Safety first!

Information for the public according to § 53 of the Radiation Protection Ordinance

Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II)
TUM-Campus Garching

Contents

Dear fellow citizens,

Ensuring the safety of the public and the environment has high priority for the people responsible for the Research Neutron Source Heinz Maier-Leibnitz (FRM II). For the past 13 years, the Garching neutron source has been operating for the benefit of science and society, without endangering either people or the environment—as indeed was the case with its predecessor, the Research Reactor Munich, during its entire operating period of almost fifty years. The FRM II is the most advanced research reactor in the world and boasts a sophisticated, redundant, that is to say the presence of several, mutually independent security system components. The design of the system makes use of the laws of physics so that, in the event of any fault, the whole system reverts into a safe, passive state and in no way impacts negatively on the employees and students at the Garching Campus, nor on local residents. This superior level of safety at the FRM II has been repeatedly confirmed by independent experts. Due to the disaster prevention measures for nuclear power plants, the Technical University of Munich, the Landratsamt München and the Government of Upper Bavaria have developed a detailed emergency plan which is constantly updated in order to act quickly, effectively and targeted in a hypothetical extreme case.

This stems from the responsibility we owe to you, the immediate and more distant neighbours of the Garching campus, students and staff, the many visitors who come each year to experience directly the fascination of research with neutrons, as well as external users from science and industry who rely on a powerful neutron source for their research and applications. For a long time, the FRM II has been more than a pure research institute of the Technical University of Munich. Through the strong involvement of partners from the Helmholtz Gemeinschaft, the largest scientific organization in Germany, the FRM II has evolved into a research facility which is supported by the

State of Bavaria and the federal government. For the information of local residents and other interested parties and the further strengthening of established trust, but also due to our legal obligation under § 53 of the Radiation Protection Ordinance, the Technical University of Munich and the Government of Upper Bavaria are publishing this brochure about the FRM II for the third time. It provides information on how the Garching neutron source operates, the science involving neutrons and the associated security concepts. We very much hope to be able to meet your information needs in a well-informed way.

Munich / Garching, March 2017

Albert Berger
Chancellor of the Technical
University of Munich

Brigitta Brunner
President
of Upper Bavaria

The Garching campus—an ideal location

The research campus in the university town of Garching is one of the most important and modern research and training facilities in Europe. It all began in 1957 with a neutron source, the so-called „atomic egg“ on account of its distinctive shape. It has long been the symbol of Garching and its research area. A variety of institutions have developed around the neutron source in the course of more than five decades. Today, the scientific and engineering faculties of the Technical University of Munich (TUM) are located here, with departments of physics, chemistry, mechanical engineering, mathematics, and computer science. In the immediate vicinity there are four institutes of the Max Planck Society, institutes of the Ludwig Maximilians-Universität, the Bavarian Academy of Sciences and Humanities, the headquarters of the European Southern Observatory (ESO), the European research centre of General Electric and other research institutions. With a subway station in the heart of the campus, trains run to the centre of Munich at 10-minute intervals during the day. The prospects look good and the Garching campus continues to grow.

The technical diversity and cooperation between the different disciplines is what defines the scientific excellence of the research site. The Research Neutron Source Heinz Maier-Leibnitz (FRM II) is ideally located here. Since 2005, it has been used by a variety of disciplines for scientific research. Physicists, chemists, engineers, physicians and biologists as well as scientists with other specialities work together here. As a corporate research centre of the Technical University of Munich, it offers students an education which is second to none. The interaction between neighbouring scientific institutes on campus, in Munich and Freising-Weihenstephan enriches research and teaching enormously. For German and foreign scientists the FRM II provides a powerful modern neutron source with excellent research potential. Through its international unique application orientation, the FRM II is an attractive focal point for the establishment of a number of high-tech companies.

The Research Neutron Source FRM II—a unique microscope

The FRM II is not a nuclear power plant. Like the old „atomic egg“, it is not designed to generate electrical energy, but works exclusively as a neutron source for scientific research and radiation. The neutrons produced during the fission process in the reactor serve as unique probes. The FRM II provides researchers with a unique tool for modern material science and basic research. Due to the high neutron flux of the source, the very brilliant neutron beams and modern instrumentation, the FRM II can be used in very different fields of research. Some of the applications are only possible in Garching and many of the experimental set-ups are the most powerful of their kind in the world. The work ranges from pure basic research through to application-oriented research, the production of semiconductor materials or pharmaceuticals and the treatment of cancer patients. Approximately 30 percent of the available beam time is reserved for industrial and medical applications.

As in the case of light, neutrons have wave properties. In a scattering experiment, they encounter the target sample being investigated and are deflected by its atoms. The spatial distribution of the scattered neutrons and the velocity change which occurs provide information on the atomic structure and dynamics of the sample. Given this information, for example, levels of stress in a component or the reasons for metal fatigue become evident. Neutron rays aimed at a target penetrate solid pieces of metal effortlessly. For this reason, neutron tomography makes the interior of complex components visible. This allows for the detection of corrosion products, cracks or material inhomogeneities in technical samples. Radiographs make fast-moving processes visible in millisecond steps. This is an important method for the nondestructive testing of components in industry.

In addition, the structure of new materials can be clarified, or characteristics such as superconductivity evaluated. Due to their particular reaction with hydrogen, neutrons are also highly suitable for investigating biological samples.

