,
 - SUR Furtwangen University, Institute for Radiation Measurement Technology⁵⁴ and
 - AKR-2 in Dresden⁵⁵.

⁴⁸ The West German educational reactor SUR-100 and its diplomatically intended export to Latin America, *Revue d'Histoire de l'Énergie* 2022/1 N° 7, [The West German educational reactor SUR-100 and its diplomatically intended export to Latin America | Cairn.info](#).

⁴⁹ The Gesellschaft für Anlagen - und Reaktorsicherheit (GRS), Research reactors in Germany: These reactors may continue to be operated in Germany beyond 2023, [Research reactors in Germany: These reactors may continue to be operated in Germany beyond 2023 | GRS GmbH](#), 2023.

⁵⁰ FRM II research neutron source at the Technical University of Munich, <https://www.frm2.tum.de/en/frm2/the-neutron-source/>.

⁵¹ The Mainz research reactor TRIGA Mark II with pulse device, <https://www.en.triga.uni-mainz.de/reactor-2/>.

⁵² APMB: Siemens Unterrichtsreaktor SUR 100, [APMB: Siemens Unterrichtsreaktor SUR 100 | Institut für Kernenergetik und Energiesysteme | Universität Stuttgart](#).

⁵³ Siemens Unterrichtsreaktor SUR 100, Institut für Strahlenmesstechnik. [ISM](#).

⁵⁴ Siemens-Unterrichts-Reaktor SUR-100 Furtwangen, [SUR-100 Furtwangen](#).

⁵⁵ TRAINING AND RESEARCH AT THE TRAINING REACTOR AKR-2, [Training Reactor AKR-2 — Chair of Hydrogen and Nuclear Energy — TU Dresden](#).

In 1989⁵⁶ and 1991⁵⁷ publications, the German experts used critical measurements for the study of criticality and dynamic evolution of critical assemblies with estimations of the probabilistic yield distribution due to preignition in reactor grade plutonium fission bombs.

Entities:

- Institute for Neutron Physics and Reactor Technology, Institute of Nuclear and Particle Physics of the Dresden University of Technology;
- The Nuclear Physics Institute, Max-Planck-Institute for Plasma physics, Technical University of Munich;
- Helmholtz-Zentrum Dresden Rossendorf, Center for Radiation Protection and Radioecology, The Helmholtz Zentrum Berlin.

3.4.3. Radiation-matter interaction studies

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • In-depth research at numerous research institutes and universities. • High quality university courses. • Numerous institutions use NGs

Radiation-matter interaction related to shock-wave phenomena studies, is a topic of thorough research in numerous research institutes and universities, such as:

- Universität Siegen
- Dresden–Rossendorf Technische Universität,
- Institute of Radiation Physics,
- Helmholtz-Zentrum Dresden-Rossendorf⁵⁸;
- Max-Planck-Institut für Astrophysik in München,
- Heidelberg Institute for Theoretical Studies,
- Zentrum für Astronomie der Universität Heidelberg⁵⁹.

⁵⁶ H.V. Freund et al., Acceleration of Spherical Metal Shells by High Explosives: Detonation Velocity Along the Shell Surface and Efficiency of Energy Transfer, Battelle Institute, Frankfurt, Germany, PROCEEDINGS sixth Symposium (international) on DETONATION, August 24-27, 1976, Coronado, California, p. 521-527, <https://apps.dtic.mil/sti/tr/pdf/ADA059120.pdf>.

⁵⁷ P. Hafner et al., Compression and reactivity build-up in a spherically symmetrical nuclear fission device, Fraunhofer Institute for Technological Trend Analysis, Report No. 139, Translated from German, 1991.

⁵⁸ C. Grunp, Radiation-matter interaction studies. In the book „Introduction to Radiation Protection, Practical Knowledge for Handling Radioactive Sources“, FB Physik, Universität Siegen, DOI 10.1007/978-3-642-02586-0_4, <https://link.springer.com/book/10.1007/978-3-642-02586-0>, 2010.

Long Yang et al., Dynamic convergent shock compression initiated by return current in high-intensity laser–solid interactions, Helmholtz-Zentrum University of Applied Sciences, Lübeck and Technische Universität Dresden, [047204 1 5.0181321.pdf](https://arxiv.org/abs/2404.04720), 2024.

Institute of Radiation Physics, The Helmholtz-Zentrum Dresden-Rossendorf (HZDR), <https://www.hzdr.de/db/Cms?pOid=10245&pNid=132>

⁵⁹ Jesu´s Zavala et al., Cosmic X-ray and gamma-ray background from dark matter annihilation, PHYSICAL REVIEW D 83, 123513, <https://journals.aps.org/prd/pdf/10.1103/PhysRevD.83.123513>, 2011.

A 2025 publication reveals related investigations at the University of Hamburg. ⁶⁰

It is worth noting the existence of a number of high quality educational training courses in this field, such as those offered by the Johannes Gutenberg University in Mainz. ⁶¹

Participation in large-scale international scientific projects such as CERN and ITER provides Germany with broad opportunities to develop related fields of knowledge. ^{62 63}

Entities:

- Universität Siegen and Dresden–Rossendorf Technische Universität;
- Institute for Radiation Physics, The Helmholtz-Zentrum Dresden-Rossendorf,
- Max-Planck-Institut für Astrophysik in München,
- Heidelberg Institute for Theoretical Studies,
- Johannes Gutenberg University in Mainz
- Institute of Radiation Physics,
- Helmholtz-Zentrum Dresden-Rossendorf ⁶⁴;
- Max-Planck-Institut für Astrophysik in München,
- Heidelberg Institute for Theoretical Studies,
- Zentrum für Astronomie der Universität Heidelberg ⁶⁵.

3.5. Materials (non-fissile)

3.5.1. Beryllium

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Companies producing Be alloys and additive manufacturing of Be-alloy parts. • The 4th largest exporter / importer of Be in the world.

