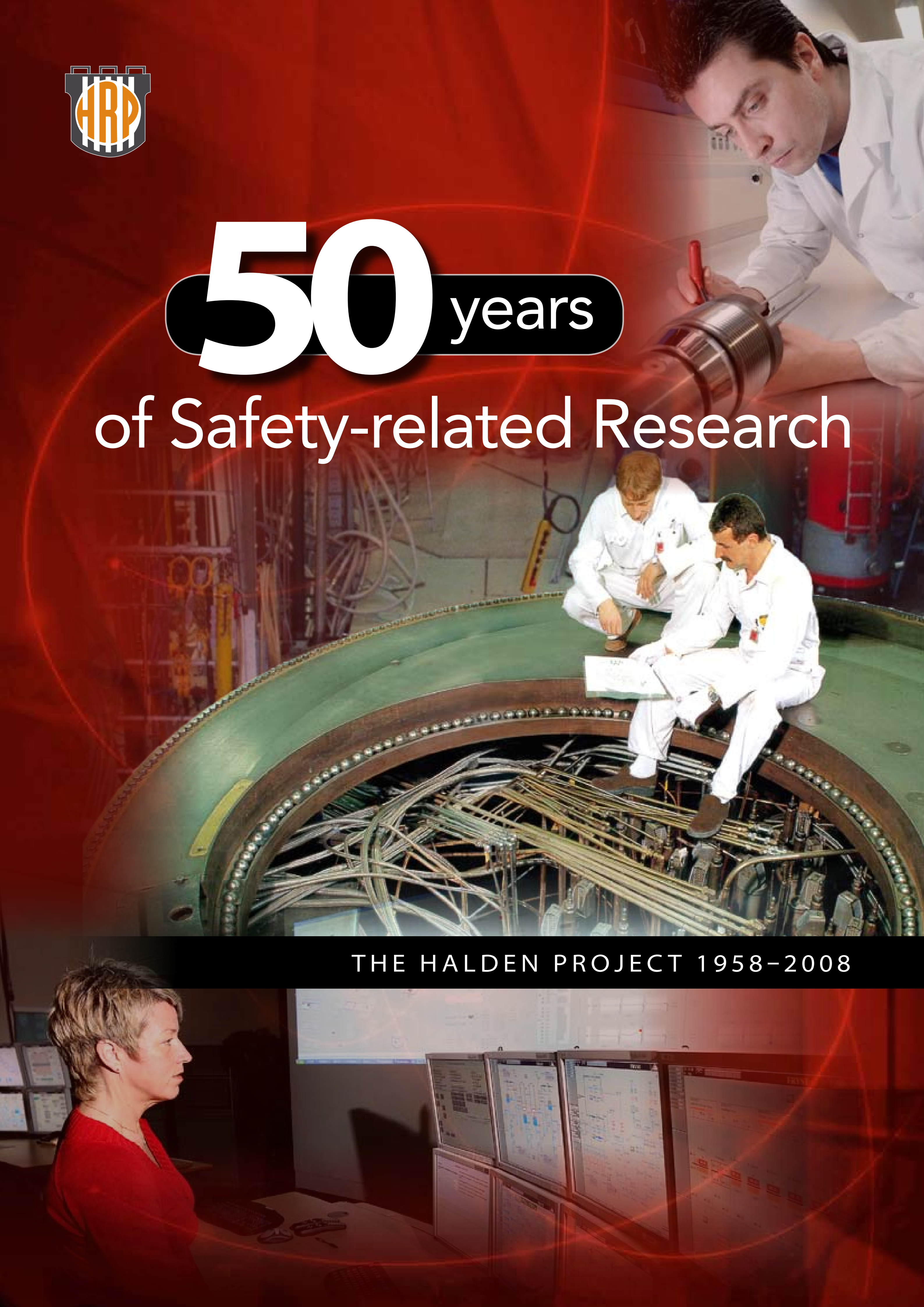


50 years of Safety-related Research

THE HALDEN PROJECT 1958–2008

Foto utlånt av Norske Skog Saugbrugs

The entrance to the Halden Reactor

The founding of the Halden Project

BACKGROUND

In the 1950s there was worldwide optimism for using nuclear power as the energy source of the future. This enthusiasm for the peaceful use of nuclear energy was particularly inspired by President Eisenhower's 'Atoms for Peace' speech at the UN general assembly in December 1953.

IFA, the Institute for Atomic Energy, (now Institute for Energy Technology) was a child of this time. It was established in 1948 with an aim to develop and build research reactors in Norway. Norway had an excellent basis for development of the new form of energy. As early as 1951, IFA had, in co-operation with the Netherlands, started up the research reactor JEEP, at Kjeller. IFA had access to heavy water and the Netherlands provided the uranium for this joint venture. Only Canada and the four super-powers – the USA, the Soviet Union, the UK and France – had made an earlier start in the field. The research co-operation between IFA and the Netherlands included an intention to build a new and larger research reactor in the Netherlands. However, this plan was abandoned, essentially as a result of changes in American policy, which allowed research reactors to be bought from the USA. Instead of starting up a new joint reactor project with Norway, the Netherlands then chose to enter into a co-operation with the USA to build a research reactor.

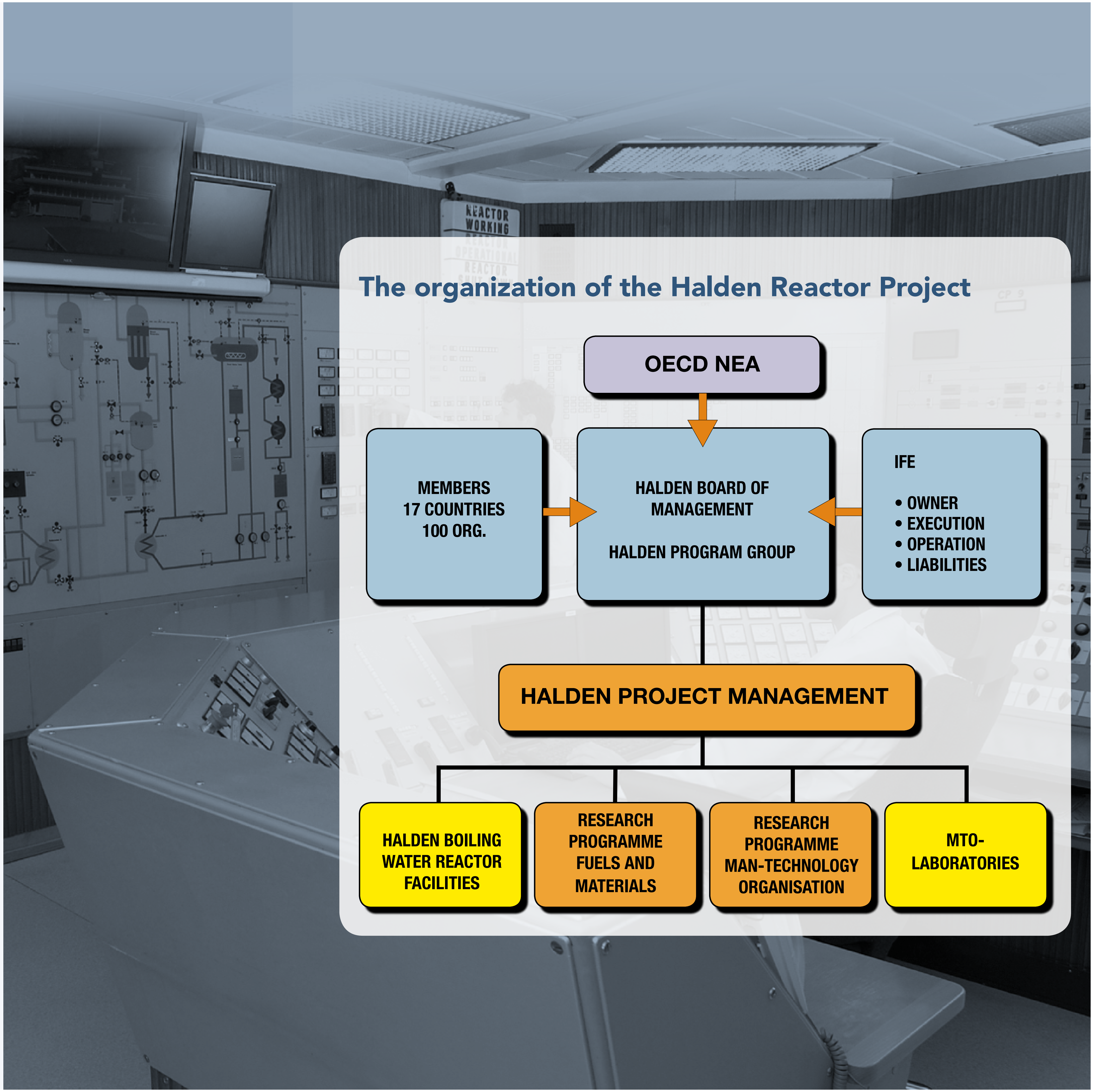
In 1955, IFA therefore started a purely national reactor scheme with the design and construction of the Halden Reactor. Halden was chosen because the company Saugbrugsforeningen provided a site for the reactor in the mountain neighbouring its factory, on the condition that the steam which was generated by the reactor was delivered to Saugbrugs paper factory.