Neutrons can convert elements. This can be used for the production of radiopharmaceuticals, extremely homogeneously doped silicon for high performance materials for the semiconductor industry or for the detection of trace elements using so-called neutron activation analysis.

Within the framework of a specific cancer therapy, tumors occurring near the surface can be irradiated with fast neutrons. This therapy has been available in the „atomic egg“ since 1985, and is still offered at the FRM II under medical supervision.

In order to open up further fields of application and to optimize their use, the neutrons themselves are, of course, the subject of modern basic research.

Conception of the facility

The FRM II is designed exclusively as a neutron source for scientific experiments and applications and cannot be used to generate electrical energy. Its modern concept derives from the use of a so-called compact core.

A single, cylindrical 130 cm high fuel element with an external diameter of 24 cm is used for 60 days. The fuel zone is about 70 cm high and contains some 7.6 kg of fissionable uranium. This fuel assembly is installed in the center of a moderator tank filled with heavy water (D_2O). This in turn is located in the reactor pool, which is filled with 700 m^3 of high-purity water (H_2O).

The fuel element of the FRM II in the central channel of the moderator tank is fed by cooling water from the reactor pool, which heats up to about 50 °C. A total of three staggered cooling circuits ensures that, on the one hand, the heat generated by the nuclear fission during operation is reliably dissipated and that, on the other hand, a doubly supervised activity barrier exists in the direction of the cooling tower. The power of the reactor is controlled via the central control rod inside the fuel assembly. Neutrons are released through the fissioning of the uranium. The compact design of the FRM II-fuel element ensures that more than 70 percent of the neutrons leave the uranium zone and that a very high neutron flux density is formed ($8 \cdot 10^{14}$ neutrons $cm^{-2}s^{-1}$, which are 800 trillion neutrons per square centimetre and second) outside the fuel assembly in the moderator. From this dense neutron field, ten horizontal and two oblique beam tubes as well as various vertically arranged radiation channels protrude. The vertical irradiation channels are used to irradiate samples.

The actual experimental spaces are located outside the reactor pool in an extension of the beam tubes in the experimental hall of the reactor building as well as along the neutron guides in the neutron guide hall (West). The latter is located between the FRM II building and the old „atomic egg“. The newly constructed neutron guide hall (East) will also be used for experiments once it has been properly equipped.

Safety first

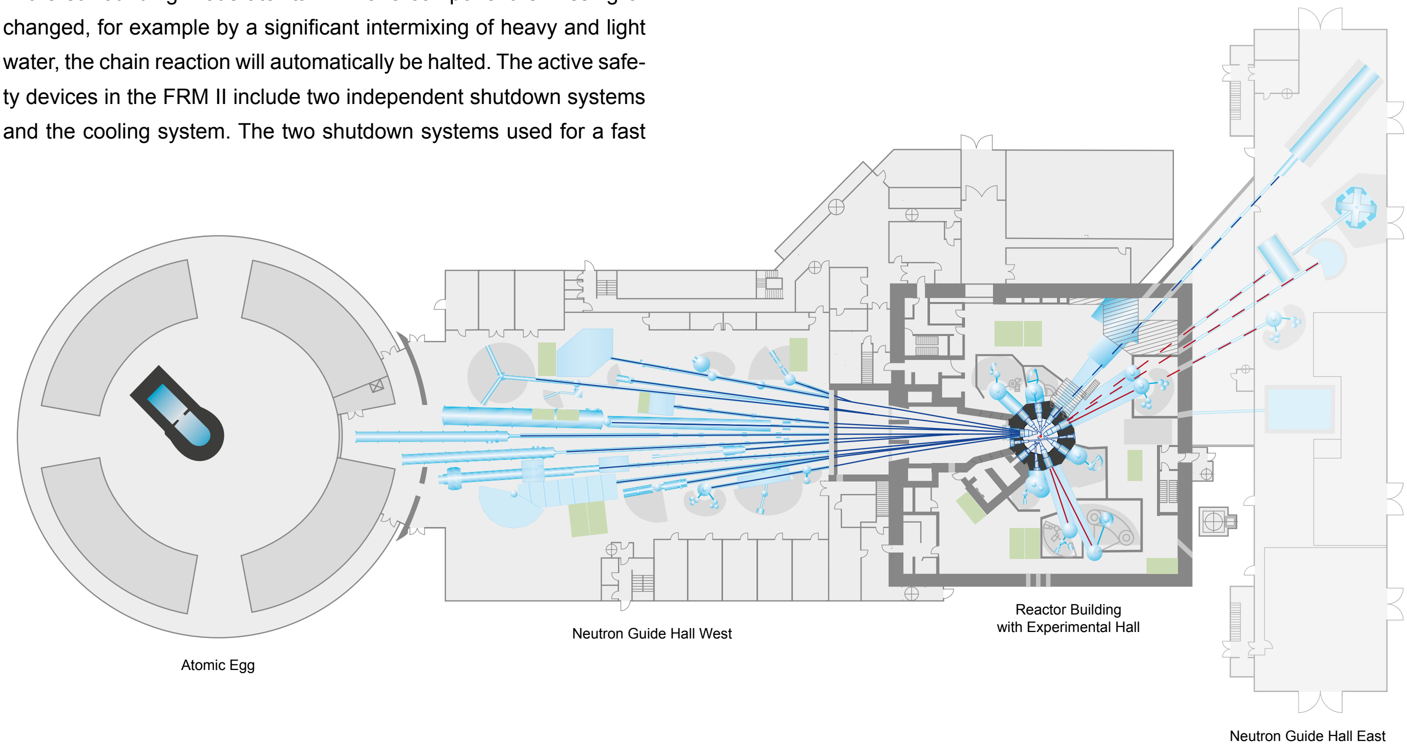
The planning, construction and operation of nuclear facilities in Germany are subject to stringent safety regulations. So, during the planning phase of the FRM II, all conceivable possibilities for accidents occurring were considered in detailed discussions with the Commission on Radiological Protection (SSK) and the Reactor Safety Commission (RSK), as well as with independent advisory bodies of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) and other experts. Taken into consideration were, amongst other things, the effects of floods, a complete power failure, earthquakes, plane crashes—even of large commercial airliners—and assumed malfunctions such as the hypothetical case of a partial or complete meltdown. The extensive precautions against possible accidents were approved by the Technical University of Munich, as the operator of the FRM II, both within the framework of the survey and the granting of the operating license and the plant specific safety review (RSK-SÜ), which was carried out taking into account the events in Fukushima (Japan).