⁶⁰ Christina Krätzig, A new frontier in understanding electron dynamics: imaging with attosecond short X-ray flashes, https://www.research-in-germany.org/idw-news/en_US/2025/1/2025-01-21_A_new_frontier_in_understanding_electron_dynamics_imaging_with_attosecond_short_X-ray_flashes.html, Federal Ministry of Education and Research, 2025.

⁶¹ Luca Doria, Interaction of Radiation with Matter, <https://www.staff.uni-mainz.de/doria/Detectors/RadMatter.pdf>.

⁶² CERN, International relations, <https://international-relations.web.cern.ch/stakeholder-relations/states/germany>, 2023.

⁶³ Fusion Forum Germany at ITER, <https://www.iter.org/node/20687/fusion-forum-germany-iter>, 2023.

⁶⁴ C. Grunpelt, Radiation-matter interaction studies. In the book „Introduction to Radiation Protection, Practical Knowledge for Handling Radioactive Sources“, FB Physik, Universität Siegen, DOI 10.1007/978-3-642-02586-0_4, <https://link.springer.com/book/10.1007/978-3-642-02586-0>, 2010.

Long Yang et al., Dynamic convergent shock compression initiated by return current in high-intensity laser–solid interactions, Helmholtz-Zentrum Dresden–Rossendorf and Technische Universität Dresden, [047204 1 5.0181321.pdf](https://arxiv.org/abs/2404.15018), 2024.

Institute of Radiation Physics, The Helmholtz-Zentrum Dresden-Rossendorf (HZDR), <https://www.hzdr.de/db/Cms?pOid=10245&pNid=132>

⁶⁵ Jesús Zavala et al., Cosmic X-ray and gamma-ray background from dark matter annihilation, PHYSICAL REVIEW D 83, 123513, <https://journals.aps.org/prd/pdf/10.1103/PhysRevD.83.123513>, 2011.

Germany has long-term experience in handling beryllium metal and alloys. There are a number of companies offering various Be alloys and related manufacturing services in Germany.

In 2021, Germany exported US\$624k and imported US\$4.09M worth of beryllium, making it the 4th largest exporter and importer of beryllium in the world. ⁶⁶

Entities:

- Wieland Metal Services Germany GmbH ⁶⁷,
- Tropag Oscar H. Ritter Nachf. GmbH ⁶⁸,
- Beryllium oxide – TECHNOLOGICA Society for High Tech Materials and Processes GmbH ⁶⁹
- Auremo GmbH ⁷⁰,
- Voestalpine High Performance Metals GmbH offers additive manufacturing of the Be-alloy parts ⁷¹.

3.5.2. Lithium, tritium

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Strongly developed Li-isotope separation and tritium production for thermonuclear science. • European Tritium Laboratory with the licence to handle up to 40 grams of tritium.

Germany has a significant interest in fusion related scientific programmes and in order to supply the existing facilities (DEMO) and future fusion power plants (ITER), the German institutions develop lithium isotopes separation processes such as ICOMAX (Improved COLUMN-based Mercury Amalgam eXchange) and counter-current flow method.

The Institute for Astroparticle Physics operates the European Tritium Laboratory Karlsruhe which is a semi-technical scale facility for processing tritium, with the licence to handle up to 40 grams of tritium. ⁷²

⁶⁶ Observatory of Economic Complexity (OEC), <https://oec.world/en/profile/bilateral-product/beryllium-articles-thereof-nes/reporter/deu>.

⁶⁷ Wieland Metal Services Germany GmbH | Kornwestheim, [Wieland Metal Services Germany GmbH | Kornwestheim](https://wieland-metal.com/en/kornwestheim).

⁶⁸ Tropag Oscar H. Ritter Nachf. GmbH, <https://tropag.com/en/products/products-by-elements/>.

⁶⁹ TECHNOLOGICA, Gesellschaft für High Tech Materialien und Verfahren mbH, <https://technologica.de/zeichnungsteile-aus-berylliumoxid/?lang=en>.

⁷⁰ AUREMO, Metals Rare, Beryllium Nugget Be 99.9%, Saarbrücken, https://auremo.net/metals-rare/2245-beryllium-nugget-be-999-pure-metal-element-4.html?srsId=AfmBOoq2MnQJukcHrH4TSg LHudKoiklGhw_so4VcarrlyTFQgav4IEPB.

⁷¹ Voestalpine High Performance Metals GmbH, www.voestalpine.com/additive.

⁷² T. Giegerich et al., Development of a viable route for lithium-6 supply of DEMO and future fusion power plants, Karlsruhe Institute of Technology, <https://www.sciencedirect.com/science/article/pii/S092037961930835X#sec0110>, 2019.

Entities:

- Karlsruhe Institute of Technology,
- Institut für Physikalische Chemie und Elektrochemie der Universität Karlsruhe,
- The Karlsruhe Tritium Laboratory (TLK) of the Institute for Astroparticle Physics (IAP)

3.6. Fusing and firing technology, MPI systems

JUNGHANS Microtec GmbH – develops, designs and manufactures arming, fuzing and firing devices for conventional arms: artillery, mortar infantry grenades, rockets, missiles and torpedoes, utilising innovative technologies based on highly reliable mechanics and electronics, and provides "smart warhead" design (multipoint initiation, precise ignition timing) and multi-point initiation for selectable and tailorable effects. It produces smaller size firesets, precise control of timing. ⁷³

TDW Gesellschaft für verteidigungstechnische Wirksysteme mbH (TDW Society for Defense Technology Systems, and Numerics GmbH, conduct experiments and numerical simulation of multipoint initiation of conventional munitions. ⁷⁴

3.7. Delivery Systems and Integration

3.7.1. Missiles

Capability	Rationale
Extensive, regarding cruise missiles	<ul style="list-style-type: none"> • The Taurus KEPD-350 with an official range in excess of 500 km and warhead weight 480 kg.

