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The Board 1996*

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As of 1.1.1997 the IFE Board has the following composition: Arve Johnsen (Chairman), Anna Inger Eide, Gerd Halma, Knut Herstad, John B. Rekstad, Trond T. Olsen, Jan Gunnar Waalmann.

Management
Kjell H. Bendiksen, Managing Director (left)
Arne Raheim, Assistant Managing Director (right)

The Halden Project
Carlo Vitanza, Project Manager (middle)
Fridtjov Øvre*, Deputy Project Manager
Wolfgang Wiesenack, Assistant Project Manager

* Acting Project Manager from 1.9.1996 to 31.12.1996

Information
Rolf O. Lingjærde

Safety and Quality Assurance
Helge Smidt Olsen
The Institute for Energy Technology is a national centre for research into energy and nuclear technologies. Approximately half of the Institute's total work volume is related to its two research reactors at Kjeller and in Halden. Of the remaining work at the Institute, about 30% is in the area of petroleum technology, and 15% in other energy and environmental technologies. The Institute performed well in 1996, with satisfactory technical and financial results.

Research highlights
Fundamental research in physics carried out at the Institute is key to Norwegian materials science R&D. This work is mainly experimentally based, depending on use of the JEEP II reactor at Kjeller. The high level of technical achievement in this area has been demonstrated through the "Geilo Seminar" series, and a long list of international publications. The reference work "Twentieth Century Physics," published in 1996, referenced about 2500 original contributions to the development of physics this century. Of these, 5 were Norwegian, and of these 3 were from IFE. The Board consider it as an important task to ensure
that the JEEP II reactor, together with the specialized suite of instruments and research culture that have developed around it, continues to remain competitive and attractive for Norwegian and foreign research workers. Accordingly, the Institute began a comprehensive program of renewal and upgrading of the laboratory's experimental equipment in 1996.

During 1996 the petroleum and energy sector has continued to be dominated by changes in the marketplace and in the R&D framework defined by the authorities. IFE has not escaped the resulting effects. Nevertheless, after several years without growth, the Institute experienced a significant increase in contract work income at Kjeller in 1996. The Institute continues to play a key role in the efforts being made by the authorities to improve the efficiency of energy usage in Norwegian industry. During 1996, the Institute was engaged in a large project for the Norwegian Water Resources and Energy Administration on the implementation of energy conservation measures in Norwegian industry. IFE has also been involved in a range of large development projects for the electricity distribution system, especially in areas related to new renewable energy sources.

In 1996 the Institute continued its successful strategy of concentrating much of the efforts in petroleum technology on larger projects carried out in close collaboration with oil companies and contractors. IFE's research in corrosion and multiphase flow is key to the Statoil-Norsk Hydro-Saga collaborative development program in this area. The Institute has placed strong emphasis on research that contributes to economically viable processes for improved oil recovery. Work continued in 1996 on the development of realistic models and tools that can be applied to help locate areas of remaining oil in reservoirs that have been flooded with gas or water. The integrated strategy for optimizing new well locations involves combining a range of specialized experimental tools, such as tracer technology. A technical breakthrough in this field, together with the application of new drilling technologies, could increase oil recovery from some oilfields by up to 20%.

The Halden Project's research program focuses on the safety and operational reliability of nuclear power stations and other complex process plants. International interest in this work is strong and on the increase; a total of 19 countries now participate in the Project. Through 1996, IFE continued to collaborate actively in work being carried out internationally to improve safety in nuclear plants in Russia and other countries and eastern Europe. With support from the Ministry of Foreign Affairs, a range of measures was implemented in 1996 to improve safety in the nuclear power stations on the Kola Peninsula in Russia. This involved close collaboration with the Norwegian authorities, the Norwegian Radiation Protection Authority, and other Nordic countries. Also, in 1996, the Institute entered an agreement with the OECD Nuclear Energy Agency, the Czech Republic and Japan, on the adaptation and implementation of an IFE-developed nuclear surveillance system in a Czech Russian-type pressurized water reactor (VVER).

An extensive experimental program was carried out in 1996 using the Halden reactor, partly for the joint international program, and partly for contract work for member countries. The main aim of this work is to improve the safety and reliability of existing nuclear power plants. The experimental equipment in the Halden reactor makes it ideal for simulating various operating conditions in different types of reactors. Processes such as corrosion in fuel cladding materials, fracture propagation in irradiated materials under the influence of additives in the coolant water, and transport of radioactive materials in different situations can be studied. Studies on the characteristics of reactor fuel are aimed at improving fuel reliability and efficiency thus allowing for a significant reduction in the amount of radioactive waste produced. In an on-going study, fuel of Russian origin is being compared with modern western fuel. The results, being the first of their kind that are openly available, form an important basis for safety assessments of Russian VVER reactors.

The Halden Project's international interface with leading technical research groups and companies gives the Institute access to research results and technologies that are being applied increasingly in contract work for Norwegian industry. The domestic contract work in Halden has increased from about NOK 38 million in the three-year period 1988-1990 to about NOK 80 million in the 1994-1996 period. An important part of this work involves the use of an advanced simulator-based control room, HAMMLAB (Halden Man-Machine LABoratory). This facility is central to a range of projects designed to develop and test new
decision, information- and control support systems for the oil industry and other process industries. Over a number of years, the Institute has been involved in developing IT tools designed to provide decision support to players in the electrical power supply market. New energy legislation has led to a significant growth in this activity, which during 1996 was spun off from IFE to a separate company: Hand-El Skandinavia A/S. During 1995 a committee, appointed by the Research Council of Norway, carried out a comprehensive review of the Halden Project and its value to Norwegian industry and the authorities. The significance of the Project for nuclear safety issues was highlighted, including its role in Norway's national nuclear preparedness. The Research Council's recommendations for the future development of the Halden Project also emphasized its impact on improving the safety of East European reactors. In dealing with the 1996 budget, the Norwegian Parliament approved funding for the Halden Project for the period 1997-1999 on condition that an acceptable collaborative agreement was reached between the international members. This agreement for the 1997-1999 period has now been finalized. The government proposed, and Parliament has now approved, a grant of NOK 25 million for the first year of the new project period (1997), and authority has been approved to provide up to NOK 50 million for the remainder of the three year period. The total Halden Project budget, including Norway's contribution, will be approximately NOK 300 million.
The Board would like to stress the importance to the Institute of international collaboration. Over 40% of IFE’s total income for 1996 came from abroad; export income from the Halden Project alone totalled about NOK 150 million. At Kjeller too, practically all of the work program is characterized by a remarkable degree of collaboration with international research groups and companies. For example, IFE’s broad involvement in the EC’s 4th R&D Framework Program involves participation in about 20 different projects. The Institute also collaborates actively with the International Energy Agency (IEA) in work related to new renewable energy resources, energy efficiency and energy- and environmental-systems analysis.

An important indicator of the quality of the Institute’s research activities is the increasing international interest in the results. This applies particularly to the fundamental physics research at Kjeller, which has extensive links with other Norwegian and international research groups. For example, during 1996, a new co-operative program was started with the European Synchrotron Radiation Facility in Grenoble, and the Nordic Neutron Scattering Society.

The Board emphasizes the importance of collaboration with other Norwegian research groups, particularly where the technical specialties of the different institutes complement each other in relation to market demands and opportunities. This is becoming increasingly important in petroleum and energy research for two main reasons: firstly to establish a group that demonstrate international presence and can compete internationally; secondly, to help co-ordinate national R&D efforts and resources so as to avoid unnecessary duplication. On this background, in Autumn 1996, IFE entered a collaborative agreement with the SINTEF Group, aimed at building up a more co-ordinated Norwegian effort in research, development, and technology transfer in the energy sector. The size of the two partners, together with the complementary nature of their expertise, will enable the widest possible range of R&D resources to be offered across the energy sector, nationally and internationally. The agreement sets out a structured framework for co-operation in the relevant technical and market areas, which will encourage joint projects and strategic technical work. Another aim is to enhance the degree of collaboration with the universities in Oslo and Trondheim.

The practical and technical co-operation between NILU (the Norwegian Institute for Air Research) and IFE is co-ordinated and maintained through a technical steering committee. The institutes in the Kjeller campus collaborate with the University of Oslo regarding the UNIK program (University Studies at Kjeller). This agreement has now been extended to include Trondheim University. In Halden, the Institute is building links with Østfold Technical College.