The aim of the project was to obtain experience in construction and operation of a power-producing test reactor. This was to be the first step towards the principal aim of introducing nuclear power plants to Norway and establishing a Norwegian nuclear power industry.
The positive attitude toward nuclear power research in Norway at the time is illustrated by the fact that it took only 10 months from when the plan for the Halden Reactor was submitted to the Ministry for Industry to there being a resolution in Parliament.

THE HALDEN PROJECT

In 1956, the council of the OEEC (now OECD) decided to investigate the possibility of joint research projects in the area of nuclear power. In the following year, IFA proposed the use of the Halden Reactor for a joint research project spanning three years. In June 1958, one year before the reactor began operation, the agreement that established the Halden Project as an international research project was signed. The Halden Project was a reality and this first three-year agreement between Norway and 11 other countries became a leading example for international atomic research co-operation. Two other international projects were initiated by the OEEC around the same time: the European Chemical Project for uranium separation in Belgium and the Dragon Project for the development of graphite reactors in the UK. These projects have long since been terminated.

The original aim of the Halden Project was to pursue reactor technology research associated with the boiling heavy water reactor with a view to power production. The focus areas of research have of course varied over the years. However, throughout its 50-year history, the Project has been working at the forefront of research within the areas of reactor fuel and materials testing, and the development of computer based systems for surveillance and control. Both are specialist fields crucial to reactor safety.



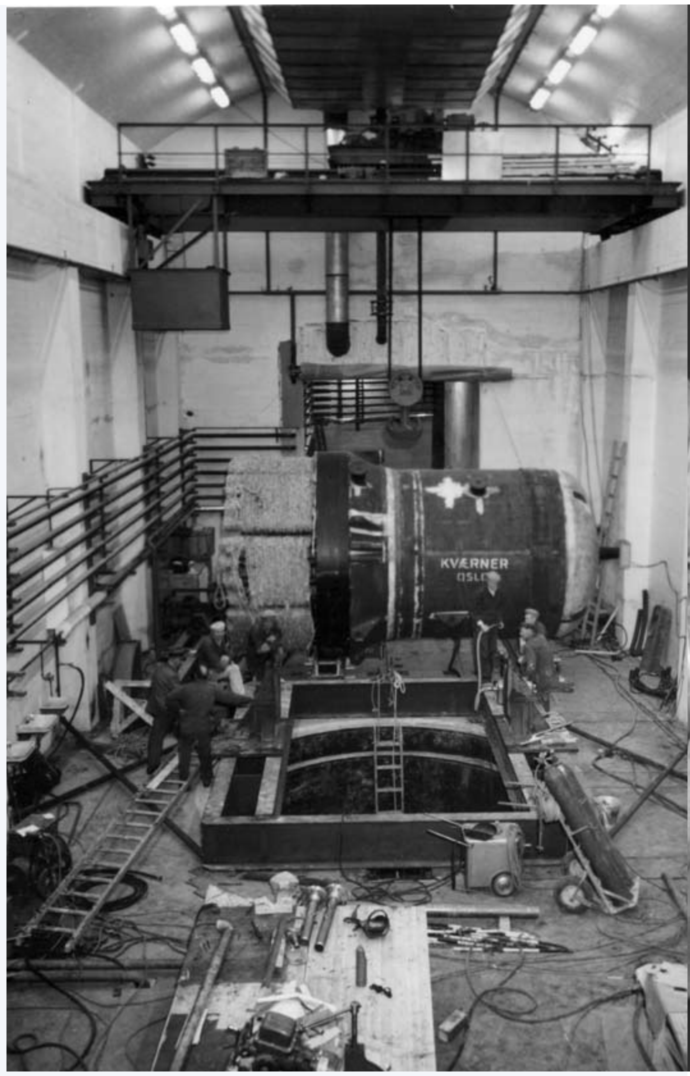
ORGANISATION OF THE HALDEN PROJECT

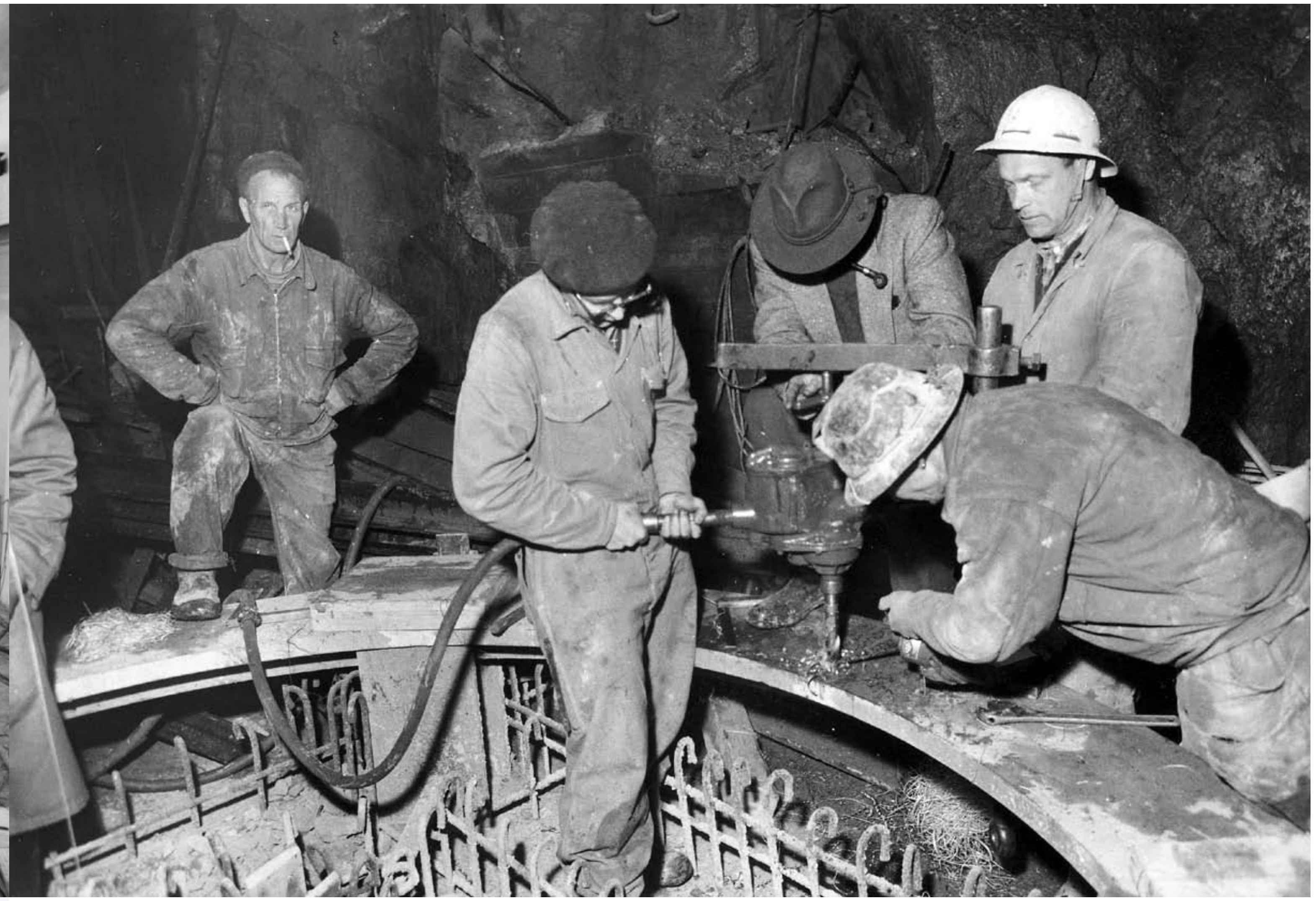
The first international agreement on research co-operation at the Halden Reactor was endorsed when the Halden Project was established in 1958. This agreement has been renewed for successive three-year periods and applies today for the period 2006–2008.

The agreement commits members of the Project to support the three-year research program with an economic contribution, in addition to providing personnel and technical information. The members can then influence the economic and technical direction of the Project's program by participation in joint committees and by sending their own personnel to participate in the Project. They also then have the right to use the results of the research for their own purposes.

The Institute for Energy Technology (IFE) administrates and executes the agreed research program. As the owner of the reactor, IFE has the sole responsibility for all issues regarding the safe operation of the reactor. All tools and equipment purchased by the jointly financed research program belong to IFE, and IFE has a right of veto in issues regarding the future use of the reactor plant The Halden agreement also gives members the right to engage IFE's staff, together with the Halden reactor and the rest of the infrastructure, for research assignments of particular interest for the individual member. This has increased the diversity of the research which is conducted and has thus been a major factor in the success of the Halden Reactor. .