U. SCHINDEWOLF et al., SEPARATION OF LITHIUM ISOTOPES BY COUNTER-CURRENT FLOW OF THE COEXISTING PHASES OF A LITHIUM-AMMONIA SOLUTION, <https://jp4.journaldephysique.org/en/articles/jp4/abs/1991/05/jp4199101C509/jp4199101C509.html>, 1991.

Sigurd Gross, Tritium Activities in Germany, Fusion Science and Technology, Volume 41, 2002 - Issue 3P2: Proceedings of the Sixth International Conference on Tritium Science and Technology Tsukuba, Japan November 12-16, 2001, <https://www.tandfonline.com/doi/abs/10.13182/FST02-A22605>.

The Karlsruhe Tritium Laboratory (TLK) of the Institute for Astroparticle Physics (IAP) is licenced for 40 g T2. A semi-technical scale facility for processing tritium. More than 20 glove box systems, total volume of about 190 m³, are operated in an area of 1600 m² for experiments and infrastructure facilities. More than 25 years of safe operation and experience with tritium, <https://www.iap.kit.edu/tlk/english/>.

M. Kovari et al., Tritium resources available for fusion reactors, <https://scientific-publications.ukaea.uk/wp-content/uploads/Dual-14pub.pdf>, 2017.

⁷³ JUNGHANS Microtec GmbH, https://ndia.dtic.mil/wp-content/uploads/2016/fuze/18481_Perrin.pdf, <https://junghans-defence.com/?lang=en>.

⁷⁴ W. Arnold, et al., A Novel Technology for Multi-Point Initiation of High Explosives, https://www.researchgate.net/publication/339292118_A_Novel_Technology_for_Multi-Point_Initiation_of_High_Explosives, 2011.

The Taurus KEPD-350 is a German-Swedish air-launched cruise missile, manufactured by Taurus Systems and used by Germany, Spain, and South Korea. ⁷⁵ It has an official range in excess of 500 km and a warhead weight of 480 kg, which makes it nuclear capable in terms of carry weight.

Germany currently possesses neither ballistic missiles nor a programme to support the development of such a weapon system. However, there are multiple rocket-launcher systems under development, which could serve as a starting point for such procurements. For instance, Rheinmetall and Lockheed Martin are jointly developing the Global Mobile Artillery Rocket System, a German adaptation of the US HIMARS system. ⁷⁶

3.7.2. Aircraft

Capability	Rationale
Extensive	<ul style="list-style-type: none"> • Panavia PA-200 Tornado IDS. • Eurofighter Typhoon EF-2000. • F-35 Lightning II in view.

The following aircraft are potentially capable of delivering nuclear weapons – bombs and cruise missiles:

- The Panavia PA-200 Tornado IDS (>200 aircrafts) is capable of delivering a variety of unguided and laser-guided bombs. Initially (during the Cold War), it was envisaged to deliver nuclear weapons (bombs)⁷⁷
- The Eurofighter Typhoon EF-2000 is a European multinational, a multi-role fighter with maturing air-to-ground capabilities, incl. Paveway II (GBU-48) 1,000 lb bombs and Taurus cruise missiles. ⁷⁸
- The F-35 Lightning II is Lockheed Martin’s fifth-generation stealth multirole fighter aircraft. The Luftwaffe planned to purchase 35 aircraft with the first 8 to be delivered in 2026. ⁷⁹

3.7.3. Submarine

Capability	Rationale
Restricted	<ul style="list-style-type: none"> • To date, six Class 212A diesel-electric attack submarines are not considered nuclear weapons capable.

⁷⁵ Janes, "[Taurus KEPD 350](#)", Janes Weapons: Air Launched, Coulsdon, Surrey: Jane's Group UK Limited., retrieved 6 February 2024.

⁷⁶ IISS, "New stand-off weapons for the Bundeswehr?", [New stand-off weapons for the Bundeswehr?](#), 23rd September 2024.

⁷⁷ Airforce Technology, Tornado Multirole Aircraft, <https://www.airforce-technology.com/projects/tornado/?cf-view>, 2001.

⁷⁸ Eurofighter Typhoon, "[Benefits to Industry](#)", 2012.

F-35 Lightning II: The Right Choice for Germany, <https://www.f35.com/f35/global-enterprise/germany.html>.

The F-35 is coming: Fifth-generation multi-role fighter aircraft for the Air Force, BUNDESWEHR, <https://www.bundeswehr.de/de/organisation/luftwaffe/presse/die-f-35-kommt-5541706>, 2022.

Germany has six 212A class diesel-electric attack submarines, all equipped with air-independent propulsion (AIP). These submarines are about 56 meters long and 7 meters wide, and can reach speeds of up to 20 knots when submerged⁸⁰. Their weapon systems can fire torpedoes using six 533mm torpedo tubes. To date, the 212A class is not nuclear weapons capable.

4. Other Considerations

4.1. Uranium and plutonium metal production (refer to NFC TCA) and fissile core manufacture

No relevant OS information identified.

4.2. High precision machining

As one of the world leaders in the development, production and sale of conventional weapons, Germany has considerable capabilities in high-precision machining.

4.3. Potential Nuclear weapon assembly facilities capable of handling both HE and fissile materials

No relevant OS information identified.

4.4. Special transport, safety and security measures

No relevant OS information identified.

4.5. Underground Testing

No relevant OS information identified.

4.6. International Support

Germany could run a nuclear weaponisation programme without international support.

4.7. Illicit Trade

Germany could run a nuclear weaponisation programme without needing to engage in illicit procurement and trading activities.

5. Gaps in Technical Capabilities

No gaps in technical capabilities identified.

6. Conclusion

Germany has capabilities in most of the scientific, technical and manufacturing areas at extensive level to develop a viable nuclear weapon programme, *should it choose to do so*. Although there has

⁸⁰ Germany Submarine Capabilities, The Nuclear Threat Initiative, [Germany Submarine Capabilities](#), 2024.

been significant research in the past which was directly applicable to nuclear weapon design, and a number of universities and technical institutes have historically investigated and generated publications on nuclear weapon topics, no evidence has been observed in the open source which could indicate that any State level programme existed or exists today.