IFE’s research activities yielded good results in 1996, in terms of successful research projects, new products and systems, and new technical solutions for a variety of applications. During 1996 IFE had 32 articles published in peer-reviewed international journals, together with about 100 presentations at conferences with associated publications in “proceedings” volumes. High priority has been given to work on quality improvement in all activity areas, including an extensive revision of IFE’s formal quality assurance system.
The Board consider it essential that the Institute's technical results are taken up and applied commercially. The most important impact of the Institute's activities is represented by the value created in our clients' companies through the targeted application of the Institute's research results. However, IFE can also demonstrate significant growth in the wider area of industry-focused technical and industrial renewal in the form of licensing agreements for IFE products and services, and new business start-ups. Important examples from recent years include the developing the phase fraction meter for FRAMO's multiphase instruments, licensing the multiphase model OLGA to Scandpower; licensing models for well control and killing to the company Well Flow Dynamics, and use of the Halden Project's graphics development tool PICASSO by Scandpower/Alcatel in telecommunications systems, and in Kongsberg Offshore's fiscal metering systems.

As mentioned above, some of the Institute's activities were spun off into two new limited companies in 1996. Development work in Halden on advanced information technology (IT) systems for the electrical power market was taken over by the newly created company Hand-El Skandinavia A/S on 1.4.96. Also, the manufacture of radioactive medicines in Kjeller's isotope laboratories was spun off on 1.9.96 as a joint venture between Nycomed Imaging and IFE. Twenty-five staff members from Halden and 22 from Kjeller left IFE and were employed by the new companies. Both Hand-El Skandinavia A/S and Isopharma AS are progressing well, with increasing turnover and positive balance sheets for 1996. The two companies had 40 and 27 employees respectively at the turn of the year. The Institute has participated actively in the Research Council/SND FORNY program for the østland area, including establishing in 1996 a new company (Nordisk Energi Kontroll AS) based on IFE's energy conservation activities at Kjeller.

Safety and the environment are high-priority issues in all of the Institute's activities. Some of IFE's nuclear-related work is, though, unique in Norway, and so generates special media attention from time to time. The Institute sees it important to maintain an open flow of information to the public.
IFE's nuclear-related work at Kjeller is based around, and depends on, the JEEP II research reactor. The Institute is in the process of a comprehensive restructuring of these activities, partly as a result of the transfer of responsibility for IFE's basic finance to the Research Council. Consequently, various segments of work, related to safety, control of fissionable materials, information, irradiation services and radiopharmaceuticals, were reorganized in 1996. Changes resulting from the EEC agreement affect the actual framework for trading and controlling radiopharmaceuticals. A proposal from the Ministry of Health and Social Affairs on the future organization of these functions was given a hearing in April 1996, and a ruling on the new arrangement is expected during 1997.

Parliament decreed in 1994 that a combined store and repository for low and medium level radioactive waste would be constructed in Hindalen, in the Aurskog-Høland area. Pre-projects are now in progress, though plans have been delayed so that it will now be at least Autumn 1998 before the facility is ready for use. In accordance with Parliament's resolution, the Institute will be responsible for operating the facility, including transfer of the low and medium level waste currently located at Kjeller to Hindalen.

The Institute is preparing an application for licensing IFE's nuclear facilities for the period 2000-2010. The application, which will be evaluated by the Norwegian authorities (Norwegian Radiation Protection Authority) includes updated safety reports for each installation - such as the JEEP II reactor at Kjeller and the Halden reactor. The application is expected to be submitted to the authorities during the course of 1997.

None of IFE's staff received accumulated radiation doses in 1996 that exceeded the recommended levels for occupational hygiene. Routine emissions of radioactive materials from the Institute's facilities were, as always, negligible and far below permitted levels.

No significant work-related accidents or personal injuries were registered with the Institute's health service in 1996. Absences due to illness were 2.6% at Kjeller and 3.2% in Halden. This compares to figures of 4.2% and 2.5% respectively in 1995.

The Institute's total income for 1996 was NOK 385.6 million, NOK 179.6 million of which was generated by activities at Kjeller, and NOK 206.0 million by activities in Halden. The accounts show a surplus for the year of NOK 13.7 million.

The total number of employees as of 31.12.96 was 573, compared to 611 at the end of 1995. Of these, 198 were university or college graduates, 43 with doctorates. The reduction in staff was due mainly to establishment of the two new companies Hand-El Scandinavia AS and Isopharma AS in 1996. Eighty employees left IFE in 1996 (46 of whom were research staff), while 35 new employees were taken on (including 16 research staff). A total of 43 foreign guest workers had long or short-term stays at IFE in 1996, while 6 of the Institute's researchers had temporary assignments abroad.
PROFIT AND LOSS ACCOUNT FOR 1996 (in NOK 1000)

<table>
<thead>
<tr>
<th>OPERATING INCOME</th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earned income</td>
<td>223,261</td>
<td>230,560</td>
</tr>
<tr>
<td>Government grants</td>
<td>93,325</td>
<td>90,639</td>
</tr>
<tr>
<td>Contribution from foreign participants in Halden</td>
<td>64,350</td>
<td>55,850</td>
</tr>
<tr>
<td>Steam income</td>
<td>2,973</td>
<td>4,800</td>
</tr>
<tr>
<td>Other operating income</td>
<td>1,736</td>
<td>1,216</td>
</tr>
<tr>
<td><strong>TOTAL OPERATING INCOME</strong></td>
<td><strong>385,646</strong></td>
<td><strong>383,066</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATING EXPENSES</th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wages, salaries and social security expenses</td>
<td>223,852</td>
<td>219,048</td>
</tr>
<tr>
<td>Direct project costs</td>
<td>112,017</td>
<td>108,841</td>
</tr>
<tr>
<td>Other operating expenses</td>
<td>34,566</td>
<td>35,858</td>
</tr>
<tr>
<td>Depreciation</td>
<td>7,369</td>
<td>8,339</td>
</tr>
<tr>
<td>Bad debts</td>
<td>93</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL OPERATING EXPENSES</strong></td>
<td><strong>377,897</strong></td>
<td><strong>372,087</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATING PROFIT BEFORE FINANCIAL AND EXTRAORDINARY ITEMS</th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7,749</td>
<td>10,979</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FINANCIAL ITEMS</th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial income</td>
<td>6,269</td>
<td>4,350</td>
</tr>
<tr>
<td>Financial expenses</td>
<td>-303</td>
<td>-155</td>
</tr>
<tr>
<td><strong>NET FINANCIAL PROFIT</strong></td>
<td><strong>5,967</strong></td>
<td><strong>4,195</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROFIT FOR THE YEAR</th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13,716</td>
<td>15,174</td>
</tr>
</tbody>
</table>
## BALANCE SHEET AS AT 31 DECEMBER 1996  (in NOK 1000)

### ASSETS

#### Current assets
- Cash and bank deposits 117 822
- Bank accounts for special energy conserv. programmes 2 305
- Accounts receivable 5) 47 221
- Projects in progress 6) 2 210
- Other receivables 2 354
- Stock-in-hand 7) 1 143

#### Fixed assets 4)
- Machinery, instruments, fittings, etc. 19 330
- Laboratory and office buildings 10 966
- Jeep II reactor 2 736
- Area 7 470
- Uranium and heavy water 26 800
- Loan to IFE's Boligselskap A/S 3 090
- Shares 8) 150

**TOTAL ASSETS** 243 598

### LIABILITIES AND EQUITY

#### Short-term liabilities
- Tax deductions, employers’ national insurance contributions, pension and holiday pay 37 366
- Accounts payable 23 488
- Payments on account 34 707
- Other liabilities 9) 3 186

#### Equity
- Undistributable reserves 70 541
- Operating capital 72 992
- Investment, Jeep II reactor 1 617

**TOTAL LIABILITIES AND EQUITY** 243 598

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31 December 1996  
Kjeller, 10 March 1997

Arve Johnsen  
Chairman  
(Sign)

John B. Rekstad  
(Sign)

Anna Inger Eide  
(Sign)

Trond T. Olsen  
(Sign)

Knut Herstad  
(Sign)

Gerd Halvorsen  
(Sign)

Jan G. Waalmann  
(Sign)

Kjell Bendiksen  
Managing Director  
(Sign)
NOTES TO THE 1996 ACCOUNTS

1. The government grants to IFE were as follows for 1996:
   - Joint programme in Halden*) 29.5 mill.kr
   - earmarked grant 25.0 mill.kr
   - basic grant 4.5 mill.kr
   - Petroleum and energy research, Kjeller 21.1 mill.kr
   - basic grant 4.5 mill.kr
   - Strategic Institute Programmes 16.6 mill.kr
   - Nuclear activities, Kjeller **) 41.8 mill.kr
   - Waste storage in Himdalen ***) 0.9 mill.kr
   Total 93.3 mill.kr

*) The Norwegian share of the Joint Programme in Halden came to NOK 33 million in 1996. To supplement the government grant, NOK 3.5 million was financed by funds the Institute earned on bilateral contracts.