Both under normal operating conditions and in the case of a malfunction, the safety of personnel, the public and the environment is the primary focus. This is achieved through a combination of passive and active security mechanisms.

The system includes passive safety features that are based on natural laws and can, therefore, never fail. They act passively in the sense that no action by personnel or by the designated system components is required.

These safety measures are particularly effective in the case of the FRM II due to the extremely compact construction of the fuel element. The low volume of the FRM II fuel element means that it will only work in the conditions for which it was intended: It requires light water between the fuel plates of the fuel element and heavy water in the surrounding moderator tank. If one component is missing or changed, for example by a significant intermixing of heavy and light water, the chain reaction will automatically be halted. The active safety devices in the FRM II include two independent shutdown systems and the cooling system. The two shutdown systems used for a fast and safe shutdown of the reactor include the central control rod, located in the inner channel of the fuel assembly, and an independent system of five shutdown rods arranged in the moderator tank. Either one of the two systems alone is sufficient to shut down the reactor quickly and permanently.

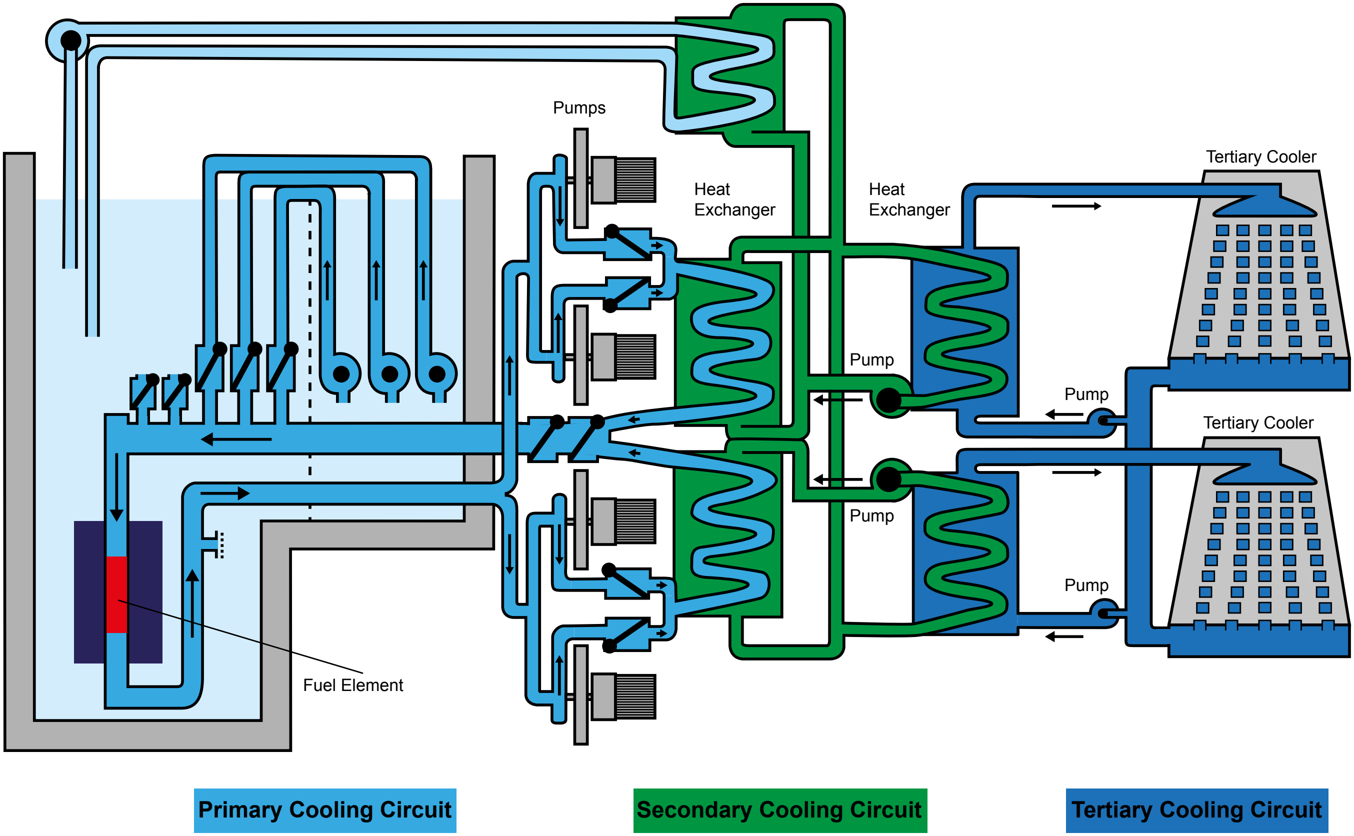
The cooling system consists of a closed primary circuit and a secondary circuit which is also closed, both located inside the reactor building. The tertiary circuit dissipates the heat through evaporation via a small cooling tower. The primary cooling circuit and the reactor pool form a structural unit. They are separated from the rest of the building by a gap some 5 cm wide. Vibrations acting on the building from the outside are not transferred to the primary circuit. Any irregularities in the cooling system would result in the immediate shutdown of the reactor.