Ongoing scientific, technical and manufacturing activities within Germany inevitably involve dual / multiple use technologies which are relevant to nuclear weaponisation. Based on the OS evidence gathered such science and technology is consistent with conventional activities and there are no current indicators of any proliferative activities within the State or through collaborations with other States.

Annex A. Generic Weaponisation Technical Knowledge Requirements

- A suitable understanding of Hydrodynamics (shock physics), Gas Dynamics and associated elements such as implosion theory and practice, Equation of State studies, measurement techniques and numerical modelling is required in the design and production of a nuclear explosive device, assuming an implosion-based design.
- High quality, well understood and powerful energetic materials (high explosives) are a key component of nuclear explosive devices. Significant research, development and testing is necessary to ensure a reliable and safe product which can be used in a nuclear weapon.
- High explosives (HE) are defined to be a class of energetic material which can be stimulated to release energy by rapid chemical decomposition proceeding at a supersonic rate (detonation), producing a high-pressure shock wave. The types of HE generally used in nuclear weapons have many similarities to explosives used in different types of conventional armaments. As a consequence, it is extremely difficult to differentiate whether a particular explosive formulation is being developed for nuclear weapons intent, or for conventional purposes. However, a number of HEs which are relatively insensitive, stable and with a good metal accelerating ability, could be adapted or developed to be potential candidates for nuclear weapons.
- An understanding of neutronics processes and radiation transport, including criticality studies is important in nuclear weapons as well as in reactor physics and nuclear engineering.
- Exotic materials such as Beryllium (Be) metal, Lithium-6, and Tritium, may be utilised in nuclear weapons development for a variety of purposes. Metallization of Be and Be-metal processing, Lithium-6 enrichment and tritium production, synthesis and storage are all complex processes that require specialist technologies.
- High-speed Diagnostics, such as Streak Cameras, Flash X-Ray (FXR), and Velocity Interferometer System for Any Reflector (VISAR) are important tools for nuclear weapon research and development.
- High power switching used for high-current spark gaps associated with detonation systems, neutron generators and FXR are important for nuclear weapon research and development.
- Numerical modelling is commonly used within the nuclear reactor field and significant developments in both computing capabilities and codes have made complex simulations much more accessible. This is particularly significant in the field of nuclear fusion systems. Although not directly applicable, expertise in some of these applications could be of potential benefit within a nuclear weapons programme.

NB. *All of these technologies can be utilised in conventional civilian and military applications*

In addition, sources of education, training and knowledge, such as leading research institutions, universities and technical fora/conferences, are a prerequisite for enabling research and development of the necessary disciplines listed above.

Annex B. Significant research and production entities (DRAFT)

This table summarizes significant research institutions, universities, and private companies conducting weaponization related R&D.

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
Dresden University of Technology	Nuclear & Neutron physics / Neutronics	Experimental criticality studies	Conducts postgraduate-level teaching and training in nuclear physics and nuclear energy technology. ⁸¹	AKR-2 training and research reactor (WDDH).
Auremo GmbH	Materials (non-fissile)	Beryllium	Offers an extensive range of various types of metals, incl. Beryllium. ⁸²	-
Battelle Institute, Frankfurt	Numerical Modelling	Hydro, neutronic, and coupled computer codes	The Battelle Institute is a U.S. contract research organization. Founded in 1929 in Columbus, Ohio, it has a number of research facilities in the US and Geneva ⁸³ . The research facility in Frankfurt am Main was founded in 1952 and closed in 1993. ⁸⁴	-
	Hydrodynamics (Shock Physics)	Diagnostics (HVP registration)	Historical investigation of MPI Pin-dome measurements.	
TECHNOLOGICA Society for High Tech Materials and Processes GmbH (Beryllium oxide)	Materials (non-fissile)	Beryllium	Manufacturer of sintered beryllium oxide drawing parts. ⁸⁵ In German usage, 'Drawing parts' are industrial metal parts that are manufactured according to customer	-

⁸¹ TU Dresden, 2024-09-16, "[Chair of Hydrogen and Nuclear Energy](#)"

⁸² https://auremo.net/metals-rare/2245-beryllium-nugget-be-999-pure-metal-element-4.html?srsId=AfmBOoq2MNQJukcHrH4TSgLHudKoiklGhw_so4VcarrlyTFQgav4IEPB.

⁸³ <https://www.battelle.org/>

⁸⁴ <https://dserver.bundestag.de/btd/13/054/1305496.pdf>, p. 19, 20

⁸⁵ [Zeichnungsteile aus Berylliumoxid - Technologica](#)

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
			requirements – as prototypes, in small quantities or in large series. ⁸⁶	
Bundesanstalt für Materialforschung und -prüfung	Nuclear & Neutron physics / Neutronics	Neutron initiators	Conducts research, test and evaluate substances, materials, and equipment safe handling and operation. Capabilities related to neutron generation. ⁸⁷	
Center for Information Services and High Performance Computing, at the Technical University of Dresden	Numerical Modelling	High Performance Computing (HPC)	Conducts teaching and training the field of computer architecture and data analytics. ⁸⁸	High Performance Computing and Storage Complex (HRSK-II), extension High Performance Computing – Data Analytics (HPC-DA), supercomputers Cray XC40.
Center for Radiation Protection and Radiation Oncology, University of Hannover	Numerical Modelling	Data libraries (Equation of State, nuclear data)	Wide application of advanced nuclear data libraries in calculations.	-
Department of Nuclear Chemistry, University of Cologne	Numerical Modelling	Data libraries (Equation of State, nuclear data)	Wide application of advanced nuclear data libraries in calculations.	-
Diehl Stiftung & Co. KG	Energetic materials	Detonation systems	HE technology, armory and ammunition production ⁸⁹	Special production and storage facilities.
	Energetic materials	Special production and storage facilities		
	Energetic materials	Detonation systems	Investigates issues from the fields of impact and shock wave physics, ballistics,	Visualization techniques: high-speed photography, high-speed

⁸⁶ [Stanzteile und Metallformteile in Kleinserien > Gutekunst Formfedern GmbH > Abkanten, Großserien, Kleinserien, Lasern, Laserschneiden, Metallformteile, Stanzbiegeteile, Stanzen, Stanzteile, Umformen](#)

⁸⁷ Bundesanstalt für Materialforschung und – prüfung, <https://www.bam.de/Navigation/EN/About-us/about-us.html>.