**) With the permission of the Research Council of Norway, NOK 0.8 million of the original grant of NOK 42 million was transferred to Isopharma AS. Of the NOK 1 million carried forward from 1995, NOK 0.6 million was spent on the fabrication of new fuel.

***) Of the original grant of NOK 3.3 million for the Himdalen Project, NOK 0.4 million was used in 1995 and NOK 0.9 million in 1996. The remainder, NOK 2 million, which will mainly be used to purchase equipment, was carried forward to 1997.

2. Fees paid to IFE’s Board of Directors totalled NOK 112,800 in 1996. Wages and other taxable remuneration to the Managing Director aggregated NOK 604,200. The Institute paid no auditors’ fees (Office of the Auditor General).

3. Other operating expenses included rent, the maintenance and operation of buildings and grounds, transport, security services, office expenses, in-house print shop, joint computer services, human resources development, etc.

4. Fixed assets (1000 NOK)

| Machinery, instruments, fittings, etc. | 18,515 | 7,258 | - | 6,443 | 19,230 | 22% |
| Lab. and office buildings | 10,467 | 893 | - | 394 | 10,966 | 2-5% |
| Jeep II reactor | 2,880 | - | - | 144 | 2,736 | 5% |
| Area | 7,470 | - | - | - | 7,470 | - |
| Uranium and heavy water | 27,200 | - | 12 | 388 | 26,800 | - |
| **| 66,531 | 8,151 | 12 | 7,369 | 67,302 | - |

*) The diminishing balance method of depreciation has been applied to operations at Kjeller, while acquisitions were charged directly against operating profits at Halden. Uranium and heavy water were written down to their estimated market value.

5. The item ‘Bad debts’ refers to two customers. The provision for bad debts remains unchanged at NOK 0.5 million.

6. Projects in progress refer to work that has been performed, but not invoiced. Accrued hours are evaluated against invoicing rates, and direct project costs are evaluated against cost. Agreed budgetary frameworks and professional progress are also taken into account.

7. The value of stock-in-trade is stated at cost.

8. Shares

<table>
<thead>
<tr>
<th>Company</th>
<th>Company’s share capital</th>
<th>No. of shares owned by IFE</th>
<th>Nominal value per share</th>
<th>Balance sheet value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFEs Boligelskab A/S</td>
<td>50,000</td>
<td>50</td>
<td>1,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Isopharma AS</td>
<td>100,000</td>
<td>50</td>
<td>1,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Multiflow A/S</td>
<td>50,000</td>
<td>250</td>
<td>100</td>
<td>25,000</td>
</tr>
<tr>
<td>Instidata A/S</td>
<td>100,000</td>
<td>150</td>
<td>100</td>
<td>15,000</td>
</tr>
<tr>
<td>Campus Kjeller A/S</td>
<td>100,000</td>
<td>100</td>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>Total book value</td>
</tr>
</tbody>
</table>

9. The item ‘Other liabilities’ includes NOK 2.3 million in energy conservation programme funds.
STATEMENT OF THE SOURCE AND APPLICATION OF FUNDS 1996
(in NOK 1000)

Source of funds:

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total generated from operations</td>
<td>13 716</td>
<td>15 174</td>
</tr>
<tr>
<td>Depreciation</td>
<td>7 369</td>
<td>8 339</td>
</tr>
<tr>
<td>Disposal of capital assets</td>
<td>12</td>
<td>56</td>
</tr>
<tr>
<td>Total</td>
<td>(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21 097</td>
<td>23 569</td>
</tr>
</tbody>
</table>

Application of funds:

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investments</td>
<td>8 151</td>
<td>9 147</td>
</tr>
<tr>
<td>Share acquisitions</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>(B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 201</td>
<td>9 157</td>
</tr>
</tbody>
</table>

Decrease/increase in working capital (A - B)

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 896</td>
<td>14 412</td>
</tr>
</tbody>
</table>

Change in working capital:

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase/decrease in cash, etc.</td>
<td>-1 710</td>
<td>52 517</td>
</tr>
<tr>
<td>Increase/decrease in short-term receivables</td>
<td>15 468</td>
<td>-11 276</td>
</tr>
<tr>
<td>Increase/decrease in stocks</td>
<td>28</td>
<td>-8</td>
</tr>
<tr>
<td>- Decrease/increase in working capital</td>
<td>-890</td>
<td>-26 820</td>
</tr>
<tr>
<td>Increase/decrease in current liabilities</td>
<td>12 896</td>
<td>14 412</td>
</tr>
</tbody>
</table>

REPORT FROM THE OFFICE OF THE AUDITOR GENERAL FOR 1996

We have audited the 1996 accounts of the Institute for Energy Technology (IFE).

Our responsibility is to examine the Institute's annual report and accounts, management of resources and treatment of other matters, as well as to comment on any circumstances of a statutory nature.

We have conducted the audit in accordance with current legislation, regulations and the auditing procedures we deem necessary to confirm that the accounts have been presented according to the guidelines that apply to the Institute for Energy Technology.

The annual report and accounts may be stipulated as the annual report and accounts for the Institute for Energy Technology for 1996.

Oslo, 17 March 1997

As authorised

Gro Hansen
Assistant Deputy Director
(Sign.)

Anne Mette Tangen
General Senior Auditor
(Sign.)
The OECD Halden Reactor Project

In the Autumn of 1996, organisations from 19 countries reached agreement to continue their research collaboration through the international Halden Project for a further 3-year period (1997-99). Increasingly, the activities of the Project focus on safety and reliability issues. Experimental work, using the Halden Reactor, aims to generate a fundamental knowledge base in materials and corrosion technology, essential for the development of safe and reliable reactor fuel and material designs. Halden’s Man-Machine Laboratory is used to study how new technologies influence the operators, and to develop computer-based systems for improving the safety and accessibility of complex processes. The Halden Project covers the needs of the Norwegian authorities for national competence in reactor technology, and contributes resources for practical radiation protection work and nuclear preparedness.
Nuclear fuel is tested in the Halden Reactor using in-house-designed advanced instrumentation supplemented by data analysis and model development. In particular, the efforts are dedicated to investigating how the properties of reactor fuel change during long-term use. This involves isolating and exploring individual processes, as well as demonstrating the integral performance of different fuel designs under normal operating conditions and in situations with reduced cooling. The results are utilized in safety analyses and model calculations, and form the basis for safety approval of fuels.

Another important subject of increased interest from the safety authorities is how the characteristics of construction materials change as a result of irradiation and corrosion. Complementing experience from commercial reactors, the experiments in Halden can be designed to focus on individual factors or processes, and on conditions representing those at the end of a reactor's lifetime. Stainless steel materials are tested under different conditions of stress and water quality to investigate the processes of corrosion and fracture resistance. Additional experiments target changes in the material's strength, hardness and brittleness as a result of irradiation.

A significant part of the Project's activities is aimed at the development of decision support and surveillance systems for nuclear power stations and other process industries. The activities include establishing fundamental data on human capabilities and limitations in a modern control room environment. This will lead to an improved and more efficient future working environment, with reduced stress on the operators. Halden's Man-Machine Laboratory, which forms the experimental focal point for this kind of research, is planned to be upgraded and expanded to include safety-related research for other industries, such as oil and gas production.

The technical and safety standards of the reactor facility are maintained through a program of continual maintenance and renewal of systems and components. The most important item of upgrading in 1996 comprised renewal of the systems that supply electricity to the reactor, incorporating safety improvements and enhanced operational and experimental flexibility.

The reactor was in operation for approximately half of the year, during which time about 70,000 tonnes of steam was supplied to Norske Skog's local paper factory. Two longer periods of downtime were used for maintenance, for installation of new equipment, and for making modifications in connection with the experimental program.