The agreed three-year programs are implemented under the supervision of two committees comprising of members from all participating countries. The technical committee evaluates results and progress and assists the Project staff with preparing the annual programs and new three-year programs. The Halden Project's international board has the paramount responsibility for finances and research strategy and is particularly concerned with ensuring that each program focuses on the relevant problems for its time. In addition, the board makes preparations for contracting of the new three-year agreements. OECD/NEA (Nuclear Energy Agency)





The reactor hall in the construction phase.

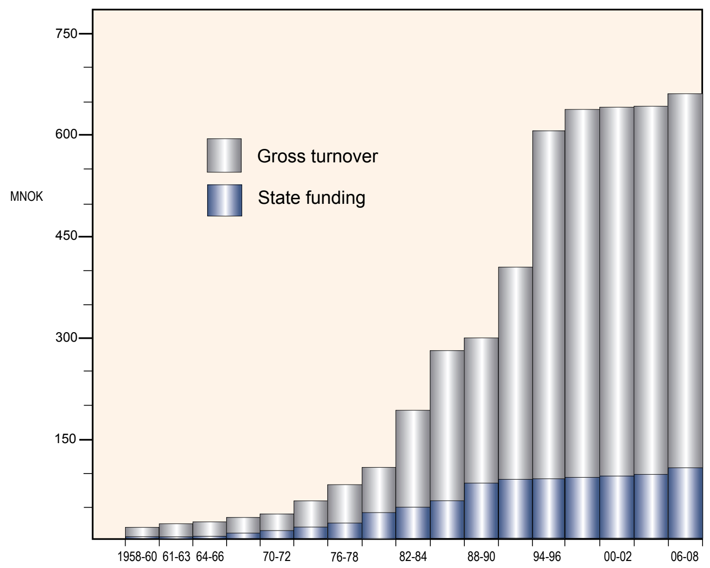
represents the international umbrella organisation in the Halden Project and holds the secretarial function in the international board.

The arrangement with two steering committees, with annual rotation of the chair, has proven to be entirely positive for the Halden Project. Critical and constructive input from these bodies has been decisive for the Project's development. The overriding goal has been to agree upon research activities of common interest.

THE MEMBERS OF THE HALDEN REACTOR PROJECT

For the first few years of the Project's life, the membership was dominated by national research institutions without access to other reactors. The Halden Project consequently was used for education and competence-building. Later, the reactor began to be used for quality assurance of tools and methods, in close cooperation with the supplier industry sector. Safety organizations, such as USA's Nuclear Regulatory Commission (NRC) were early participants, closely followed by power station operators and reactor vendors. The Halden Project has therefore been a neutral meeting point where all parts of the nuclear industry can exchange experiences, build common databases, get to know developing trends, and discuss safety-related issues.

Though there has been membership turnover throughout the Project's history, the number of members has always been high. From 1958 to 2008, organizations from altogether 24 countries have been members, and the membership in 2008 comprises 130 organizations in 17 countries. In addition to simple economic support, some organizations send visiting research scientists, who actively take part in the Project's work. Altogether, the Halden Project has had 388 visiting research scientists, all of whom have quickly become an integrated part of the Project staff. In 1958, the total number of employees was under 40, but by early the next year the number had already increased to around 60. In 2008, the Halden Project has approximately 270 employees.



Development of the budget in the period 1958–2008

Total turnover in the period: 4.7 billions Norwegian Kr. Norwegian governmental grants in this period: 890 millions Norwegian Kr.

THE HALDEN REACTOR

From the official opening of the Halden Reactor on the 10th of October 1959. From the left: The Director of the Institute, Gunnar Randers, H.M. King Olav V, main designer of the reactor, Director Odd Dahl and the king's ADC Colonel Arne Haugli.

During the planning of a power-producing research reactor, IFA considered several reactor types. The final choice was a boiling heavy water reactor with a maximum operating pressure of 40 bar and steam temperature of 250 °C. Heavy water made it possible to use natural uranium as fuel. A reactor with ordinary water (light water) requires enriched uranium, which was not available to Norway in 1958. The heavy water was produced by the company Norsk Hydro at Rjukan in Telemark.

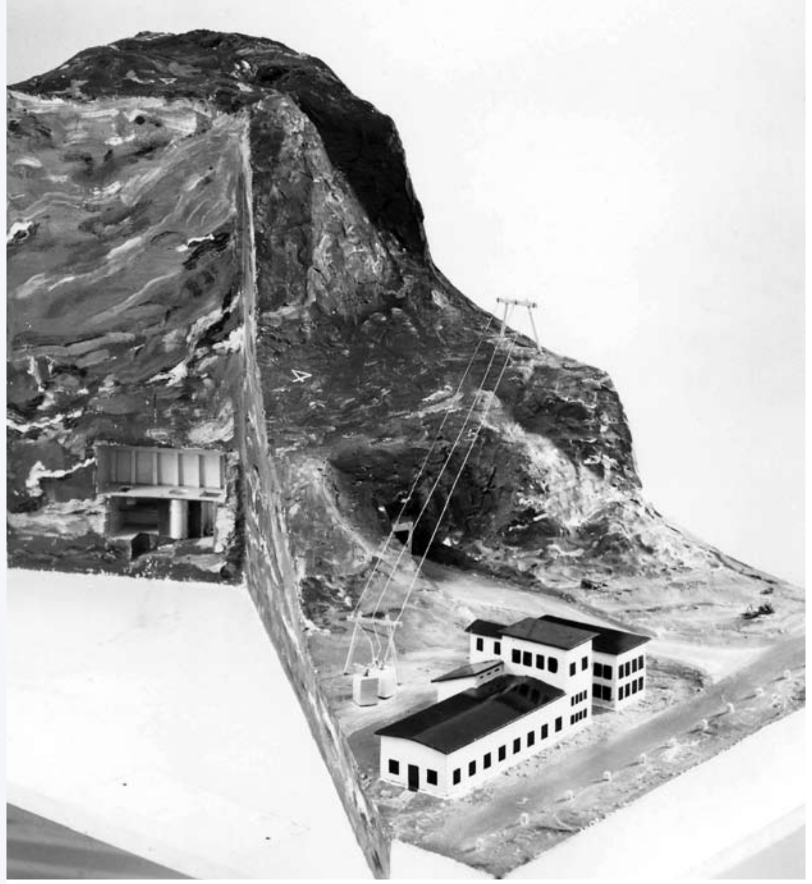
As soon as parliament had consented in 1956 and allocated funding, excavation of the reactor hall started in the hillside close to the paper factory in Halden. The building of the reactor plant was to be done as far as possible by Norwegian industry. The facility was planned and built by IFA, Kjeller. The main contractors were the Kværner-Myhren-Thune group for mechanical components, including the reactor vessel itself; Chr. Michelsens Institutt (a research institute) for control and instrumentation; and Høyer Ellefsen for civil engineering in connection with excavation of the reactor hall.

The volume of the reactor hall is 4500 m^3, and the hall is covered by 50 meters of rock. Access to the hall is through a 50 meter-long tunnel. The tunnel is supplied with an air lock of concrete walls and steel doors.

Start-up of the reactor took place on June 29, 1959. The official opening was held on October 10 of the same year in the presence of HRH King Olav.