⁸⁸ [Center for Information Services and High Performance Computing — Center for Information Services and High Performance Computing \(ZIH\) — TU Dresden](#)

⁸⁹ Diehl Stiftung & Co. KG, <https://www.diehl.com/group/de/>.

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
Ernst-Mach-Institute (Fraunhofer Institute for High-Speed Dynamics)	Energetic materials	Special production and storage facilities	laser effects, blast effects and blast physics. ⁹⁰	videography, schlieren photography; flash X-ray photography, X-ray tomography and X-ray cinematography; laboratory acceleration facilities; in-house computer cluster.
	Hydrodynamics (Shock Physics)	Diagnostics (HVP registration)		
	Numerical Modelling	Hydro, neutronic, and coupled computer codes		
	Hydrodynamics (Shock Physics)	Experimental blast facilities		
	Energetic materials	HE development, testing and production		
Jülich Research Centre (Forschungszentrum Jülich) The Jülich Supercomputing Center	Nuclear & Neutron physics / Neutronics: Neutron initiators, experimental criticality studies		Experimental measurements of neutron cross-section data and fundamental nuclear properties using radioactive ion beams. ⁹¹	COoler SYnchrotron COSY. Plans and builds the High Energy Storage Ring (HESR) at the international accelerator center FAIR (Facility for Antiproton and Ion Research) in Darmstadt.
	Numerical Modelling: Data libraries (Equation of State, nuclear data High Performance Computing)		Develops models and algorithms for the simulation, optimization and control of energy systems. ⁸⁹	Supercomputers, JUWELS and JURECA, and the new JUPITER is under construction.
Fraunhofer Institute for Ceramic Technologies and Systems	Nuclear & Neutron physics / Neutronics	Neutron initiators	Conducts research, test and evaluate materials, technologies, and components in the field of advanced ceramics and hard metals/cermets, hydrogen and fuel cell	-

⁹⁰ Fraunhofer Institute for High-Speed Dynamics, research into fast-moving processes through experiments and simulations, [Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institute, EMI](#)

⁹¹ Jülich Research Centre, [Forschungszentrum Jülich](#).

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
			related technologies. Capabilities related to neutron generation. ^{92 93}	
Fraunhofer Institute for Chemical Technologies and Systems (ICTS)	Hydrodynamics (Shock Physics)/Energetic materials: HE development, testing and production, Detonation systems, Special production and storage facilities, Experimental blast facilities		Covers the entire development chain for propellants and explosives, with focused research for the Federal Ministry of Defence ^{94 95}	<i>Over 100 laboratories, multiple pilot plants and 3 test centers.</i>
	Numerical Modelling	Hydro, neutronic, and coupled computer codes	Modelling and simulation calculations, quantum mechanical and molecular dynamic simulations, the modelling of burnup behaviour. ⁹⁶	
Fraunhofer Institute for Technological Trend Analysis	Numerical Modelling	Hydro, neutronic, and coupled computer codes	Conducts research and development in the areas of defense and civil security. solutions and operational support at the national and international levels, in particular for the German Ministry of Defence. ⁹⁷	-
Freiburg, Institute of Physics, University of Rostock	Hydrodynamics (Shock Physics)	Implosion & Shock Physics, Detonation	Conducts postgraduate-level teaching and research in intense laser-matter interaction and high energy density physics. ⁹⁸	Energetic pulsed laser systems and X-ray sources; a state-of-the-art computer network

⁹² Fraunhofer Institute for Ceramic Technologies and Systems, <https://www.ikts.fraunhofer.de/>

⁹³ Fraunhofer IKTS, <https://energy-saxony.net/en/mitglieder/fraunhofer-institute-for-ceramic-technologies-and-systems-ikts/>

⁹⁴ Fraunhofer Institute for Chemical Technology ICT, Core expertise explosives technology, https://www.ict.fraunhofer.de/en/comp/explosives_technology.html

⁹⁵ Fraunhofer Institute for Chemical Technology ICT, Energetic Materials, <https://www.ict.fraunhofer.de/en/comp/em.html>

⁹⁶ [Explosive's technology, safety and security - Fraunhofer ICT](#)

⁹⁷ [Fraunhofer Segment for Defense and Security VVS](#), <https://www.vvs.fraunhofer.de/en.html>

⁹⁸ [Track: "Intense Laser-Matter Interaction and High Energy Density Physics" - Institut für Physik - University of Rostock](#)

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
Goethe University Frankfurt	Numerical Modelling	Data libraries (Equation of State, nuclear data)	Conducts teaching, training and research in particular in computer science and mathematics (numerical analysis, discrete mathematics and oth.) ⁹⁹	-
Heidelberg Institute for Theoretical Studies	Radiation-matter interaction studies		Conducts basic research in the natural sciences, mathematical and computer science. Models thermonuclear explosions of white dwarf stars, improves data storage and the search for science data. ¹⁰⁰	-
Helmholtz-Zentrum Berlin	Nuclear & Neutron physics / Neutronics	Neutron initiators	Conducts research on materials and technologies, incl. related to energy supply and information technology. Capable for neutron source related R&D ¹⁰¹	Modern laboratories and BESSY II synchrotron.
Helmholtz-Zentrum, Dresden-Rossendorf, Dresden.	Numerical Modelling	Data libraries (Equation of State, nuclear data)	Conducts research with a long-term focus in the fields of energy, health and matter. ¹⁰²	Department of Information Services and Computing High Performance Computing at HZDR.
	Nuclear & Neutron physics / Neutronics	Neutron initiators	Capable for neutron source related R&D. ²⁰	Radiation Source at the ELBE Center for High-Power Radiation Sources. User Facilities at the Ion Beam Center IBC.
	Hydrodynamics (Shock Physics)	Implosion & Shock Physics, Detonation	Studies complex flow phenomena under realistic conditions for process engineering, chemical industry and safe operation of nuclear power plants.	Institute of Fluid Dynamics, TOPFLOW -Transient Two Phase FlowTest Facility.