The international collaboration with high-technology research groups and centres of expertise in the other 18 member countries provides access to data and knowledge that are increasingly being applied in development-work for domestic users. The Project's graphics development tool PICASSO is for instance being used by Scandpower/Alcatel in telecommunications systems, and by Kongsberg Offshore in fiscal metering systems. During 1996 the Project carried out an assessment of the Ekofisk II control room for Phillips Petroleum, including examining how operational disturbances are handled. A new alarm system has been designed in collaboration with Oslo Energi. For Kongsberg Norcontrol, the

- Nuclear fuel reliability
- Materials technology
- Man-machine interaction
- Operation of the Halden reactor
- A national resource
Project has emulated the control system for the Hydro Rußnes VCM factory and developed a model-based diagnosis system for monitoring machinery on ships.

The Project has carried out several studies for Oslo's new Gardermoen airport, including evaluation of the security system for cabin baggage. In collaboration with the Radiation Protection Agency and the Meteorological Institute, a consequence analysis was carried out for various accident scenarios in nuclear installations on the Kola Peninsula.

The Halden Project received its first EC project from the 4th framework program in 1996. As the only Norwegian representative, the Project will participate in the multimedia part of the ESPRIT program. The aim of this effort is to create a training program for civil aviation maintenance personnel. Industrial partners in 4 EC countries are involved, with SAS (Scandinavian Airline System) as the main industrial link. The program, called ASSIST, is based on the integrated use of Virtual Reality and expertise in Human Factors.

FUEL, MATERIALS AND INSTRUMENTATION TECHNOLOGY

Thermal conductivity is a material property that has major influence on the operational reliability of reactor fuel. It determines the thermal capacity of the fuel and thus affects the fuel behaviour in terms of stresses, strains and internal pressure under normal operating conditions and under transient conditions. However, conductivity decreases gradually with time (burn-up), and this must be accounted for in fuel safety assessments. This is especially important considering the extended fuel lifetimes now required so as to reduce the amount of radioactive waste produced.

A series of experiments is being carried out in the Halden reactor to investigate the various factors which affect fuel behaviour. In some experiments a fuel burn-up almost double that experienced in commercial reactors is achieved. In other, short-term experiments, fuel rods that have previously been irradiated in commercial reactors are being studied. The performance is measured using special instruments that have been developed in-house, and which maintain accuracy and reliability through many years of irradiation. Based on the temperature measurements, a quantitative relation was established in 1996 between thermal conductivity and burn-up, expressed in a formula which can be incorporated in the codes that are utilized for safety clearance of fuels.
The cladding materials that surround the fuel pellets in water-cooled power reactors are subjected to large thermal and mechanical stresses. The radiation and the corrosion on the water side can modify the structure and characteristics of the cladding material in ways that can influence its reliability. The materials may be deformed elastically or plastically due to the influence of fuel expansion on the one side and the varying external overpressure on the other side.

An ongoing series of experiments has the main aim of investigating how various cladding materials behave with respect to creep deformation under different operating conditions. The deformation rate depends on mechanical load, temperature and radiation level, and the experiments include different irradiated and non-irradiated cladding alloys and systematic variations of other external factors.

These experiments are carried out in specially designed test rigs in the Halden reactor, where conditions that affect deformation rate can be controlled closely, and which have instruments that can measure deformations in the micrometer range. The results achieved are unique, and they have an accuracy that makes them well suited for testing the deformation models that are used in codes for fuel safety assessment.

Corrosion can limit the useful lifetime of construction materials. In a reactor, stress corrosion cracking of steel materials in water at high temperature under the influence of radiation, is of special interest.
Corrosion damage can be reduced through better choice of materials and optimization of water chemistry.

Monitoring of water chemistry is usually carried out at low temperature and pressure. Important factors, such as pH and corrosion potential, are nevertheless temperature dependent, and there is thus a need to develop sensors that are reliable at higher temperatures and pressures.

The Halden Project, in collaboration with VTT (Finland), is developing a miniaturized palladium electrode for monitoring corrosion potential. The electrode is of a size that can easily be adapted to different geometries. The practical problems related to the development of this new instrument are to ensure simple production and watertight electrically insulated signal transmission. Prototypes of the instrument are now undergoing final validation tests in autoclaves.

The collaboration with power stations on the Kola Peninsula (Russia), carried out as part of a Norwegian aid program for improved safety, is progressing satisfactorily. Equipment for monitoring water quality in reactor cooling systems, for ultrasonically monitoring pipes and welded joints, and for gamma spectrometric surveillance of radioactivity, has been commissioned and delivered.

Along with the new equipment, an extensive training program is being carried out with regard to usage, maintenance and work routines. So far over 50 specialists from the Kola plants have been to Halden for training. Additionally, two senior Kola staff members have been stationed in Halden. The work is followed up by reports on how the equipment is functioning and on general experiences related to improvements compared to the established work routines.

The collaboration is continuing, and during the first half of 1997 further transfer of equipment is expected for monitoring the condition of rotating machinery, for underwater inspection and for surveillance of critical safety functions.

The Halden Project is developing a system aimed at improved management of accident situations. The CAMS project (Computerised Accident Management Support) is investigating how advanced information technology can be used to provide those who have to make decisions with a firmer basis on which to make the decision, in order to avoid or minimize the consequences of an industrial accident.

The CAMS prototype was evaluated by Svenska Kärnkraftinspektionen (SKI) as part of a preparedness exercise for dealing with a simulated accident situation in one of the Swedish nuclear power stations. SKI considered the system to provide valuable information on the instantaneous situation and on the expected course of development of an accident. SKI recommended that the CAMS prototype should be developed further in collaboration with the Swedish utilities.

The prototype includes a range of modules that provide the best possible estimate of the condition of a plant, as well as predicting the progress of an accident. In addition, an on-line risk analysis is carried out on possible alternative interventions, so that the best measures can be selected and implemented to reduce the consequences of the accident.
Reuse of knowledge makes it possible to test out new methods and develop system solutions at reduced costs. However, knowledge must be formalized before it can be reused. Thus new formalization tools have been developed, based on a so-called black-board solution. This is an information centre for a set of knowledge agents who aid in the localization of the appropriate knowledge for a given problem. The knowledge agents can be databases, expert systems or conventional procedural solutions. In the development of operator support systems, this formalization will practically always overlap from one system to another.

At the Halden Project, reuse of knowledge will enable improving the quality of new process surveillance and operator systems, for example through better quality assurance of the process knowledge upon which the programs build their instructions. In collaboration with the French company Aerospatiale, the Project has developed the formalization tool ACCES, which is used in technical design work.

The use of programmable systems for the control and surveillance of critical safety systems is increasing. In order to improve the reliability of such systems it is necessary to arrange for comprehensive quality assurance, included as an integral part of the software development process. High level of safety can be achieved by using formal (i.e. mathematical/logical) methods. The Halden Project has developed such a formal method with its own demonstration tool that can be applied in all phases of the programming process.

If bugs do appear it is important to have appropriate methods for identifying and removing as many faults as possible before putting the system into use. These methods can be grouped conceptually into program analysis and testing. In collaboration with leading European safety organizations the Institute has developed analysis tools for programs in machine code, and has investigated the effectiveness of different test strategies experimentally.

Even if a program contains faults before it is being taken into use, it will still be possible to improve reliability by having more than one program to carry out the same functions. If three or more such programs are run in parallel, a majority decision will determine the most likely solution. In collaboration with organizations associated with the Halden Project, this principle is being studied experimentally in Halden.
Several pilot experiments have been performed to provide a basis for the main study. These pilot experiments have confirmed the value of verbal protocol analyses, and have also revealed a number of methods that improve the efficiency of analysing different types of data. The experiments have also shown that operators use different types of diagnosis strategies suited to different operational and work situations.

The pilot experiments have been followed up by a study in which basic methods and models were developed and tested for their ability to predict the most likely errors that will occur in given situations. The results will make a significant contribution to the design of systems for man-machine interaction, and will serve as a basis for improving models of operator behaviour and performance. In addition, a system is under development that will be able to give a profile of degree of difficulty, based on eight difficulty factors identified through statistical techniques. These factors can be used to calculate the overall degree of difficulty of a given situation, and this can be applied in selecting appropriate scenarios for other experiments. Further development of this tool will enable it to be used to improve models for estimation of operator behaviour and performance, and to aid in risk assessment.

The application of VR (Virtual Reality) technology is opening up new possibilities in the field of control room development. This technology allows an immediate verification of new design solutions, and the operators and management can at a very early stage in the design process become acquainted with the new control room. A VR model can be controlled by a process simulator such that specific dynamic sequences can be visualized on a colour screen, inside the VR-model. In this
way the man-machine interface and different scenario outcomes can be assessed before a new control room is constructed.