THE REACTOR VESSEL

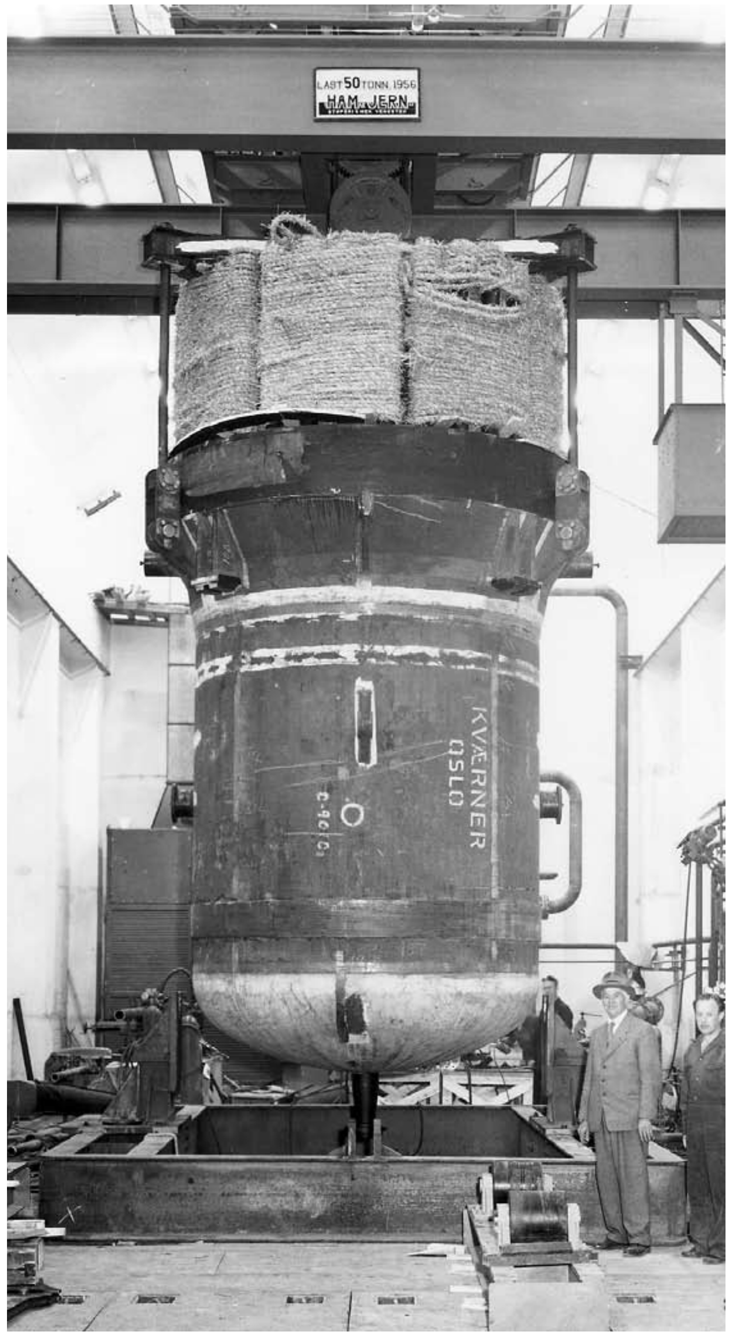
The reactor pressure vessel was the subject of special attention. The vessel is a simple cylindrical steel tank with soft, ductile steel walls and a stainless steel liner. A flat lid was chosen, with a penetration for each fuel element and control rod, a design that later proved to be invaluable because of the great flexibility it allows for experimental work.



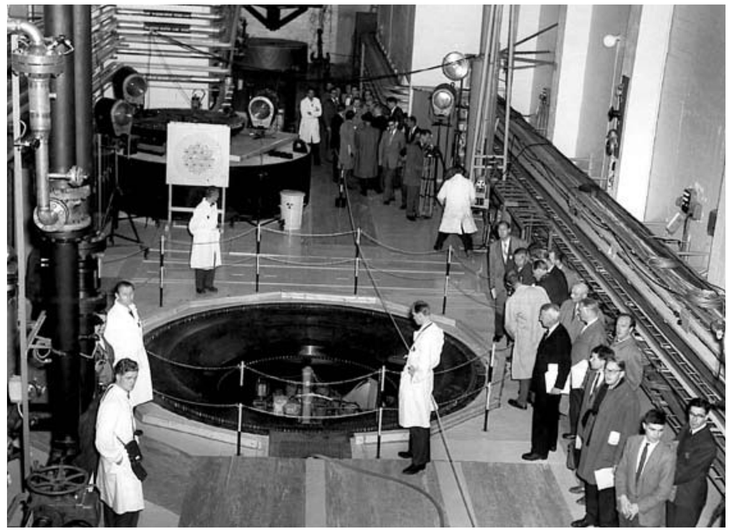
Model showing the reactor hall inside the mountain.

The reactor vessel was built in accordance with Norwegian regulations for steam pressure vessels. One special characteristic of reactor pressure vessels is that, over time, neutron radiation reduces the ductility of the steel. This effect was known from the start of operation, and a large number of materials tests were made on the pressure vessel steel.
In addition to the initial steel tests, specimens were installed in the reactor to allow later investigation of the effects of irradiation. Such follow-up tests have continued through the whole period of operations, and analyses of these steel specimens are done by laboratories in other countries in accordance with international regulations. The results of testing show that there are no limitations to the use of the reactor pressure vessel in the foreseeable future.

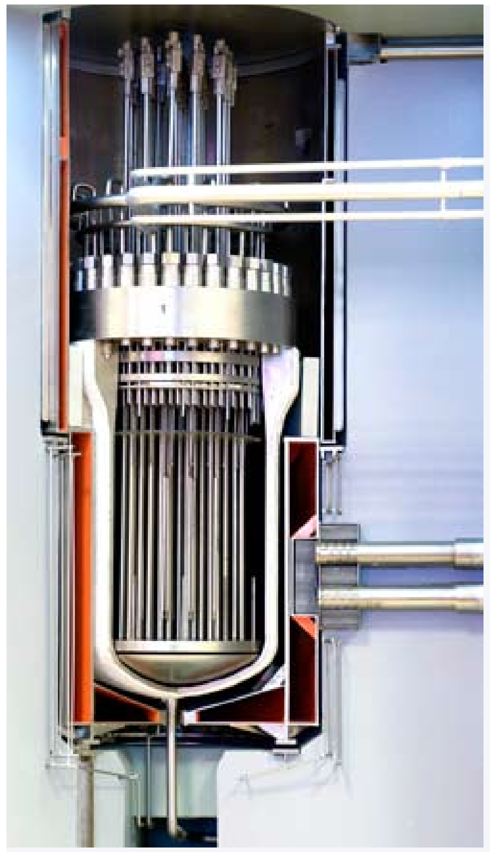
In 1976, the Norwegian authorities required that the pressure vessel's welded seams be checked afresh. This was satisfactorily carried out in cooperation with DNV (Det norske Veritas consulting firm). Such inspections are done regularly, along with pressure tests of the reactor vessel and steam circuits.
Large parts of the rest of the reactor plant have been renewed, and the whole facility is maintained in accordance with requirements from licensing authorities.

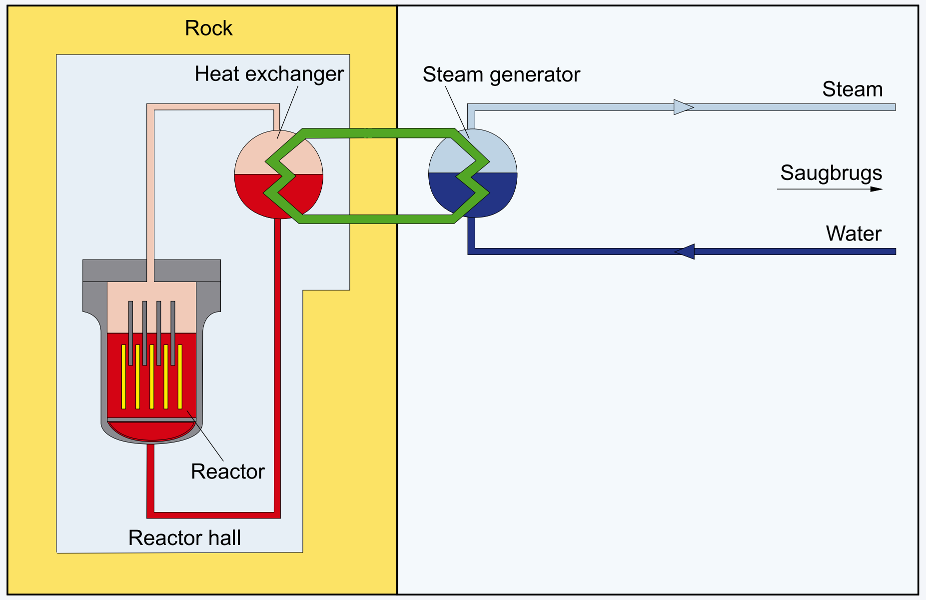


From the installation of the reactor vessel.



Visit in the reactor hall.





Model of the reactor vessel (left) and schematic of the three water/steam cooling circuits.

REACTOR OPERATION

The main reactor plant comprises of three water/steam circuits. The cooling medium in the reactor vessel is heavy water, which circulates in a closed circuit within the containment. The energy from the heated heavy water is transferred by steam transformers to a second, closed circuit containing light water. The pipes transporting the steam in the second circuit pass out of the containment, transferring the heat to a third, light water circuit which in turn delivers steam to the neighbouring paper factory. Steam is only produced when the reactor is in operation, and hence delivery of steam to the paper factory is regulated by the international research program. The factory has received steam from the Halden reactor on a regular basis since 1964.

The first fuel core of the Halden reactor comprised of seven tons of natural uranium. A maximum energy production of 5 MW and a steam temperature of 150 °C were achieved. The research performed during the initial reactor operating cycles focused mainly on reactor physics, water chemistry and the effects of radiation. After the first fuel was taken out in 1960, modifications were done to allow an operating pressure of 28 bars. The second loading of the reactor core comprised of 1.5% enriched uranium dioxide fuel rods.

Inspection of the fuel.

Since 1967, the reactor has operated at a pressure of 33 bars with a corresponding steam temperature of 240 °C. In the course of the 1970s and 1980s, the experimental installations in the reactor became increasingly more complex. Experimental installations now include a large number of fuel elements equipped with a variety of highly sophisticated instruments, and a number of high-pressure flasks

The reactor hall.

with separate cooling circuits, some using heavy water, others using light water. An operating pressure of up to 150 bars in these high-pressure loops posed new challenges regarding leak tightness. Increasing demands on cooling water quality lead to the installation of new water purification systems and a laboratory for quality control. The increasing complexity of the research program also made it necessary to extend the experimental control room.