⁹⁹ Goethe University Frankfurt, Department 12 - Computer Science and Mathematics, https://www.uni-frankfurt.de/99556206/Fachbereich_f%C3%BCr_Informatik_und_Mathematik

¹⁰⁰ Heidelberg Institute for Theoretical Studies, <https://www.h-its.org/>

¹⁰¹ Helmholtz-Zentrum Berlin, [Helmholtz-Zentrum Berlin \(HZB\) - Mainpage.](#)

¹⁰² Helmholtz-Zentrum Dresden-Rossendorf, [HZDR – Helmholtz-Zentrum Dresden-Rossendorf.](#) [HZDR – Helmholtz-Zentrum Dresden-Rossendorf](#)

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
High Performance Computing Center Stuttgart, at the University of Stuttgart.	Numerical Modelling	High Performance Computing (HPC)	Provides essential tools and solutions for academic and industrial research. ¹⁰³	Houses several supercomputers, including "Hawk" system.
Institut für Physikalische Chemie und Elektrochemie der Universität Karlsruhe	Materials (non-fissile)	Lithium, tritium	Conducts teaching, training and research in Physical Chemistry of Condensed Matter, Physical Chemistry of Microscopic Systems, Molecular Physical Chemistry, Theoretical Chemistry. ¹⁰⁴	-
Institute for Radiation Physics, The Helmholtz-Zentrum Dresden-Rossendorf	Radiation-matter interaction studies		Conducts investigation of the interactions of light and matter, using the state-of-the-art radiation sources and high-power lasers. ¹⁰⁵	ELBE Center for High-Power Radiation Sources. Development and improvement of existing installations and establishing novel accelerators and the further is an essential goal of the institute.
Johannes Gutenberg University in Mainz	Radiation-matter interaction studies		Conducts teaching, training and research in fundamental physics, incl. radiation-matter interaction ¹⁰⁶	New electron accelerator MESA on the Gutenberg Campus.
Josef Meissner GmbH & Co. KG.	Energetic materials	HE development, testing and production, Detonation systems	Innovative technologies in plant construction for the chemical industry and the industry of explosives incl. initiating explosives. ¹⁰⁷	Laboratory facilities for research and development located in Immekeppel/Bergisch Gladbach.

¹⁰³ High Performance Computing Center Stuttgart, [HLRS High Performance Computing Center Stuttgart: Home](https://www.hlrs.de/)

¹⁰⁴ Institute of Physical Chemistry, <https://www.ipc.kit.edu/3063.php>

¹⁰⁵ Institute for Radiation Physics, The Helmholtz-Zentrum Dresden-Rossendorf, <https://www.hzdr.de/db/Cms?pOid=10245&pNid=132>

¹⁰⁶ Luca Doria, Interaction of Radiation with Matter, <https://www.staff.uni-mainz.de/doria/Detectors/RadMatter.pdf>

¹⁰⁷ Josef Meissner GmbH & Co. KG, <https://www.josefmeissner.com/en/contact>

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
Jülich Research Centre.	Nuclear & Neutron physics / Neutronics	Neutron initiators	Conducts research into Neutron Scattering and Soft Matter, Neutron Analytics for Energy Research, Neutron Methods. ¹⁰⁸	Jülich Centre for Neutron Science (JCNS) operates <i>neutron instruments at the national and international leading sources</i> FRM II, ILL and SNS, low energy compact accelerator based neutron source, Proton Beam Multiplexer, Target-Moderator Unit, Cold Moderator Systems.
Jülich Supercomputing Center of the Institute for Advanced Simulation (IAS)	Numerical Modelling	High Performance Computing (HPC)	Provides with supercomputing resources, IT tools, methods, and expertise; conducts educational activities ¹⁰⁹	Supercomputers JUPITER, JEDI, JUWELS, JURECA JUSUF, quantum computing JUNIQ facility
JUNGHANS Microtec GmbH	Energetic materials	Detonation systems, Special production and storage facilities	Develops, designs and manufactures arming, fuzing and firing devices for conventional arms; provides multipoint initiation, precise ignition timing. ¹¹⁰	-
	Fusing and firing technology, MPI systems			
Research Center Karlsruhe Institute of Neutron Physics and Reactor Engineering, Karlsruhe Institute of Technology	Numerical Modelling	Hydro, neutronic, and coupled computer codes	Conducts teaching, training and research in neutronics and nuclear data s, Reactor physics and dynamics multiphysics methods and codes, safety studies for reactor systems (fission, fusion). Wide	Multi-physics code systems for safety and dynamics of nuclear systems: SIMMER-III and SIMMER-IV (accident scenarios), KIN3D and ERANOS (subcriticality), ERANOS and PARTISN (neutron transport), MCNP, KORIGEN and C ⁴ P-TRAIN (preparation of multigroup neutron
		Data libraries (Equation of State, nuclear data)		
	Materials (non-fissile)	Lithium, tritium		

¹⁰⁸ Jülich Research Centre, [Forschungszentrum Jülich](#).