In collaboration with Oskarshamn Kraftgrupp, the Halden Project has carried out a pre-study on upgrading the control rooms of three nuclear power stations in southern Sweden. In addition to assessing and recommending new control room systems and equipment, a new control room philosophy was developed, as this is being considered the most important design foundation for the functional demands that will be required of the new control room concept. It was also important to assess comprehensive solutions which may be economically attractive because they enable coordinated remodelling of several control rooms.

In one sub-project, changes were made in the control room of one of the reactors, including improving the working environment of the shift manager and equipping it with several colour monitors for presenting alarms and administrative information. The tasks and responsibilities of the shift manager were assessed, and the Project's expertise in man-machine interaction and ergonomics was used as the basis for designing the work station, which was initially visualized with the aid of VR technology.

IFE has entered into a collaborative agreement with Ericsson Radar in Halden on the development of the user interface for their radar systems. This work, which builds on the Institute's expertise in man-machine interaction, includes the design, development, testing and integration of several software modules.

In connection with the modernization of the surveillance radar system along the Norwegian coast, the Institute is involved in the development of operator applications for the new system. This work will continue until the Summer of 1997, and the system will be installed in
surveillance aircrafts was developed, for which very high demands in terms of performance and capacity are required. The Institute’s experience in the development of high-performance graphics systems for real-time applications was crucial for establishing the cooperation. Additionally, the Institute had the responsibility for designing and developing a set of modules for user interfaces in radar trucks.

Statnett SF and IFE have been collaborating for several years on the development of a system for monitoring, operating and maintaining Norway’s central electricity distribution grid. This system, which now incorporates over 30 operator stations, integrates the national centre in Oslo with Norway’s regional centres by means of a network. In 1996 the system was extended to include features to monitor exchange agreements with other countries.

In another collaborative project with Statnett, IFE has developed an information system in which multimedia techniques such as video, pictures and graphics are employed. The system is being used for training, maintenance and planning, and makes information more readily accessible through Statnett’s intranet system.

In collaboration with Hand-El Skandinavia, IFE has developed a system for Statkraft’s new marketing centre. The system accesses production data from Statkraft’s power stations and important measurements on grid transmission, and uses these data to monitor the instantaneous power balance. At any one time this provides an overview of how Statkraft’s production compares to its contractual obligations. The system thus makes it possible to continuously follow developments in production and consumption, and thus measures to plan the purchase or sale of electricity on the power exchange can be investigated at an early stage.
Natural gas - isotopic composition and generation processes

The analysis of carbon and hydrogen isotopes plays an important role in the genetic characterization of hydrocarbon gases and determination of gas maturity. IFE carries out a variety of isotopic analyses, including all tested gases from the North Sea and gases from other exploration areas.
Internationally, using various pyrolysis methods, the generation of oil and gas is being studied in the laboratory. Hydrous pyrolysis, where the heated material is always in contact with water in the fluid phase, is used for studying the generation of hydrocarbon gases, carbon dioxide, and organic acids from different North Sea source rocks.

The results have provided valuable information regarding the degree to which source rock and maturity determine gas isotopic composition, and regarding various diagenetic processes. Additionally, the results of this work help form a basis for mathematical modeling of porosity and permeability in clastic reservoir rocks. IFE has also developed methods that make it possible to simulate thermal cracking of oil to gas, using long-term experiments under high pressure (1000 bar). All of the cracking products are analysed quantitatively. On the basis of these experiments it has been possible to establish kinetic parameters for processes related to thermal cracking of oil to gas, and to evaluate the possible roles of catalysts and high pressures. These results will have an important influence on the oil companies' exploitation strategies.

Over the past 6 years IFE has been running an extensive tracer technology collaborative program with the oil companies BP, Conoco, Mobil, Phillips, Saga and Statoil, nicknamed the "Tracer Club." The main aim has been to improve reservoir description, and interesting results have been achieved in a number of areas. Particularly noteworthy has been the verification in field trials of new non-radioactive tracers that have been developed for water flooding. These tracers, mainly fluorinated carboxylic acids, have yielded good agreement between field and laboratory measurements. An important consideration in choice of a tracer is that it can be analyzed in trace concentrations; in this business parts per million is a huge amount! The relevant tracer substances can be used and detected in IFE's laboratories at the parts per billion or parts per trillion levels. Using state of the art gas chromatographic and mass spectrometric methods these extremely low detection levels can be achieved, together with accurate identification of the tracers. Many feel that these new non-radioactive tracers for water flooding will become the industry standard within a few years, in the same way as has happened with the Institute’s non-radioactive gas tracers.

Water or gas is often injected into oil reservoirs in order to increase recovery factor. To prevent the injected water or gas moving rapidly through high-transmissibility zones in the reservoir, these zones can be plugged with substances such as foams. In this way the injected fluids are forced to move through the less transmissible areas of the reservoir where the remaining oil is located. Studies of foam formation mechanisms, and variations in foam efficiency with time, are underway in a collaborative project with the oil companies BP and Saga, using tracer technology. During 1996, a pilot project was carried out in the Snorre Field (North Sea), in which...
the new IFE-developed non-radioactive gas and water tracers were employed. Tracer analysis and tracer response simulation were performed using the STARS reservoir simulator. Results from this experiment have provided an important basis from which to develop a more optimal procedure for generating foam in the reservoir formation.

The next phase of the project will include studies of foam formation, flooding and long-term integrity by performing flooding experiments on sandstone core samples under reservoir conditions. The injected aqueous phases will be imaged with the help of a radioactive tracer-\(^{22}\text{Na}\) - which is well-suited as a tracer in saline water and is also simple to measure. As part of this work, a process has been developed for labelling foam-forming components (surfactants) with radioactive carbon-\(^{14}\text{C}\). This will provide information on the efficiency of surfactant absorption onto sandstone, and simplify the measurements of foam production time.

The characterization of geological formations plays an important role in studying and modelling heterogeneous oil reservoirs. Current reservoir studies are based on data from core samples of reservoir rocks, well logs, and seismic response. Because core samples are expensive to recover, studies must often be based mainly on log data.

Recent research results have shown that microresistivity data (with a resolution of 1-2 cm) contain important information about texture and variability in geological formations, in addition to angle of dip. Dipmeter logs are, however, extremely complex, and it is not always easy to distil out the required information. To help with the analysis of such data, IFE has developed a signal processing tool based on multifractal analysis. By generating so-called textural logs, it is now possible to distinguish between geological structures with different degrees of heterogeneity. These experimental logs are used as input to the software package DIPFAN (Dipmeter Facies Analysis), which has been developed by Agip/Schlumberger.

**MULTIPHASE FLOW**

The OLGA multiphase model is becoming the industry standard for analysing and designing North Sea oil-gas transport systems. The data on which OLGA is based are mainly derived from multiphase experiments performed with liquids of constant viscosity, often equal to that of water.

Oil-gas pipelines often have to transport relatively complex fluids, such as waxy oils, oil/water emulsions and hydrate mixtures. These behave in a completely different manner to the "ideal" oil that the computer models are based on.

IFE has now begun a research program in multiphase pipeline flow with complex fluids. This work is seen as very important to improve OLGA to tackle new problems in multiphase flow.

When the fluid temperature in an oil and gas pipeline is low, and when water is present, there is a danger that hydrates could form and block the pipes. As a precaution, bundles of pipes are often used rather than single pipes, each carrying a different fluid. The produced reservoir fluids, often a mixture of oil and gas, are transported in one pipe, corrosion-inhibiting chemicals in a second one, and warm water in yet another to control the temperature of the bundle.

In collaboration with Scandpower, IFE has developed a mathematical model for heat transport in pipe bundles for the Gullfaks satellite fields. This model has been integrated into OLGA in order to calculate the temperature in the oil stream along the pipe length. In this way it is possible to analyse the conditions under which hydrate blocking of the pipeline would occur, and to optimize the pipe dimensions to prevent this.