FUEL HANDLING

Non-irradiated nuclear fuel can be handled safely without shielding. Whilst in the reactor, however, radioactive elements are produced in the fuel rods. Special lead containers that shield the environment from the strong radiation fields are used to remove and transport irradiated fuel. All handling of spent fuel is regulated by strict procedures. When fuel is unloaded from the reactor, it is transferred to storage ponds within the containment. After a period of decay of the radioactive elements, the fuel can be transferred to an adjacent storage building. Experimental fuel is shipped either to Kjeller or to a laboratory abroad for further examination and analysis as a part of the research program.

RADIATION PROTECTION AND REACTOR SAFETY

The radiation protection department, in cooperation with the operational management, ensures that IFE complies with all laws and regulations regarding radiation doses and radioactive emissions. Radiation protection personnel participate in planning and installation of experimental systems, and in the continuous surveillance and monitoring of the reactor plant with an aim to limiting radiation doses to personnel and radioactive emissions from the plant to as low as reasonably achievable.
The Norwegian Radiation Protection Authority (NRPA) is the principle regulatory authority.
In addition, the IAEA inspects IFE's fuel storage facilities in accordance with the international Non-Proliferation Treaty. Emergency preparedness exercises are carried out at regular intervals, in cooperation with local, regional and central crisis management, including NRPA and the local police.
The Directorate for Civil Protection and Emergency Planning is the regulatory authority for pressurized equipment and electrical installations at the plant.

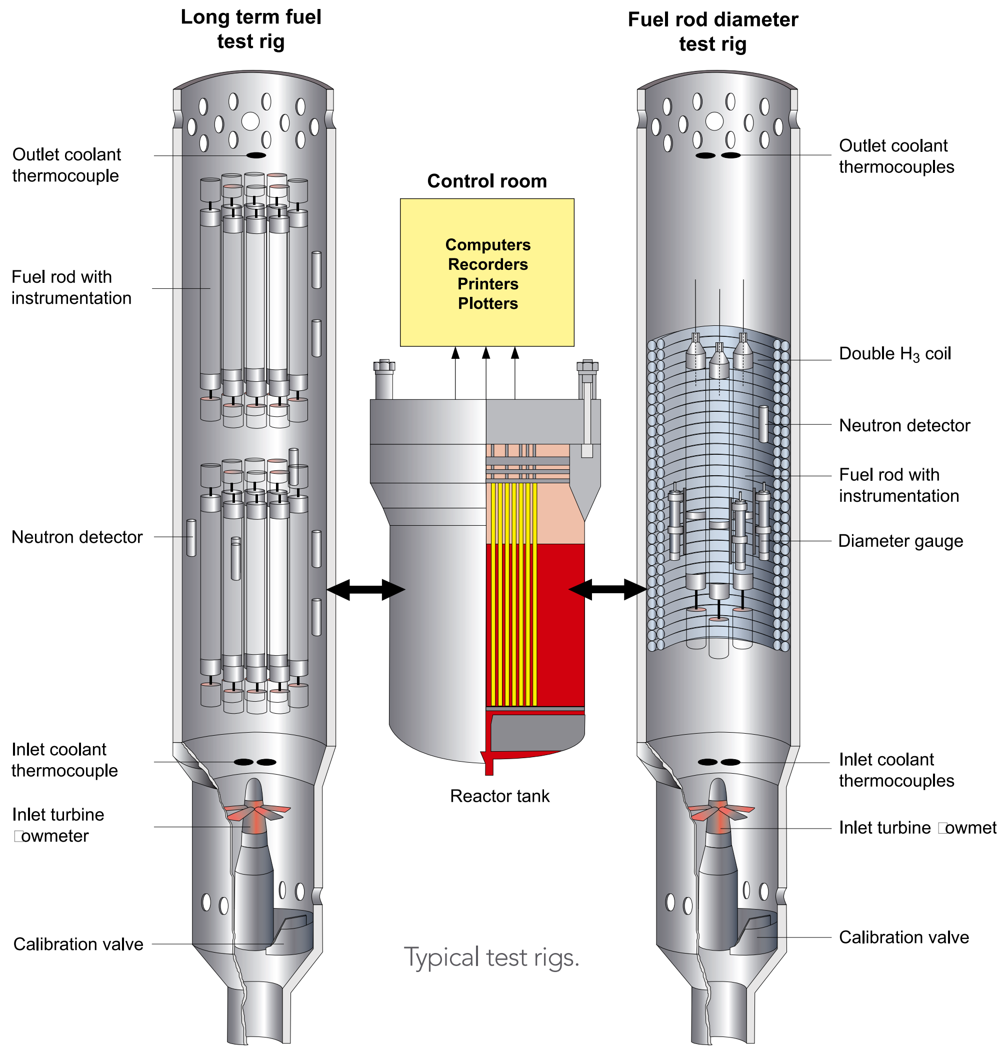
Control and supervision of the Halden reactor is performed from this control room. Also the experimental rigs are monitored from this room. In the mimic display on the backpanel vital process information from the reactor and the cooling circuits is presented in an intuitive way such that the operators get a good overview of the current plant situation. Detailed information and historical trends may on request be displayed on the computer screen on the control desk.

LICENCE FOR OPERATION

Licences for operation of the reactor are granted for periods of nine years. IFE has applied for a renewal of the licence to cover operation during the period 2009–2018.
In June 2007, the NRPA engaged an international team of experts from the IAEA to perform an evaluation of safety at the Halden reactor. The main conclusion from their evaluation was that 'from a safety point of view, the team considers at present, that there is no major problem which may constitute a hold point against the continuation of the HBWR operation'.

Already early in its history, the Halden Project started to develop its own precision instruments for internal use in the experiments. The construction of an experimental rig, anno 2008, is shown in the picture.

Advanced computer based equipments are used to make instrument components with accuracy within micro-meters.



Typical test rigs.

THE PIONEER AGE (1958–1968)

The countries participating in the Halden Project saw nuclear power as the energy source of the future, and the research performed in the Halden reactor was a means of building up competence in the area with a view to building commercial plants. The Norwegian attitude towards the Halden Project was also positive. The goal of the Institute for Atomic Energy was to conduct research that would make nuclear power in Norway possible, and the Halden Project played a key role in this work. With newly developed instrumentation, it was possible to study the physics parameters and dynamic properties of boiling water reactors, as well as to assess fuel performance under various operating conditions.

When the second core loading, with enriched uranium, was loaded into the reactor in 1962, reactor pressure and power could be increased. As a result, a wide range of studies could be performed under conditions that closely simulated those found in commercial plants and international interest increased.

Towards the end of the first ten-year period, it became clear that the advantages of the Halden reactor lay in its versatility and the ability to

RESEARCH HISTORY

conduct many experiments simultaneously. The unique instrumentation that was developed and produced in Halden ensured continued interest in the Project. The emphasis of the fuel research shifted from fundamental physics experiments to fuel performance studies addressing reactor licensing and safety related issues. From the start of the three-year programme in 1967 research focused on two areas which remain key activities to this day, namely the fuel and materials testing program and process supervision and control systems. The latter was the precursor to today's Man, Technology, Organisation (MTO) program.

CHANGING TIMES (1968–1980)

During the first few years of this period, plans to build nuclear power plants in Norway gained impetus. In 1972–73 NVE, in accordance with instructions from Parliament, identified potential sites for the first plant. IFA, in anticipation of substantial assignments, founded the company Scandpower (ScP) in 1971. ScP, with divisions at Kjeller and Halden, had close to 50 employees (recruited primarily from IFA) and was planned to act as the main consultant for the buyers when the first nuclear power plant was built.

Two things then occurred which gradually changed the political opinion on nuclear power in Norway. An increasing opposition to the nuclear power plans, both locally and on a national level, lead to the nation-wide Action against Nuclear Power in 1974. Even more significant was the discovery of oil in the North Sea. The oil reserves meant that future electricity demands could be covered by oil- or gas-fired plants.

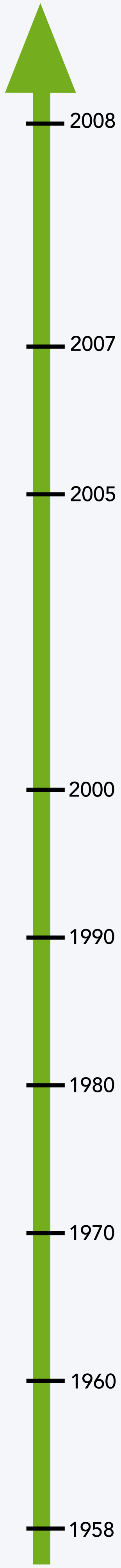
In 1975 the decision to introduce nuclear power in Norway was postponed and Parliament requested the Government to appoint a committee to evaluate the safety of nuclear power. The so-called Granli Committee delivered their report in 1978. Although the conclusion was positive, plans for nuclear power in Norway came to an end. Oil was about to become Norway's most important export commodity. After the Three-Mile Island accident in Harrisburg, USA in 1979, opposition increased and it was clear from the 1979 Parliamentary white paper on energy issues that nuclear power would not be an option for Norway in the foreseeable future.