¹⁰⁹ Jülich Supercomputing Center, <https://www.fz-juelich.de/en/ias/jsc/about-us/profile>

¹¹⁰ JUNGHANS Microtec GmbH, https://ndia.dtic.mil/wp-content/uploads/2016/fuze/18481_Perrin.pdf, <https://junghans-defence.com/?lang=en>.

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
			application of advanced nuclear data libraries in calculations. ^{111 112}	cross sections), COUPLE (basis accident scenarios in molten salt reactors), Fuel Performance Codes
KNDS Group	Energetic materials	Detonation systems, Special production and storage facilities, HE development, testing and production	Manufactures main battle tanks, armored vehicles, artillery systems, weapons systems, ammunition etc, ¹¹³	Locations in Munich, Kassel, Constance, Remscheid, Hamburg and Freisen
Leibniz Supercomputer Center	Numerical Modelling	High Performance Computing (HPC)	Offers technologies, solutions and services, incl. supercomputing data and storage systems, AI and big data, quantum computing, network, IT security. ¹¹⁴	Munich Scientific Network, Data Science Storage and the Data Science Archive, AI systems with powerful clusters equipped with Graphics Processing Units, Super MUC-NG high-performance computer, Quantum Integration Centre
Lutradyn - Energetic Materials	Energetic materials	Detonation systems, Special production and storage facilities	Provides scientific and technological support in the field of Energetic Materials with an emphasis on insensitive & high explosives. ¹¹⁵	-
Max-Planck-Institut für Astrophysik in München	Radiation-matter interaction studies		Conducts theoretical research and numerical simulation of astrophysical systems with high-performance and ultra-high-performance computers, and develop algorithms to analyse the vast	-

¹¹¹ Institut für Neutronenphysik und Reaktortechnik – Karlsruhe Institute of Technology, [KIT - Karlsruhe Institute of Technology](http://www.kit.edu).

¹¹² Institute of Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology, <https://www.inr.kit.edu/967.php>

¹¹³ KNDS Group, <https://www.knds.com/>

¹¹⁴ Leibniz Supercomputer Center, [LRZ: Leibniz-Rechenzentrum der Bayerischen Akademie der Wissenschaften](http://www.lrz.de).

¹¹⁵ Lutradyn - Energetic Materials, Kaiserslautern, <https://www.lutradyn.com/>

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
			amounts of data produced in ever-larger simulations and satellite missions. ¹¹⁶	
NUMERICS GmbH	Numerical Modelling	Hydro, neutronic, and coupled computer codes	Offers a variety of engineering services and software products for defense and safety-related tasks, incl. Weapon Effects Modeling, Blast and Impact Effects Analysis, numerical modeling with hydrocodes and FE-codes, and the development of material models. ¹¹⁷	Software products: SPLIT-X (blast-fragmenting warheads), PS3D (penetration), FI-BLAST (structural analysis of weapons' effects on vehicles), and SPEED (shock and impact physics in 2D and 3D).
Rheinmetall Waffe Munition GmbH (RWM), Rheinmetall AG	Energetic materials	Detonation systems, HE development, testing and production, Special production and storage facilities	Development and production of large-caliber weapon systems and the corresponding ammunition. ¹¹⁸	50-square-kilometer Center of Excellence for Research and Development in Unterlüß (Lower Saxony), test center in Ochsenboden (Switzerland).
Diehl Stiftung & Co. KG	Energetic materials	Detonation systems, HE development, testing and production, Special production and storage facilities	Supplies high-tech equipment for defense. With the development and production of guided missiles and ammunition for the Army, Air Force, and Navy. ¹¹⁹	-

¹¹⁶ Max-Planck-Institut für Astrophysik, <https://www.mpg.de/155071/astrophysics>

¹¹⁷ NUMERICS GmbH, <https://numerics.de/products/>

¹¹⁸ Rheinmetall Waffe Munition GmbH (RWM), Rheinmetall AG, <https://www.rheinmetall.com/de/unternehmen/tochtergesellschaften/rheinmetall-waffe-munition/ueber-uns>

¹¹⁹ Diehl Defence GmbH & Co. KG, <https://www.diehl.com/defence/de/company/zahlen-und-fakten/>

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
RWTH Aachen University - Rheinisch-Westfälische Technische Hochschule Aachen	Hydrodynamics (Shock Physics)	Experimental blast facilities	Conducts teaching, training and theoretical and experimental research in gas dynamics ¹²⁰	TH2 (Hypersonic Shock Wave Channel), STK (shock tube transonic duct), Q54 (shock tube has a low- pressure part with a square cross- section for Flow Visualization), rocket nozzle flow simulation facility.
SUR Measurement Technology	Nuclear & Neutron physics / Neutronics	Experimental criticality studies	Conduct teaching, training and research in neutronics and nuclear data, reactor physics, methods and codes, nuclear safety for reactor systems. Wide application of advanced nuclear data libraries in calculations. ^{121 122 123}	Operating research reactors SUR.
SUR Stuttgart				
SUR Ulm				
TDW Society for Defense Technology Systems, and Numerics GmbH	Energetic materials	Detonation systems	Conduct experiments and numerical simulation of multipoint initiation of conventional munitions. ¹²⁴	-
	Fusing and firing technology, MPI systems			
Technical University Darmstadt	Numerical Modelling	Data libraries (Equation of State, nuclear data)	Wide application of advanced nuclear data libraries in calculations. ¹²⁵	-

¹²⁰ RWTH Aachen University, Chair of High Pressure Gas Dynamics, Experimental Facilities, <https://www.hgd.rwth-aachen.de/cms/HGD/Forschung/~kfmdw/Experimentelle-Anlagen/lidx/1/>

¹²¹ Siemens-Unterrichts-Reaktor SUR-100 Furtwangen, [SUR-100 Furtwangen](#).

¹²² Siemens Unterrichtsreaktor SUR 100, Institut für Strahlenmesstechnik. [ISM](#).

¹²³ APMB: Siemens Unterrichtsreaktor SUR 100, [APMB: Siemens Unterrichtsreaktor SUR 100 | Institut für Kernenergetik und Energiesysteme | Universität Stuttgart](#).