Ground plan showing the Research Neutron Source Heinz Maier-Leibnitz (FRM II) and the “Atomic Egg”.

The FRM II is a facility for the production of neutrons and as such is completely different from a nuclear power plant designed to generate electricity. The thermal power, that is to say the maximum thermal energy generated, is 20 megawatts (20 MW). A nuclear power plant produces up to 200 times as much power (4000 MW). These crucial differences in performance allow for completely different options for removing the so-called decay heat after a reactor shutdown. Just a second after the shutdown of the FRM II, the dissipated power is only about 1.2 MW while, at a nuclear power plant, it is as much as 220 MW. Therefore, following shutdown the FRM II requires neither electrical energy from an outside source nor the availability of an emergency generator in order to dissipate the decay heat.

After a reactor shutdown, three independent residual heat removal pumps are activated immediately. These are operated by a triple set of batteries and convey pool water through the core to dissipate heat. Just one would suffice to dissipate the decay heat of the reactor. After about three hours, the decay heat is so low that there is no further need of these pumps. Any residual heating of the pool water leaves through natural convection. Even in the event of a complete failure of all the cooling systems, the 700 m³ water in the reactor pool would be sufficient to remove the entire residual heat of the fuel element. The water would heat up to a maximum of 80 °C. Without any further external intervention, the natural laws always ensure the removal of the entire residual heat of the FRM II fuel element, this being a further passive safety feature.



On the fissioning of uranium in the fuel element, fission products are formed which are radioactive. The FRM II has three barriers that prevent release:

- The fuel plates ensure that the resulting fission products remain trapped in the fuel.
- Should radioactive fission products escape from the fuel element due to a serious accident, the water in the reactor pool would act as an effective barrier.
- The outer wall of the reactor building, built of reinforced concrete 1.80 m thick, forms the last and effective barrier to an uncontrolled release of radioactive materials.

These three barriers contribute to the safety concept of the FRM II, which meets the most stringent standards.

Monitoring of FRM II and its surroundings

The quality and functionality of the technical equipment and the qualifications of the personnel, guaranteed by on-going training, are permanently monitored by the nuclear licensing and supervisory authority—the Bavarian State Ministry for the Environment and Consumer Protection (StMUV). The StMUV calls upon independent experts.
Furthermore, inspectors continuously check the stock of nuclear fuel at the FRM II in order to fulfill international obligations stipulated by the European Atomic Energy Community (EURATOM) and the International Atomic Energy Agency (IAEA).

The probability of gaseous or liquid radioactive substances (emissions) being released via the expelled air (chimney) or the waste water is extremely low, especially with respect to the radiologically significant aerosols and iodine. Both the radiation protection service of the FRM II and the supervisory authority check constantly and independently that the predetermined radiological limits within the system and in the environment are observed, so that there is no danger to either people or the environment.

Measurement devices are located in the vent stack of the reactor, the reactor building and the FRM II and campus areas. All the relevant values are continuously transmitted to the Bavarian Environment Agency (Bayerisches Landesamt für Umwelt, LfU; Kernreaktorfernüberwachungssystem). In addition, the LfU operates its own monitoring network within the Bavarian nuclear facilities.

FRM II open to visitors

Anyone who is interested in learning more about the security concept and research at the FRM II is welcome to visit the facility. The FRM II is open not only to specialists, but also to the general public by appointment. In addition, once a year, usually in October, an open day is held. For reasons of safety, all visitors must carry a valid identity card or passport and pass through a security check similar to that at an airport.

A guided tour in small groups includes a visit to three areas. The reactor hall with the reactor pool and fixtures there can be viewed through a visitors' window. In addition, the tour takes in the experimental hall with its impressive instrumentation and gives an insight into the diverse applications of neutrons.

Finally, there is a view into the neutron guide hall with its very specific instruments and, in particular, the neutron guides which, analogous to light guides, convey the neutrons over greater distances to the instruments.

Interested visitor groups can obtain information from the Visitors' Service (besucherdienst@frm2.tum.de) or by calling 089.289.12147 or making initial contact via the internet:

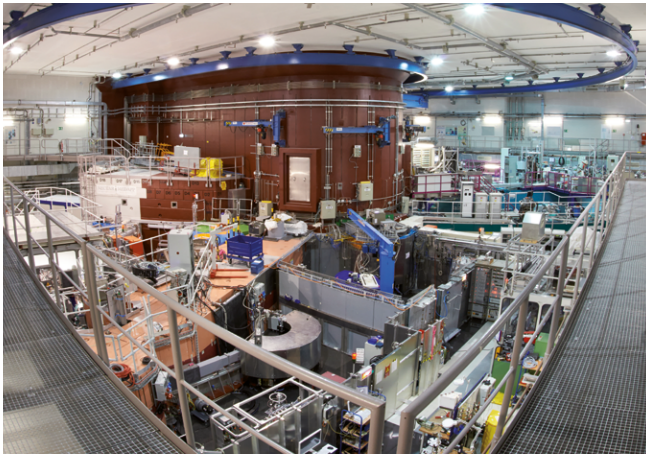
www.frm2.tum.de

Civil protection

The responsibility owed to employees, students and neighbours also requires detailed planning in the event of a disaster. Here, it is based on the hypothetical case of the most serious incident, a complete meltdown. Even in this scenario, the reactor building would offer effective radiological protection. The 1.80 metre thick outer walls of the reactor building are a reliable protection against direct radiation. Moreover, the reactor building can be rendered almost airtight. Calculations show that the filters of the ventilation systems are capable of adequately retaining the fission products even in the hypothetical event of a total meltdown. The maximum effective dose due to direct radiation and the contribution via the chimney into the residential environment would then be about 6.5 mSv (millisievert) for an adult.

The Technical University of Munich, as the operator of the neutron source, and the Municipal Office Munich, as the competent civil protection authority have, in addition to precautions for the protection of staff in the research precinct, also taken steps to protect all other persons in the vicinity.

An in-house alarm plan exists for the FRM II site in which all emergency and relief services are shown. This plan is kept up to date and also serves as a basis for civil protection exercises.



View into the experimental hall within the reactor building. In the middle of the picture the reactor pool is shown viewed from the outside.

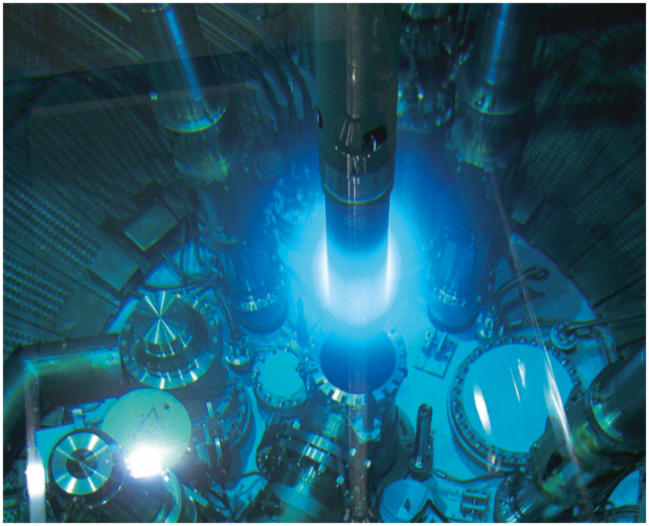
The Municipal Office Munich, has developed a special emergency plan, based on the internal alarm plan of the FRM II. In an emergency situation, this coordinates all the necessary protection and assistance for people who reside in the vicinity of the reactor site. The basis is „Basic Recommendations for Emergency in the Vicinity of Nuclear Facilities“, developed jointly by the Federal and Bavarian states. These are concretised in Bavaria by the „Guidelines for Object-related Emergency Response Plans and for Civil Protection in the Case of Nuclear Accidents“ (04/11/2015).

The civil protection authorities are prepared for the introduction of the following measures:

- Alarm signals
- Formation of a steering group for civil protection
- Organization of radiological measurements
- Alerting and informing the general public, including schools, kindergartens and similar establishments
- Traffic control
- Recommendations for dwellings and other possible measures (e.g. distribution of potassium iodide pills)
- Cooperation with the responsible authorities and bodies.

Alerting procedure

Following an incident or accident, the operator of the FRM II will immediately inform the responsible authorities and bodies according to a detailed and specified reporting scheme. The alarm and reporting channels and functionality designated for protected lines are continually checked by the police, together with the operator of the FRM II.



When the fuel element is being changed the characteristic blue Cherenkov radiation becomes visible.

Mission control

After an incident with possible impact on the environment, the Municipal Office Munich, will assume operational control and—if necessary—initiate and coordinate civil protection measures.

Organization of measurements

The LfU in Bavaria constantly undertakes measurements to monitor the vicinity of nuclear facilities. These monitoring networks are complemented by the measuring devices of the FRM II and, in the aftermath of an incident, in addition by the increased use of mobile measuring teams from the Federal Emergency Management Agency and the fire services. These field crews carry out measurements and sampling around the research site and share the results with the Bavarian State Office for the Environment, which, together with the Bavarian State Ministry for the Environment and Consumer Protection, will advise the Municipal Office Munich, and propose the necessary measures to be taken on the basis of the data.

In Germany, environmental radioactivity is continuously and comprehensively monitored by, amongst other things, automatic measuring systems. Current measurement data for Bavaria and additional information can be accessed by all citizens via the internet, e.g. at:

www.lfu.bayern.de/strahlung/kfue_messdaten

http://odlinfo.bfs.de

Informing the general public

The public will be alerted and notified in the following ways:

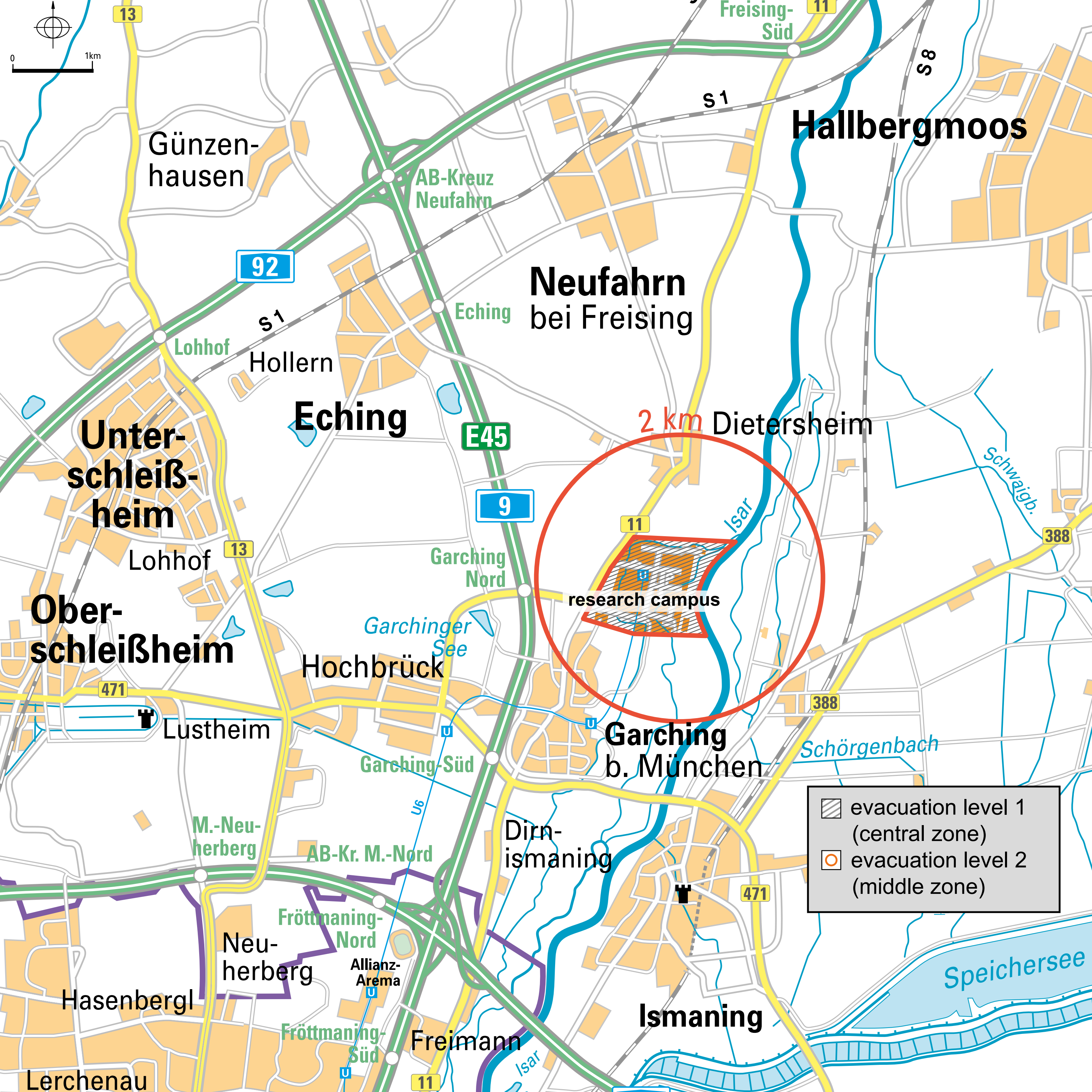
- Announcements over loudspeaker from police, firefighter and civil protection vehicles
- Information on radio, television, teletext and internet
- Warning information via smartphone app “KATWARN”.

The radio announcements will be made on the radio stations that also broadcast traffic information (e.g. Bayern 3, Antenne Bayern and some private channels). The announcements will reflect the current situation, and be sent at regular intervals. In such an event, the radio should therefore always be switched on. In addition, this information can also be received via the teletext pages of Bayerischer Rundfunk and on the website of the Municipal Office Munich:

www.landkreis-muenchen.de.

Traffic control

Traffic control will be implemented should this become necessary due to data measurement, or to allow access for assistance crews. The police and fire brigade will be deployed in this capacity. Instructions given over the radio must be followed.



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Recommendations for staying safe

In the case of an accident, the radioactive substances released would be transported mainly through the air. Since buildings provide considerable protection, the civil protection authority recommends—if necessary—staying indoors and closing doors and windows, and turning off ventilation and air conditioning units. In this way, contact with radioactive substances is largely avoided. The independent Radiological Protection Commission (SSK) recommends staying indoors from a predicted effective dose of 10 mSv through external exposure in seven days and also the subsequent dose by the inhaled radionuclides during this period. In regard to the FRM II, such measures would not be necessary in the residential area, even in the hypothetical case of a core meltdown.

Distribution and intake of iodine tablets

Radioactive iodine is one of the substances which could be released in the event of an accident at a nuclear plant. When taken up by the thyroid, radiation can be particularly harmful to the body. The timely intake of potassium iodide tablets leads to the thyroid being saturated with non-radioactive iodine, so that only a very limited amount of radioactive iodine can be taken up by the body. Iodine tablets are therefore kept at hand by the authorities in the vicinity of nuclear facilities—specifically by the Municipal Office Munich, and the affected cities and communities.

These tablets should be taken exclusively after the appropriate governmental order prompted by loudspeaker and radio announcements, as they present health risks when ingested unnecessarily or in excessive doses.