The founding of the program on process control led to collaboration with Norwegian industry in the following ten years. Partnerships with Norsk Data and Kongsberg Våpenfabrikk were of particular importance and the Halden Project became a key development partner for these companies. The Project participated in the development and installation of Kongsberg Våpenfabrikk's control room systems at the Stafjord A oil/gas production platform in the North Sea, and products developed in Halden were, in collaboration with Norsk Data, installed in a number of Norwegian process and energy companies and Swedish nuclear power plants. A number of these contracts were handled by ScP who needed to target other industries when plans to develop the Norwegian nuclear industry were shelved.

In the mid-70s the Halden Project also played a part in the outcome of an important socio-political issue, namely the decision that the Østfold University College would be localised in Halden. The proximity of the research environment provided by the Halden Project was one of the key factors influencing this decision. The international interest in the Halden Project was stable throughout the period. The continuous advances in the development of new test equipment and instrumentation, including local power control systems, led to an increasing diversity in the types of experiments that could be performed in the reactor, for example, evaluation of the effects of power and temperature transients on fuel performance. In the 1970s the number of instrumented fuel assemblies increased to about 40, while between 1970 and 1980 the number of signals being logged at the reactor increased from ~500 to ~1000. In the area of process control, an operator process communication system, utilising computer based devices and colour TV screens, was developed for the Halden reactor. Modified versions of the system were subsequently installed in several Swedish nuclear power plants.

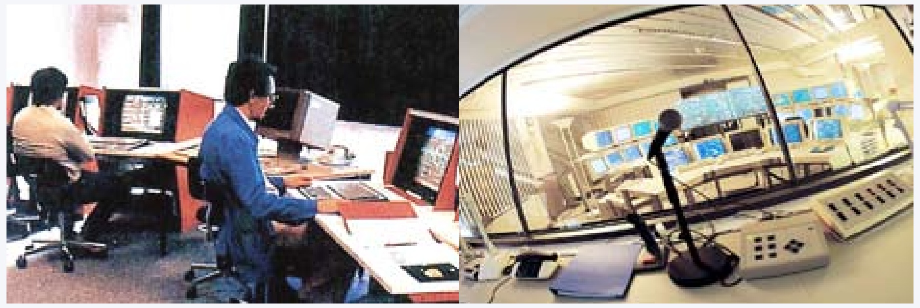
The control room of the Statfjord A oil production platform where the Halden Project designed the colour-graphic systems and the control desk.

THE DIFFERENT HISTORICAL PHASES OF THE RESEARCH ACTIVITIES IN THE MTO-AREA



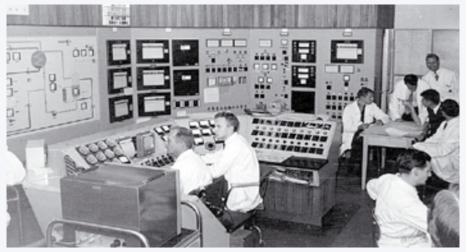
The development of integrated operation concepts for the Norwegian oil industry.

Virtual Reality (VR) technology taken into use.



The Halden Man-Machine Laboratory (HAMMLAB).

Research on computer-based control rooms.



The control room of the Halden reactor.

Halden Man-Machine Laboratory, Os Allé 7, anno 2008.

CONSOLIDATION PERIOD (1980–1990)

Parliament's White Paper on Energy Issues in 1979 stated that nuclear power reactors would not be installed in Norway for the foreseeable future. This was the primary reason that the Institute in 1980 was given new statutes and a new name (The Institute for Energy Technology, IFE). For Kjeller this implied a change of focus to a broader energy based research.

However, there was still considerable interest and financial support from the international community for the research being conducted at Halden. For the Norwegians, it was argued that the work in Halden provided Norway with important knowledge in radiation protection and emergency planning. Further, it was argued that Norwegian industry benefited directly from the research conducted at Halden.

The Kola Nuclear Power Station.

Equipment for condition monitoring of the Kola NPP delivered by the Halden Project.

Work at the Halden reactor continued, with new experimental instruments and techniques being developed. These included high pressure loops in which conditions present in commercial reactors could be simulated. This anchored the Halden Project's position as a leading centre for fuel research and also gave new possibilities for material investigations. The properties of stainless steels and other alloys under irradiation were, and are still, of high importance.

The Three Mile Island reactor accident showed that poor information design in the control room can be an important factor in accident development. This resulted in a bigger international interest in Halden's work on control room design, including the use of digital technology and computer screen based information displays.

During the 1980s the number of contracts with Norwegian industry increased dramatically, especially through the establishment of the Halden Man-machine Laboratory (HAMMLAB). This resulted in simulator projects for the petroleum industry and collaborations with Norsk Data and Kongsberg Våpenfabrikk (Kongsberg Norcontrol IT). During this time a new strategy was under development at Halden. Research for the nuclear industry maintained the international interest whilst the MTO (Man, Technology, Organization) activities also provided services to Norwegian industry.

EXPANSION (1990–1999)

The future of the Halden Project was again discussed at the beginning of the 1990s. Pressure, both political and from the Norwegian Research Council (NTNF), was placed on IFE to declare its future plans for the Halden Reactor. Environmental groups lobbied for its closure and Parliament debated a proposal to close down the reactor when the then three year program came to an end in 1993.

IFE met this challenge twofold: firstly by increasing the utilization of the Halden Project's skills by Norwegian industry; and, secondly, by showing that the skills which the Project possessed could be used to increase safety in reactors in Russia and Eastern Europe.

IFE was successful in both these areas. From 1991 to 1996 research contracts with Norwegian industry more than doubled in value. IFE, Halden also became an important partner in the programme aimed at increasing safety in reactors on the Kola Peninsula in Russia. International interest in the Halden Project also increased strongly during the 1990s, with the number of member countries doubling. At the same time there was an increase in the number of fuel and materials tests, reinforcing Halden's position as a leading research centre for nuclear safety. This increased activity also resulted in a percent wise reduction of the Norwegian contribution to the Project's cost.

The Halden Project's image, both politically and with the research council, improved significantly. This was due both to the economic development of the Institute and the realization that Norway's competence in nuclear safety was important for both Norwegian radiological protection planning and for the nuclear safety assistance programme in Russia. A commission appointed by the research council in 1995 to review the Halden Project recommended continuation of the Project and operation of the reactor beyond the year 2000, when the licence for operation expired.

Strong growth in activities in the electricity sector during the first half of the 1990s resulted in formation of a spin-off company, Hand-El Skandinavia AS, in 1996. This was very positively received by the government and clearly demonstrated that research at Halden resulted in innovation and generated employment.

THE PRESENT AND THE FUTURE

THE GLOBAL NUCLEAR POWER SITUATION

Internationally, there is increasing interest in the use of nuclear power as an energy source, among other reasons due to its economic competitiveness. Nuclear power is also attractive because it does not release greenhouse gases. Increased use of nuclear power in the coming years can reduce the need for fossil fuels for power production and hence lower the release of greenhouse gases.

A new reactor is under construction in Finland, and the United Kingdom government has accepted in principle the construction of new water-cooled reactors to replace aging units. In the USA, nearly 50 units have received license extensions from 40 to 60 years, and applications have been approved for construction of four new units. In France, where 59 nuclear power plants provide 80 per cent of the country's electrical power, new units are also planned. Russia and several Asian countries (China, India, Japan, and Korea) have ambitious civil nuclear power programs. In Eastern Europe, nuclear power has a strong base in many countries and further construction is planned. In Western Europe, shutdowns and the current moratorium on new construction are being reconsidered (Austria, Belgium, Italy, The Netherlands, Spain, Sweden, and Switzerland).

There is a wide international research program into new reactor types, the so-called 4th generation reactors, which will include a higher level of built-in safety than the current generation of reactors. Such improvements in reactor design can remove one of the most important barriers to widespread public acceptance of nuclear power as the future's energy source. In Norway, the debate on the use of thorium – a source of which Norway has large deposits – as nuclear fuel in future reactor designs has led to a new discussion of nuclear power.

There will thus be a need for continuing research into nuclear power, especially into nuclear safety. Regardless of reactor type, it will be important to maintain a high level of safety in the construction, operation and maintenance of current and future power reactors.

H.R.H Crown-prince Haakon performed the official opening of the MTO laboratory building in Os alle 7 in the spring 2003

H.R.H. Crown prince Haakon greeting the children during the opening sermony of the MTO-building.