Carbon steel oil and gas pipelines are prone to attack from corrosive mixtures of water, \(\text{CO}_2\) and sometimes \(\text{H}_2\text{S}\), which may be co-produced with the hydrocarbons. Corrosion problems could be avoided by using stainless steel, but this would add greatly to development costs. Corrosion prediction models are important because they can be used to optimize the choice of materials in terms of performance and cost.
In a collaborative project with Saga, Statoil and Norsk Hydro, IFE started development in 1996 of a new prediction model for use within NORSOK. This model is based on curve-fitting to data mainly generated through laboratory experiments at IFE. In parallel with this activity, IFE is running a large project together with 9 oil companies and a steel manufacturer in which one of the main aims is to develop a completely new model for CO$_2$ corrosion in carbon steel. This model builds on mathematical modelling of the fundamental electrochemical and mass transport-controlled reactions.

Chemicals are often added to the fluid stream to inhibit corrosion. Their effect depends on water chemistry, the quality of the steel and the flow conditions. IFE is running an extensive experimental program in this area. Collaborating partners include Agip, BP and Statoil. This project has its background in problems with corrosion protection under slug flow conditions in BP's Prudhoe Bay field in Alaska.

In collaboration with Kongsberg Simrad a.s. (formerly Kongsberg Norcontrol Systems), new training and engineering simulators are being developed. For example, in 1996 a simulator was developed for the new production platform in the Ekofisk field. In petroleum-related areas, IFE exploits its expertise in mathematical modelling, process control and optimization in order to study different oil field development alternatives. Using reservoir models, well flow models and optimal production control, the economic and operational impacts of multilateral wells are being evaluated compared to conventional wells.

In collaboration with Hydro Aluminium, IFE is developing an advanced mathematical model for calculating stability relations in electrolysis cells. These cells measure about 10x4x3 m, and are constructed of a carbon anode at the top, with the electrolyte beneath (containing dissolved aluminium oxide) and beneath this a cathode consisting of a layer of molten aluminium, held in place by a carbonized frame. The electrolysis current, together with current in all the conductors, creates a strong magnetic field. The interaction between the magnetic field and the electrical current generates an electromagnetic force, the Lorentz force, that causes movement in the metal and electrolyte and can under certain conditions cause instabilities in the interface between the electrolyte and molten metal. The mathematical representation of this phenomenon gives rise to a special class of mathematical problems. Links have been established with the University of Utrecht in Holland to work these problems further.

In a collaboration with Hydro Aluminium and the Automotive Research Centre at Raufoss, IFE has developed a mathematical model for aluminium welding. This forms part of the PROSMAT project...
Aluminium Structures in the Transport Industry. The aim is to model microstructures, mechanical properties, residual stresses and deformations in welded complex frameworks of extruded structures. One model for microstructure and hardness has been implemented in a thermal model of welding. Calculations of temperature development and hardness have agreed well with experimental measurements.

In a project for the Nordisk Jernkontor, the STEELTEMP model has been expanded to incorporate routines that calculate the basis in materials data for phase transitions during steel rolling and cooling. The model can now handle the heat treatment of steel bands, where such effects are significant. STEELTEMP is also suited to calibrating control systems for heating steel blocks. A licensing agreement has been entered into with ABB, who market such control systems internationally.

IFE is involved in several projects in the area of renewable energy systems, for example wind power and solar cell technology. In a collaborative project with Libra Plast and CFD Norway, development work is continuing on modern wind turbine blades. In collaboration with Elkem silicon division, solar cells are being developed.

Energy systems analysis, based on the MARKAL model, is aimed at cost and technology-choice issues when attempting to meet targets for environmentally harmful gas emissions, and on the analysis of the role of special technologies and their introduction into the energy system (e.g. fuel cells). In this area, collaboration has been established between NILU, ECON, FNI and CICERO, through the Norwegian Consortium for Energy and Environment (NORCE), who market this expertise internationally. In 1996, IFE and NILU, together with ECON and CICERO began a NORAD-financed project in Guangzhou, China. This 3-year project will establish a system for analysing the harmful effects of air pollution and measures for reducing atmospheric emissions in the Guangzhou region.

IFE has built up a significant know-how in the area of industrial energy efficiency. Under contract to the NVE (Norwegian Water Resources and Energy Administration), IFE runs the program "Industrial Energy Efficiency Network." Almost 500 Norwegian companies are participating in this program, and industrial trade organizations are involved in directing the program. Member companies report annually their data relating to production and energy consumption. This is collated and presented in such a format that allows the companies to determine their own course in relation to their anonymous competitors.

Hunton Fiber A/S produces wood fibre boards from timber.
An important part of the production process is drying. Presently there are no instruments capable of making on-line measurements of moisture content in the production line, so IFE was commissioned to remedy this situation. The IFE-offshoot firm LokalData Instruments A/S will collaborate with the Institute to develop an instrument based on nuclear measuring principles - deceleration of neutrons on collision with hydrogen nuclei. This instrument will be used for controlling the drier and measuring the fibre mass.

A laboratory model has been developed at IFE consisting of a neutron source and detector. Measurements demonstrated a clear relation between the moisture-free content of the wood fibre boards and nominal density. The model also measured moisture content with satisfactory accuracy. A prototype of the instrument is now under development, with trial installation scheduled for 1997.

Spent reactor fuel and samples of radioactive materials are analysed in specialized laboratories at Kjeller. All operations and measurements are carried out remotely, using mechanical and electronic manipulators inside radiation-shielded cells. A range of physical, mechanical and chemical methods, destructive and non-destructive, is employed to characterize fuel properties and to verify measurements from irradiation experiments in the Halden reactor.

Much of the research on safety, improved burn-up and extended fuel lifetime requires instrumentation and refabrication of irradiated fuel. In 1996, twelve fuel rods from an American nuclear power station were refabricated and instrumented with temperature and pressure sensors to study phenomena such as the generation of fission gasses in the fuel, a factor that is closely connected to improved operational reliability and increased fuel lifetime. Seven fuel rods from British AGR reactors were also refabricated and instrumented in 1996. So far over sixty fuel rods from reactors in the USA, England, Japan, Switzerland, Sweden and Germany have been refabricated and instrumented at Kjeller, followed by further irradiation and testing in the Halden reactor.

During 1996 the production facility for new fuel has been upgraded and renewed. This facility produces standard and experimental fuel for IFE's two reactors.

IFE's capacity in electron beam (EB) welding are among the largest in Scandinavia. The Institute's 3 EB machines are used for welding fuel rods, nuclear fuel instruments and experimental equipment. Product development and production welding account for more than half of the work load, most of this in collaboration with Norwegian and foreign companies. Aeroplane and spacecraft components in steel, titanium and aluminium are among the products with demanding standards that the Institute fulfills for Raufoss A/S, the Kongsberg Group and the Norwegian Air Force.

During 1996 a program of production welding was carried out on end sections of Swedish commercial reactor fuel, along with test welding of a new product for Raufoss A/S which could yield a significant export volume in years to come.
Most of the nuclear-related work at Kjeller is based on the operation of the JEEP II reactor, and the continued running of the reactor is thus a necessity. This kind of work includes:

- Basic research in physics
- Development and production of radioactive medicines (radiopharmaceuticals)
- Irradiation of materials for various technical applications

During 1996 the reactor maintained a high degree of availability and there were few operational disturbances. Technical and safety standards were maintained by a well-planned program of maintenance and improvement work. A new system for being able to rotate the isotope channels has improved the quality of irradiated products.

Neutron irradiation in the JEEP II reactor is used to create radioactive materials for use in the production of radiopharmaceuticals and radiochemicals. Radioactive tracers are also produced, along with radiation sources for use in industry and research.

Neutron irradiation is also used in the treatment of superpure silicon crystals. Neutron doping generates in the crystals an evenly distributed content of phosphorous atoms, thereby optimizing their electrical conductivity. IFE's activity in this area covers about 10% of the world market for such products.

The Institute's gamma irradiation plant is based on ionizing radiation from a radioactive cobalt (60Co) source. The radiation is used to reduce the bacterial content of various products, and to sterilize disposable medical equipment and other materials. The main users of these services are the foodstuffs industry, the plastics industry, and manufacturers of disposable medical equipment and packaging. The most important product group at present comprises spices and other flavorings for the foodstuffs industry. Almost 400 tonnes of these products were treated in 1996.

Materials science is today developing internationally at a rapid pace, and extensive research is going on in all of the industrialized countries. A number of important material properties can only be studied using neutron scattering techniques. These include structural investigations of materials such as single crystals, powders, macromolecules, liquids, liquid crystals and porous media with special physical, chemical and biological properties. Aerogels are light porous materials that can contain up to 95% air. They can occur in a variety of different forms. In a collaborative program with the Institute for Inorganic Chemistry at NTNU, neutron scattering is being used to study the formation processes and microstructures of silica aerogels. Because of their porous structure, aerogels are well suited to being used in insulation, for example in windows, especially since some of these substances are transparent.