Evacuation

The Radiological Protection Commission (SSK) recommends evacuation if there is a predicted effective dose of 100 mSv through external exposure within seven days and subsequent dosing through inhaled radionuclides during this period. Such values would not arise even in the worst imaginable accident at the FRM II since the radioactivity remains securely contained within the building. Although, even in the case of a core meltdown, the maximum effective dose at the FRM II of about 6.5 mSv remains far below the legal limits, the emergency plan still envisages evacuation measures. This is in continuation of the emergency response plan for the FRM (Atomic egg), and which is continuously updated for the FRM II.

The emergency plan includes as evacuation level 1 (central zone) the whole research campus. Evacuation level 2 (middle zone) extends to a radius of 2 km around the FRM II. These areas are shown on the map on page 22/23.

The Disaster Incident Steering Group determines the exact evacuation area. All those affected will receive the necessary information via radio, loudspeaker or smartphone regarding:

- Evacuation routes
- Assembly points where people who do not have a car will be picked up
- Contact points for people who are not able to travel in a car or go to an assembly point
- Contamination controls.

Kindergartens and schools

If necessary, the Disaster Incident Steering group will provide separate and direct information to schools, kindergartens and similar facilities and ensure that children and staff remain in the facilities or, if necessary, are brought to safety. The Steering group will make sure, that the families are then reunited at the reception centers.

Cooperation with responsible authorities and bodies

If necessary, the Municipal Office Munich, will form a steering group for civil protection to coordinate, on the one hand, the deployment of assistance crews and on the other hand stay in contact with all relevant authorities and bodies. Here, it is important to emphasize cooperation with the Bavarian State Ministry for the Environment and Consumer Protection and the Bavarian State Office for the Environment.

Frequently Asked Questions

What natural radiation exposure occurs in the neighbourhood of the FRM II?

Everyone is constantly exposed to natural background radiation. This varies greatly from place to place and depends, for example, on the height above sea level. In the Munich area, the effective dose outdoors is almost 1 mSv/year (= 1,000 µSv/ year), as a result of the height and the ground radiation. On top of this, natural radioactive materials must be taken into account, and especially through the inhalation of radon and its radioactive decay products, so that the average overall radiation exposure is about 2.1 mSv/year (= 2,100 µSv year) in the Munich area.

What is the effective dose that people around the FRM II additionally receive via the air expelled as a result of the operational delivery of radionuclides?

As required by law, independent consultants calculated this as part of the approval process for a fictitious „reference person“ who spent 24 hours a day for 356 days at the perimeter fence of the FRM II and ate only products grown there. This dose is less than one hundredth of the natural radiation exposure (see above). At full utilization of the authorized values for the discharge of radioactive materials at the FRM II, the effective dose for an adult reference person is only 18 µSv/year.

Operational experience to date has shown that, from the first production of neutrons at the FRM II in March 2004 until the end of 2015, even calculations of radiation exposure based on the real output values of radioactive material are still far below the hypothetical estimates for this „reference person“. For the adult „reference person“, the effective dose was about 0.4 µSv/year on average, for a toddler about 0.7 µSv/year on average. In addition, neither a real adult, nor certainly an infant, would stay permanently in the immediate vicinity of the fence and eat food grown there.

For the inhabited area closest to the FRM II, the doses do not exceed a tenth of these values, that is to say for adults a maximum of 0.05 µSv/year and for a toddler a maximum of 0.08 µSv/year.

What dose results from the release of radioactivity into the Isar?

Radiochemistry and the FRM II at the Technical University of Munich in Garching between them release so little radioactivity via the brook that, even at the point of maximum activity, namely the point where it flows into the Isar, it is throughout the year of the order of parts per thousand, which is less than one thousandth of the natural radioactivity that occurs in the river.

Also, for the release of low-level radioactive waste water from the FRM II, during the course of the approval process, a consultant calculated the maximum effective dose for a fictional „reference person“ on the basis of the discharge of wastewater from the FRM II at full use of the authorized values. A very conservative estimate for an adult reference person is 3.2 µSv/year.

The actual radioactivity released as a result of operation to date amounts to far less than one hundredth of this value.

A conservative calculation in accord with legal regulations resulting from the actual amount of wastewater from the FRM II for an adult „reference person“ results in a maximal dose of less than 0.12 µSv/year in the vicinity of the discharge point. For a toddler, purely mathematically, it results in about 0.06 µSv/year, although it is necessary to state that here the dominant, but legally required, so-called „breast milk path“ does not apply at all.

Conclusion

The statutory stipulated evaluated safe limit for the annual dose of the population due to the discharge of radioactive material via exhaust air or waste water from a facility handling radioactive materials are each laid down as 300 microsievert / year respectively.

The conservative doses calculated based on actual releases—both for adults and for young children—due to the emissions of the FRM II to waste water and exhaust air amounted to about one-thousandth of the legal limits.

The dose that both adults and infants are subjected to is therefore so minimal as to be negligible. Additional doses are well within the fluctuation range of natural background radiation, to which every adult or infant is in any case exposed.

The results of the annual calculations of radiation exposure of the population in the vicinity of the FRM II, determined by the LfU, are published on the internet:

www.lfu.bayern.de/strahlung.

Technical terms and their meaning

In this brochure or other articles dealing with radiation protection and the effect of radioactivity on people and the environment, terms that always occur are explained below:

Aerosols
smallest airborne particles (e.g. dust).

Activity
The number of atomic nuclei that decay in a radioactive substance per second. The unit of activity is the becquerel (Bq). If the activity is in relation to other variables such as the mass, volume or space, we speak of specific activity, activity concentration or surface activity respectively.