RESEARCH ACTIVITIES IN THE HALDEN PROJECT

The Halden Project is well placed to contribute to these safety-related research activities, as many of the countries that are revitalising their nuclear power programs are members of the Project. The jointly-financed, cost-effective research program renders it attractive to conduct research within the Halden Project. The Project has a staff of 270 highly qualified workers with the required technical competence, together with a first class infrastructure in the form of the reactor, laboratories, workshops, scientific equipment, etc. The reactor and its associated systems have been steadily updated, and, today, the Halden reactor is one of the world's leading material testing reactors. A new laboratory complex for Man-Technology-Organisation (MTO) research was commissioned in 2003, while the workshops and research staff were re-located in new, up-to-date premises in 2007.

Research in Halden is concentrated in two main areas connected with reactor safety: fuel and material testing; and studies into how the interaction between people, technology and organisation influences safety in the operation of complex industrial processes.

The fuel and material research is conducted in the Halden reactor itself, and consists of the irradiation and examination of nuclear fuel and reactor materials.

STATUS OF POWER PRODUCING REACTORS IN OPERATION

Country	Number	Capacity (MW)	The part of electrical power produced by nuclear power reactors in 2006 (%)
Belgiun	7	5.624	54.4
Finland	4	2.696	28,9
France	59	63.260	76,8
Japan	55	47.587	30,0
Korea	20	17.454	38,6
Russia	31	21.743	15,9
Slovakia	5	2.034	57,2
Spain	8	7.450	17,4
Great Britannia	19	10.222	18,4
Switzerland	5	3.220	40,0
Sweden	10	8.074	48,0
Czech Republic	6	3.538	31,5
Germany	17	20.430	31,4
Hungary	4	1.829	37,7
USA	104	100.322	19,4
Total in the Halden Project's member countries	**354**	**315.483**	
Total in the world	**439**	**371.797**	

STATUS OF POWER PRODUCING REACTORS UNDER CONSTRUCTION

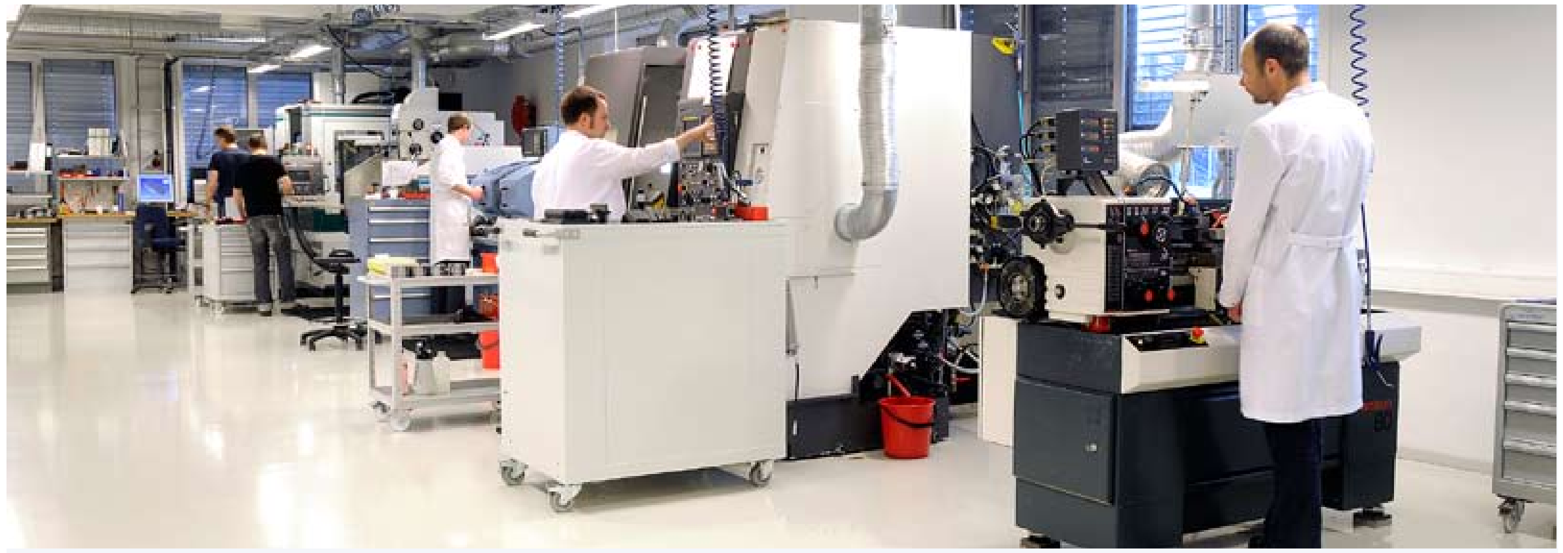
MEMBERS OF THE HALDEN PROJECT

Country	Number	Capacity (MW)
Finland	1	1.600
France	1	1.600
Japan	1	886
Korea	3	2.880
Russia	7	4.484
USA	1	1.165
Total in the Halden Project's member countries	**14**	**12.595**

REST OF THE WORLD

Argentina	1	692
Bulgaria	2	1.906
India	6	2.910
Iran	1	915
Pakistan	1	300
China	5	4.220
Taiwan	2	2.600
Ukraine	2	1.900
Total in the world	**34**	**28.139**

Source: IAEA 2006



The workshop for installing experimental rigs, Os Allé 5.

The other area, MTO, includes development of process surveillance and information systems for control rooms, with the objective of increasing operational safety of nuclear reactors.

With its many associated high-pressure experimental loop systems, the Halden reactor is an excellent research tool for studies of both basic safety-related phenomena and more topical, short term studies related to the safe operation of today's water-cooled reactors. The capability of simultaneously conducting many experiments under different experimental conditions also makes it cost effective to conduct research in the Halden reactor.

There is an increasing requirement to study changes in the properties of construction materials over time when they are exposed to irradiation. A series of experiments has been performed in the Halden reactor to study these issues. Permits to extend reactor lifetimes, which have been given in many countries, are issued on the basis of such experimental data to ensure that the extended operation does not lead to reduced safety or reliability.

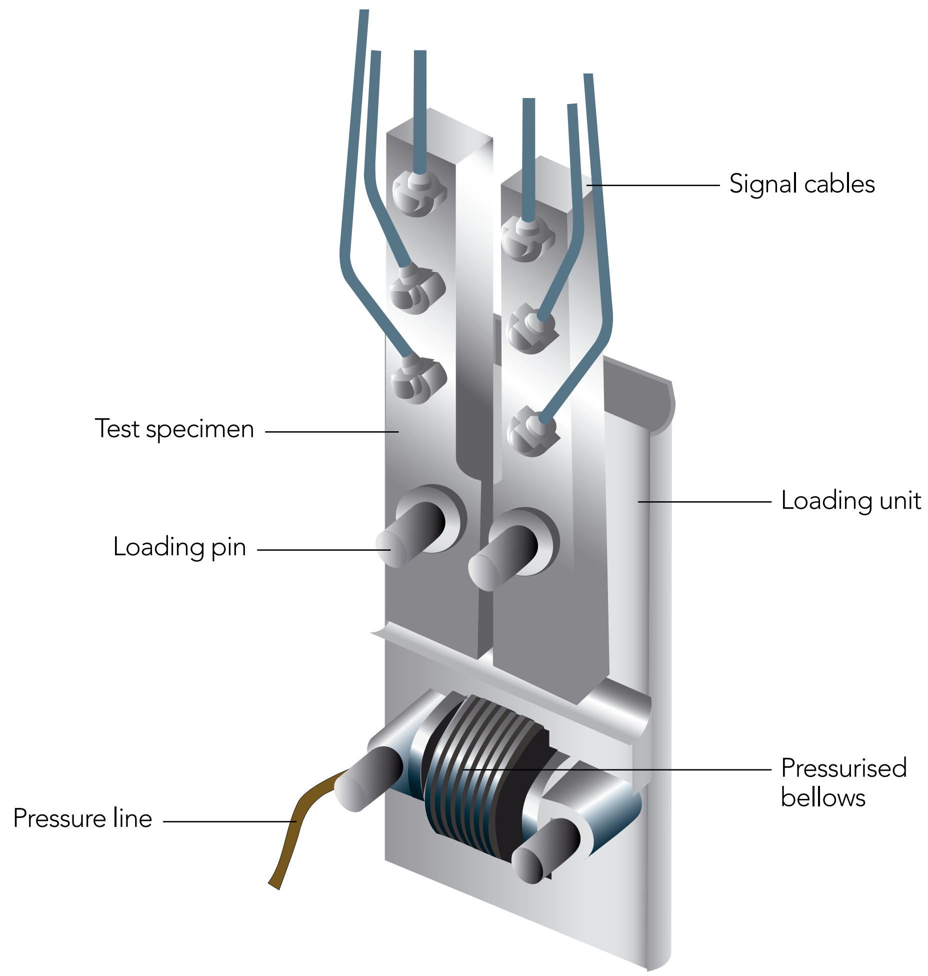
Testing of fuel at increasingly higher burn-up levels is still of large interest to Halden Project members. More efficient utilisation of uranium fuel leads to lower fuel costs and smaller volumes of highly active radioactive waste. New cladding materials and fuel element designs that are compatible with higher fuel burn-up levels are under constant development by fuel vendors, and many of these are tested in the Halden reactor.