¹²⁴ TDW (TDW Society for Defense Technology Systems, and Numerics GmbH) is a European company that develops and manufactures warheads for guided weapons, <https://www.mbda-deutschland.de/das-unternehmen/tdw-gmbh/>

¹²⁵ Institute for Nuclear Physics (IKP) at the Technical University of Darmstadt, https://www.ikp.tu-darmstadt.de/das_institut_kernphysik/index.en.jsp

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
Technical University Dresden	Numerical Modelling	Data libraries (Equation of State, nuclear data)	Wide application of advanced nuclear data libraries in calculations. ¹²⁶	-
Technical University of Munich	Nuclear & Neutron physics / Neutronics	Experimental criticality studies	Experimental neutronics for research and industry. ¹²⁷	FRM II research neutron source
Karlsruhe Tritium Laboratory, Institute for Astroparticle Physics	Materials (non-fissile)	Lithium, tritium	A semi-technical scale facility for processing tritium. More than 25 years of safe operation and experience with tritium. ¹²⁸	More than 20 glove box systems, total volume of about 190 m ³ , are operated in an area of 1600 m ² for experiments and infrastructure facilities. Is licenced for 40 g of ² T
The Leibniz Supercomputer Center in Garching	Numerical Modelling	High Performance Computing (HPC)	Operates the "SuperMUC" supercomputer. ¹²⁹	"SuperMUC" supercomputer.
University of Mainz	Nuclear & Neutron physics / Neutronics	Experimental criticality studies	Experimental research in neutron physics. ¹³⁰	TRIGA Mark II research reactor
Tropag Oscar H. Ritter Nachf. GmbH	Materials (non-fissile)	Beryllium	Produces special metal alloys, high-grade chemical products. Provides processing industries with special raw products and chemical primary and intermediate products. ¹³¹	-
Universität Siegen	Radiation-matter interaction studies		Conducts fundamental research in the fields of elementary particle physics and quantum optics. Carries out research in theoretical and experimental physics to	-

¹²⁶ Technical University Dresden, Center for Interdisciplinary Digital Sciences, <https://tu-dresden.de/cids#intro> s

¹²⁷ Research Neutron Source Heinz Maier-Leibnitz (FRM II) Technical University of Munich, <https://www.frm2.tum.de/en/frm2/the-neutron-source/>

¹²⁸ The Karlsruhe Tritium Laboratory (TLK) of the Institute for Astroparticle Physics (IAP), <https://www.iap.kit.edu/tlk/english/>.

¹²⁹ Leibniz Supercomputer Center, [LRZ: Leibniz-Rechenzentrum der Bayerischen Akademie der Wissenschaften](https://www.lrz.de/).

¹³⁰ The Mainz research reactor TRIGA Mark II with pulse device, <https://www.en.triga.uni-mainz.de/reactor-2/>.

¹³¹ Tropag Oscar H. Ritter Nachf. GmbH, <https://tropag.com/en/products/products-by-elements/>.

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
			study matter and quantum information technology. ¹³²	
Dresden–Rossendorf Technische Universität	Radiation-matter interaction studies		Conducts research in fundamentally new states of quantum matter, understanding the principles of structure-property relations and interactions of materials in various environments. ¹³³	-
Universität zu Lübeck - Institute of Medical Engineering	Nuclear & Neutron physics / Neutronics	Neutron initiators	Conducts research in Nuclear Imaging diagnostic techniques, dealing with a variety of radiation sources. ¹³⁴	-
Voestalpine High Performance Metals GmbH	Materials (non-fissile)	Beryllium	Offers additive manufacturing of the Be-alloy parts. ¹³⁵	-
Wieland Metal Services Germany GmbH	Materials (non-fissile)	Beryllium	Supplies semi-finished and special copper alloys, incl. those containing beryllium ¹³⁶	
Wirksysteme GmbH	Energetic materials	Detonation systems	Manufacturer of guided missile systems, develops and produces explosives, fuses, performance-matched warheads and intelligent detonation systems. ¹³⁷	ELECTROMAGNETIC COMPATIBILITY TESTING LABORATORY; Blasting site is unique in Germany in terms of testing capabilities, equipment. A permit for blasting tests with up to 50 kg of explosive; Environmental laboratory tests the mechanical and thermal resilience

¹³² Universität Siegen, <https://forschung.uni-siegen.de/en/>

¹³³ Dresden–Rossendorf Technische Universität, <https://tu-dresden.de/forschung-transfer/forschungsprofil/forschungsprofilinien/forschungsprofilprofilinien>

¹³⁴ Neutron Radiography Laboratory, University of Applied Sciences, Lübeck, [Technische Hochschule Lübeck, Nuclear Imaging: Institute of Medical Engineering.](#)

¹³⁵ Voestalpine High Performance Metals GmbH, www.voestalpine.com/additive.

¹³⁶ Wieland Metal Services Germany GmbH | Kornwestheim, [Wieland Metal Services Germany GmbH | Kornwestheim.](#)

¹³⁷ TDW Gesellschaft fürverteidigungstechnische Wirksysteme mbH is the competence center for weapon systems within MBDA Germany, <https://www.mbda-deutschland.de/das-unternehmen/tdw-gmbh/>

Name	WN topic area	WN topic area sub-sets	Role	Operational WN-related or other infrastructure available
				of the objects containing explosives and potentially explosive objects.
Center for Astronomy of Heidelberg University (Zentrum für Astronomie der Universität Heidelberg in German)	Radiation-matter interaction studies		Conducts research and teaching on from planet formation, galaxy evolution, cosmology computer physics. ¹³⁸	Astronomical Computing Institute, Institute for Theoretical Astrophysics.

¹³⁸ Center for Astronomy of Heidelberg University (Zentrum für Astronomie der Universität Heidelberg in German) <https://zah.uni-heidelberg.de/standard-titel>