Neutron beams that pass through such samples change direction when they interact with the gossamer-like microstructure. From information that is contained in the scattering patterns produced, it has been discovered that the pores in this material progressively fill up during curing under the influence of a catalyst. This increases the strength of the material, and makes it possible to tailor-make materials for different purposes. Presently much research work is being carried out internationally on the development of new forms of mathematics and physics to help describe so-called complex processes, such as the weather, or turbulence in a fluid stream or in boiling water. During 1996 the research group at the Institute has delineated a new direction in chaos research that has attracted international attention, using so-called knot and braid theory. The interplay between randomly moving Ugelstad monodisperse microspheres that mutually influence each other has been studied, and these spheres can be used as simple models for turbulence. For example, the path followed by the spheres can be considered as a complex braid-like pattern in space. This part of knot theory is thus called braid theory. The inherent order or disorder of the braids can be represented as a code, much as a game of chess can be coded.
using a series of letters and numbers. The braid patterns defined by randomly moving Ugelstad spheres are in many ways reminiscent of strands of DNA in which each molecule is a very long strand containing billions of "letters" in a long list of "words."

Analysis of the braid patterns defined by Ugelstad spheres reveals that some "words" occur more often than others. This means that certain patterns of movement are repeated more often than others. This method has the possibility to open up a whole new direction in the interpretation of neutron scattering results in materials research.

The history of knot theory in some ways illustrates the very nature of science, and the strong links between physics and mathematics. About 130 years ago, the physicist Lord Kelvin proposed that atoms consisted of small knots in the ether. The idea was wrong, but diligent mathematicians continued to work for over a century on the knot's innermost secrets. Without Kelvin's knot-atom theory we would not have today the well-developed mathematical tools that enable us to see with new eyes these natural phenomena.

After several years preparation, a new neutron diffractometer PUS (Powder Universal Spectrometer) has now been fully tested. The new PUS is about 50 times more efficient than the old instrument OPUS (Old PUS). The instrument, which cost around NOK 5 million (with a 50% contribution from the Research Council), will be a great step forward for Norwegian materials research.

All radiopharmaceuticals that are presently used in the nuclear medical departments of Norwegian hospitals are distributed via the isotope laboratories at Kjeller. Here, the products pass through pharmaceutical and radiation protection-related controls before being forwarded to the hospitals. The isotope laboratories have established safe and effective transport routes from the different manufacturers to the end users. This is important because the radionuclides used in medicine often have a very short shelf-life, and thus cannot be stored for long. During 1996 around 6500 regulated consignments of radioactive medicines were sent out from the isotope laboratories.

Radiopharmaceuticals are applied mainly in diagnostics, for organ visualization and for studying organ function. However, the use of radioactive medicines therapeutically and for pain-silleviating treatments is on the increase. Hospital nuclear medical departments, and research laboratories in Norwegian universities and colleges form the largest customer groups for the products.
The isotope laboratories also deal with the special production of radiopharmaceuticals that are not readily available on the market. Also, radioactive labelling of peptides, proteins and other relevant substances is carried out for use in research and clinical studies. Using such compounds, the movement and distribution of a substance in the body can be monitored and measured. Education is another important part of this activity. This includes lectures and practical courses for personnel in the various user groups, and education of university students in nuclear medicine and radiopharmacology.

The newly established firm Isopharma AS and the isotope laboratories together provide topics for postgraduate research theses at the Pharmacological Institute, University of Oslo. In this way, postgraduate students can benefit from exposure to a wide range of expertise in this field of technology. Additionally, in the transition period, the isotope laboratories have provided help to Isopharma AS by loaning out experienced operators to help with the production and quality control of radiopharmaceuticals.

Patients who have malignant metastases (secondary tumours) in their bone marrow can survive for many years in this condition. The treatment of such patients aims to relieve pain, improve mobility, and thus improve quality of life. Traditional forms of pain relief for bone metastases are radiation therapy, surgery, chemotherapy and the use of analgesic substances that work on the peripheral or central nervous systems.

During 1996, the isotope laboratories continued development of a product for internal irradiation treatment. Samarium-153, which is produced routinely in the JEEP II research reactor, is a radionuclide with useful radiation properties for pain relief in secondary bone metastases. The radionuclide is coupled to a carrier molecule (methylene diphosphonate) which is taken up by the bone marrow. In this way the radioactive material is transported directly to the cancer cells, which it destroys. However, the irradiation has such a short penetration distance that healthy cells nearby are unharmed. Preliminary clinical results for Samarium-153 appear promising, and with this form of treatment the cancer cells can be given a radiation dose double that which can be achieved by external irradiation of the tumours.

Research projects and contract work in radiation protection, radioecology and radioactivity measurement form an important part of the work program. The Institute now participates in multinational research projects in the EC’s radiation protection program in the area of radioecology, and in a number of Nordic collaborative nuclear projects.

Several projects are being carried out for the Norwegian authorities. For example, IFE participates in the Norwegian-Russian expert group for investigating radioactive pollution around the Mayak plant in Russia. The results have now been published in a White Paper that provides a description of the plant’s history and the discharges and accidents that have led to the extensive radioactive pollution of the surroundings. The aim of this work is to analyse the possible consequences of incidents at Mayak for pollution of Arctic marine environment via the 2000 km long Ob river system.
THE Halden PROJECT: FUEL - AND MATERIALS TECHNOLOGY

Akselsen, L., Skarbhammar, T.
Some applications of WMD in the analysis of experiments on improved fuel performance at the OECD Halden Reactor Project.

Ahare, M.T., Hirni, M., Wiesnek, M.
Analysis of the thermal behaviour of Gil-Sberg fuel in IFAs 615/10.

Barro, F.
Fuel temperature constant determination using thermal analysis.

Bennett J.P.
The local effects of zinc addition on cobalt deposition in PWRs.

Bennett J.P.
Cohort Deposition Studies in the Primary Circuit under BWR Conditions.
(HWR-478).

Bennett J.P.
The Incorporation of Zirc into Oxide Films in PWRs.
(HWR-498).

Cavet, N.
Investigation of delayed fission gas release.

Devold, H., Lemeshov, S.E., Yakovenko, V., Rodda, K.
Competition of thermal and mechanical behaviour of PWR/WWE fuel in IFA 503.

Ikeda, K., Kolstad, E.
In-pile determination of thermal conductivity of oxide layer on LWR cladding. Final report.

Ikeda, K., Kolstad, E.
In-pile determination of thermal conductivity of oxide layer on LWR cladding. Final report.

Jensen, B., Lemeshov, S.E., Devold, H.
Model analysis of the HWR IFA 503-L PWR/WWE comparative test results.

Kasimh, M.
Comparison of models for zircaloy cladding corrosion in PWRs.

Makoli, K., Pettersen, K.J.
Current status of Pd-reference electrode exchange system.

McGraw, M.A.
In-reactor creep behaviour of Zircaloy-2 under variable loading conditions in IFA 603.

Nieuwenhoven, R. van
Assessment of fuel temperature sensor degradation effects during in-pile service.

Pettersen, J.K., Gunnerud, P.
Overview of LWR loop facilities and water chemistry at Halden.

Skarbhammar, T., Akselsen, L., Wiesnek, M.
Application of advanced reactor physics methods in the analysis of experiments on improved fuel performance at the OECD Halden Reactor Project.

Vankeerberghen, M.
Fuel rod failure in the integral fuel rod behaviour test IFA-507.

Vitrus C.
Fuel irradiation experiment at Halden.
The 11th Joint annual conference of the Korea Atomic Industrial Forum, 1996.

Vitrus C.
AES Conference, Sendai, Japan, 1996.

Wallin, H., Kolstad, E.
The high burnup rim project IFA-601.
Final report on the Halden irradiation.
3rd HBR SC Meeting, Kawasaki, Japan, 1996.

Wiesnek, W., Vankeerberghen, M., Thakappan, R.
Assessment of UO2 conductivity degradation based on in-pile temperature data.

Wiesnek, W.
Fuel testing capabilities and high burnup data for modelling and safety analysis.
IAEA research coordination meeting on fuel modelling at extended burnup.
(FUEMEX, Bombay, India, 1996).