Alpha (α-) radiation
Ionizing particle radiation, which occurs in radioactive decay (alpha decay). The decaying nucleus emits a helium nucleus (He atom without its electron shell). α-radiation can for the most part be shielded by a sheet of paper.

Atom
The smallest particle of a chemical element. Atoms have a core which consists of protons and neutrons, as well as a shell of electrons. The core is 10 000 to 100 000 times smaller than the atomic diameter.

Becquerel (Bq)
Unit of the activity. The activity 1 Bq occurs when one nucleus per second decays.

Beta (β-) radiation
Ionizing radiation, which occurs through radioactive decay (beta decay): Emission of electrons (β-) or positrons (β+). β-radiation can for the most part be shielded by a few millimetres of plastic (e.g. plexiglass).

Cherenkov radiation
Deep blue light which can be observed in the water in the immediate vicinity of the core element. It is caused by high-energy electrons passing through the water at a speed higher than that of the light.

Contamination
Undesired contamination of objects, people or the environment by certain substances, e.g., by radioactive substances (→ decontamination).

Contamination monitor
A measuring device which detects and displays contamination by radioactive substances of persons and objects.

Decontamination
Elimination or reduction of superficial radioactive contamination, in the simplest case by washing.

Dose
Measurement for a further and hereinafter defined radiation effect on materials (see, e.g. equivalent dose).

Dose, effective
Short for effective → dose equivalent. Account is taken of the fact that the various organs of the human body react with different sensitivity to radioactive radiation.

Dose equivalent
A measure by which the biological effect of radiation on human beings is described. The unit of equivalent dose is the sievert (Sv). Small doses are often indicated in thousandths of sievert (millisievert, mSv) or in millionths of sievert (microsievert, μSv). → Ionizing radiation can damage biological tissue by destroying or changing cells. The degree of damage depends on the type and amount of radiation absorbed. When specifying the equivalent dose, the different biological effectiveness of various types of radiation (alpha, beta, gamma radiation or neutron radiation) is considered.

Dose rate
Radiation dose per unit time. The unit of the equivalent dose is given in Sievert per hour (Sv/h).

Emission
Delivery of gaseous, liquid or solid substances into the atmosphere or into water.

Exhaust air
At nuclear facilities, this is the name given to the filtered air discharged through the exhaust air stack.

Exposure
The process which exposes people or objects to radioactive radiation. It is necessary to distinguish between external and internal exposure. People who are in the vicinity of a radiation source are exposed to an external exposure. By contrast, internal exposure occurs when radioactive substances have been absorbed by the body (→ incorporation).

Fission products, radioactive
Radionuclides that result from the fission of nuclear fuel. Major degradation products are strontium-90, iodine-131 and caesium-137.

Gamma (γ-) radiation
High-energy electromagnetic radiation that is emitted from an atomic nucleus. γ-radiation can be efficiently shielded only by high density materials such as lead. Depending on the energy, for example, anything from a few mm to 10 cm of lead are needed.

Half-life
The length of time in which the initial amount of a radionuclide, and thus its activity, is reduced by a half. The half-life is characteristic for each radionuclide.

Half-life, biological
The length of time in which the initial amount of radionuclides absorbed by the body diminishes by a half through natural elimination.

Half-life, effective
The length of time in which the amount of a radionuclide in the human body decreases by a half through the interaction of radioactive decay and biological elimination.

Immission
Effects of radioactive substances on human beings, animals and vegetation.

Incorporation
The inclusion of certain products, for example, radioactive substances in the body. The main incorporation paths are breathing in (inhalation) or swallowing (ingestion).

Isotopes
Atoms of an element, which differ in the number of neutrons in the nucleus. The chemical properties of all isotopes of a given element are identical (→ nuclide).

Natural convection
Circulation of water in the reactor pool by thermally induced different densities (hot water rises to the top).

Nuclide
A type of atom which is determined by a certain number of protons and neutrons and a particular energy level
(→isotope).

Radioactivity
The property of certain atoms to transform into other nuclei (to decay) without any external influence, and in the process emit a characteristic, high-energy radiation. The resulting atom may be stable or radioactive.

Radionuclides, radioisotope
Unstable → nuclides , isotopes that decay spontaneously by radiation emission.

Radiopharmaceutical
Drugs whose impact is based on the radiation of a radioisotope. Radiopharmaceuticals are used for both diagnosis and therapy.

Redundancy
Multiple presence of systems in which the function of a single one is already sufficient for the fulfillment of the task.

Radiation damage, acute
A disease caused by a high dose of → ionizing radiation that occurs within a short time after exposure. The severity of acute radiation damage depends on the dose. However, there is a threshold dose below which no acute health effects occur.

Radiation damage, stochastic
Late health effects induced by ionizing radiation, which may manifest itself as genetic damage or cancer even years after exposure. In stochastic radiation damage, it is not the severity of the disease, but rather the probability of occurrence, that depends on the dose.

Radiation, ionizing
Collective term for all types of radiation, which may build charged atomic and molecular components (ions). During radioactive decay, ionizing radiation is emitted by atomic nuclei, whose nature and energy is characteristic of the radionuclide. One differentiates between alpha (α-) radiation from helium nuclei, beta (β-) radiation of negatively charged electrons or positively charged positrons and electromagnetic gamma (γ-) radiation. The γ-radiation generally occurs as a side effect of α-radiation and β- radiation.

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