There is a considerable, and increasing, interest in studies of fuel behaviour under operational disturbances or postulated accident scenarios (such as short or long term loss of coolant). The Halden Project's contribution in this area is substantial: experimental data from Halden are used to supplement the results from other studies conducted in many of the leading nuclear countries.

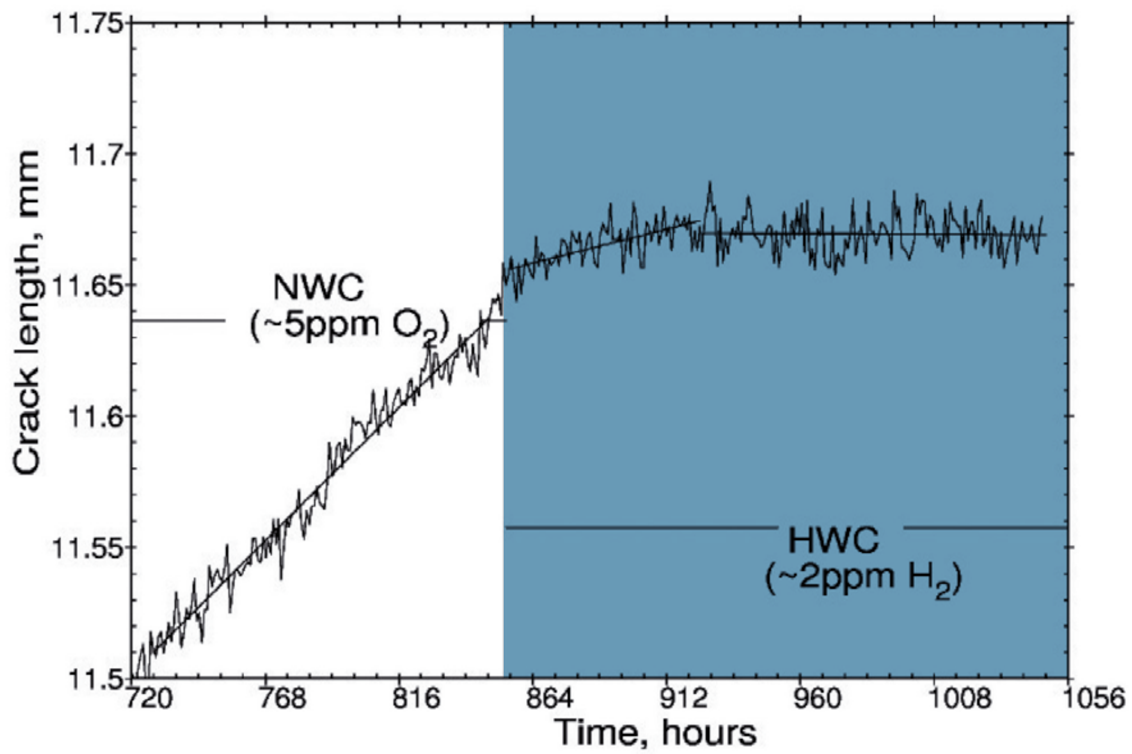
Safety authorities require qualified mathematical models to approve safety cases for use of specific fuel designs and reactor construction materials under different operational conditions. Many of the data, and the knowledge on which the models are based, are acquired through research and development programs in test reactors, and the Halden Project is one of the leading suppliers of such data.

The development of more complex and highly automated technological systems in different sectors of society leads to new challenges with respect to operation and maintenance. It is thus increasingly important to plan and construct technical systems on human premises to minimise human error and achieve safe and efficient operation. This has resulted in increased attention being given to safety-related research connected to human capability and ability to manage technological and organisational changes, which is exactly IFE's competence in the MTO area.

The MTO research at the Halden Project encompasses the development and evaluation of new control and information systems for reactor operators, using full-scope simulations of normal operation and accident sequences in HAMMLAB. The experiments lead to improved control room solutions, enabling operators to ensure stable operation and identify any issues in a facility before they have time to develop into serious incidents.



Test specimen for measuring crack growth in steel material exposed to radiation.



The results from measurements in the Halden Reactor of crack growth in a test specimen. By adding a small amount of hydrogen in the coolant (coloured background) the crack growth is significantly reduced.

The Snow White plant, producing LNG gas, is localised at Melkøy, an island near by the city Hammerfest.

The large screen in the control room at the Snow White plant was designed at the Halden Project.

An important topic in the time ahead is the challenges related to the aging of nuclear power stations. Early fault detection methods and process monitoring have received increased attention, and the Halden Project develops such systems. For example, a new measurement method has been developed to identify weakening of the isolation around electrical cables, which is very important for safe operations of both nuclear power stations and other industrial facilities. Applications in other industries include the monitoring and testing of subsea cables to seabed installations in the petroleum industry and power transmission cables used for electricity distribution. This is an example of research and development initiated in the nuclear power industry finding new applications in other industries. This measurement method is being commercialised through the establishment of the company Wirescan, as a spin-off from IFE.

Internationally, research is underway into so-called fourth generation reactor concepts, which will be even safer than current reactors. The MTO research in Halden will be in demand to support the development of these new kinds of reactors. New reactor concepts will have a higher degree of automation than current reactors and multiple reactors may be controlled from a single control centre, and these new operation concepts will necessitate the thorough validation of new control room solutions in HAMMLAB.

The MTO expertise of the Halden Project staff has been both important and useful for the petroleum sector in Norway. While the focus in the 1980s and 90s was on the development of training simulators for the oil industry, current activities are focused on providing assistance with control room technologies. Amongst other things, this includes supporting the Norwegian Petroleum Safety Authority in the development of new guidelines for alarm handling and control room design. Petroleum companies have received assistance in control room design, as well as the deployment of new large-screen display solutions, for a large number of oil and gas installations, including the facilities for the Snow White field. New monitoring methods are being developed, including environmental monitoring of NOx emissions from gas turbines and the determination of the levels of oil traces in cleaned water.

The petroleum industry is in the process of implementing 'Integrated Operations', where several functions that are currently performed offshore are being moved to land-based centres. An MTO methodology has been developed to assist the oil companies in the required planning and work process re-engineering. In 2006, IFE Halden, together with NTNU and SINTEF, was chosen to run one of fourteen national centres for research-based innovation: The 'Centre for e-Field and Integrated Operations for Upstream Petroleum Activities'.
In addition to its recognition of IFE's competence in the field, the centre provides an opportunity to become an international supplier of new knowledge and technology in the oil and gas sector.

FUTURE PROSPECTS

The current license to operate the Halden Reactor expires at the end of 2008, and an application to extend operation into the future has been sent to the Norwegian authorities. The Norwegian Radiation Protection Agency is the technical instance that is processing the application for the government, and will give its recommendation during the spring of 2008. The reactor is systematically maintained and upgraded and is in excellent technical condition, as confirmed in 2007 by the International Atomic Energy Agency (IAEA) after a thorough inspection of the safety aspects of the Halden Reactor. The Norwegian Government's decision regarding the application is expected towards the end of 2008.

At present, nuclear power production contributes to a significant reduction in CO_2 emissions from the electric power sector. Without nuclear power, the CO_2 emissions of the OECD electrical power sector would be 30% higher than today, assuming that the same amount of electricity had been produced using a combination of oil and gas fossil fuels. This represents an annual emissions saving of 1,200 million tons of CO_2. As a comparison, the Kyoto Protocol's target for CO_2 reduction within the OECD countries is 700 million tons by 2012, determined relative to the 1990 emission levels. On a global basis, nuclear power reduces the total emissions of CO_2 by the power industry by approximately 17%.

Each country's government faces the challenge of reducing its climate gas emissions while simultaneously ensuring a reliable and sufficient energy supply. In order to meet this challenge, an increasing number of countries have decided that nuclear power will play a significant role in their energy production, alongside other low-carbon technologies. This has led to a renewed interest and revitalisation of the nuclear power industry in many of the Halden Project's member countries. The member countries therefore have a strong desire for continued collaboration through the Halden Project. The life-extension of existing reactors and the construction of next-generation reactors consolidate the long-term requirement for continued irradiation studies and safety research at the Halden Reactor.

The level of activity in transferring competence to other industries is also expected to increase. In particular, MTO expertise has proved to be of considerable value across many industries. Activities for the petroleum sector are already extensive, and other examples that can be mentioned include projects for the process industry, transport sector, electrical power, and mining industries. It is expected that activities will continue to expand into new markets in the future.

The Halden Project and the Halden Reactor will therefore remain an important resource for international safety research for many years ahead, as it has been for the last fifty years.

The Virtual Reality (VR) data technology is a very powerful tool for simulating and evaluating the control rooms of the future

The national flags in the illustration above show all countries that are, or have been, participating in the Halden Project:
In the current three-year period 2006–2008 there are 17 member countries.
These are: Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Japan, Korea, Norway, Russia, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom and USA.

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