Wiesnek, W., Kolstad E.
OECD Halden Reactor Project Fuel Test Facilities and Irradiation Techniques.Determination of fuel behaviour and high burnup effects.
LANEBS Seminar, Argonne, USA, 1996.

Wiesnek, W., Kolstad E.
OECD Halden Reactor Project Fuel Test Facilities and Irradiation Techniques.Determination of fuel behaviour and high burnup effects.
LANEBS Seminar, Argonne, USA, 1996.

THE HALDEN PROJECT: COMPUTER -BASED PROCESS CONTROL AND INDUSTRIAL SURVEILLANCE - AND CONTROL SYSTEMS

Akerberg, T., Louska, M.
The software bus: An object-oriented data exchange system.

Berg, O., McEllin, M., Jasadi, M.
Application of the Core Surveillance system SCORPE at Sizewell B.
 Specialists’ Meeting in In-Core Instrumentation and Reactor Core Assessment, Mito, Japan, 1996.

Bjelaj, T.J., Berg, O.
Use of computer based operator support systems in control room upgrades and new control room designs for nuclear power plants.
ANS International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Interface Technologies, Pennsylvania, Pa., 1996.

Folleso, K., Kaarstad, M., Drevoldo, A., Hollnagel, K., Kirwan, R.
Practical insights from initial studies related to Human Error Analysis Project (HEAP).

Fordstrommen, T.N., Knolmen, J.
Halden Man-Machine Laboratory as of 1996.

Gran, B.A., Thunem, H.
Experimental investigation of software testing and reliability assessment methods (EASTRAM).

Gronen, A.K.
Formal specification of real-time systems.

Hallbrett, J.P., Sebok, A., Persanski, J.J., Montesano, D.
Results of the study of control room crew staffing for advanced passsor reactor plants.

Hallbrett, J.P.
A summary of lessons learned activities conducted at the OECD Halden Reactor Project.
24th WRSM, Bethesda, USA, 1996.

Haugset, K.
Design principles and evaluation of human-machine interfaces for use in control centres.
HM Seminar by KEMA, København, 1996.

Hollnagel, E., Drevoldo, A., Kirwan, R.
Practical insights from studies of operator diagnosis.
4th European conference on cognitive ergonomics (ECCE-8), 1996.

Hollnagel, E.

Hollnagel, E., Wraithall, H.
HRA at the turning point?
PSAM 3, Kreta, 1996.

Hollnagel, E., Brannad, P.O., Drevoldo, A., Folleso, K., Holgar, S., Kaurstad, M.
Human Error Analysis Project: The fourth pilot study: Scoring and analysis of raw data.

Hollnagel, E., Niwa, Y.
A cognitive systems engineering approach to computerised procedure presentation.
SEPC 96 Conference, Kyoto, Japan, 1996.

Hollnagel, E.
On the road to «human error».
The Top Meeting on Probabilistic Safety Assessment, Park City, Utah, 1996.

Development of a control room philosophy: A study for development of an advanced computerised BWR control room design concept in Sweden.
ANS International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Interface Technologies, Pennsylvania, Pa., 1996.

Iijima, T.
Application study of fuzzy logic methods for plant state identification.

HAMMALAB 2000: Long-term perspectives for use of HAMMALAB.

Fantoni, P.F.
Neuro-fuzzy models applied to full range signal validation in nuclear power plants.
ANS Int. Topical Meeting on Nuclear Plant Instrumentation, Control and Human Interface Technologies, Pennsylvania, Pa., 1996.
A case study on the formal development of The Halden Reactor Project Workshop on Wien, 1996. 
Advantages and disadvantages of hydrate studies of Operator Performance during Night Shifts.
Moum, B.R., Decurnex, C., Fredestrommen, N.T., Karlsen, T.V., Olsen, T.V.
Lund, P.C., Mathisen, K.W., Nedrelid, 0., Slora, B.R.
Nordrelid, O., Petterson, G.
Development of simulator configuration tools.
Sobol, A.L., Halbrett, B.F.
Crew performance issues in nuclear power plant process disturbances.
ASISOFT Meeting on Nuclear Plant Instrumentation, Control and Human Interface Technologies, Pittsburgh, Pa., 1996.
Sivertsen, T.
A case study on the formal development of a reactor safety system.

RESERVOIR TECHNOLOGY, PETROLEUM TECHNOLOGY, THERMAL TECHNOLOGY, INSTRUMENTATION AND ANALYSES

Andresen, B., Throntsen, T., Johannsen, I.
Characterization of saturated fraction of a North Sea crude oil: Stochastic reconstruction and dynamic properties.
Meeting in Organic Geochemistry, Bergen, 1996.

Bagø, O.E., Throntsen, T.

Bagø, O.E., Lyssel, F.T., Throntsen, T., Pedersen, T.
Predicting prediction of hydrocarbon change to the Nyk High, Vering Basin. Meeting in Organic Geochemistry, Bergen, 1996.

Eriksen, D.O.
Production of some radioalladinated compounds for tracing flow in porous media. PhD. Radiological Nodular Measurements and Application, Raleigh, N.C., 1996.

Johanssen, H., Åberg, G., Ringås, J.E., Khíkha, L., Skoog, J., Holstad, A., Lacharpagne, J.C.
An integrated isotopic approach to the assessment of reservoir anatomy: A case study from a North Sea Middle Jurassic reservoir.

AAGF/EAGE Reservoir Symposium, Houston, Tex., 1996.
Johanssen, H., Idorn, K., Åberg, G., Stray, H.
A new isotopic approach to the assessment of reservoir properties.
EAGE Conference and Technical Exhibition, Amsterdam, 1996.
Johanssen, H., Pedersen, T., Wangen, M.
Controls on CO2 budget in deep and ultra deep sedimentary basins: importance of mineralization and diagenetic reactions for gas composition, carbonate cementation, and for preservation of porosity at great depths.
Johanssen, H., Pedersen, T., Throntsen, T.
Depth control of diagenetic carbonate seals.
Johanssen, H.
The DAPERD Project: An example of research cooperation with ELF from basic research to commercialization.
French-Norwegian Seminar, Trondheim, 1996.

Kihlé, J., Throntsen, T.
A case-study of continuous non-destructive hydrocarbon qualification and quantification.
Meeting in Organic Geochemistry, Bergen, 1996.
Klæve, R., Dahl, J.B., Hjørnestad, T., Qvemil, C., Tollan, O.
Use of technical tools for fracture detection and completion fluid invasion studies.
Klæve, R., Høring, O., Opdal, J., Bjornstad, T., Dugstad, A., Hundere, I.A.
Non-destructive tracer of injection gas in reservoirs.
Müller, J.
Characterization of pore space in chalk by multifractal analysis.
Müller, J.
Image analysis and multifractal statistics as tools for predicting permeabilities of sedimentary rocks.
Müller, J.
Multifractal analysis of dipmeter well logs for characterization of geologic facies.
Müller, J.
Multifractal analysis of heterogeneous porous materials.
Lecture at the Federal University of Santa Catarina, Brazil, 1996.
Müller, J.
Porous media activities at Institute for Ergotropicology.
Lecture at the Oil and Gas Research Institute of Academy of Sciences of Russia, 1996.
Meeting in Organic Geochemistry, Bergen, 1996.
Pedersen, T., Johannsen, H., Wangen, M.
Flow along fractures in sedimentary basins.
Chapman and Hall, 1996.
Pedersen, T., Bjørlykke, K., Johannsen, H., Wangen, M.
Flow along fractures in sedimentary basins: Flow along fractures.
Pedersen, T., Johannsen, H., Throntsen, T.
Heat flow and geochemical modelling at the Voring and Møre volcanic margins.
Meeting in Organic Geochemistry, Bergen, 1996.
Pedersen, T., Skog, J., Johannsen, H., Throntsen, T.
Integrated leucogranitic and basic modeling at the Voring Basin volcanic margins: magmatism, source and reservoir rocks.
Pedersen, T.
TECTONIC, MAGMATIC AND BASIN MODELLING OF THE VOLCANIC VORING KLINGEN.
EUROCORREL conference: Origin of Sedimentary Basins, Torskaava (Finland), 1996.
Pedersen, T., Skog, J., Throntsen, T.
Volcanic margin formation and exploration potential: The Voring Margin.
EAGE Conference and Technical Exhibition, Amsterdam, 1996.
Sagen, J., Cvetkovic, R., Brandstad, E., Hahovsen, B., Bjørnstad, T.
Reservoir chemical-thermal simulation with tracers.
European Petroleum Conference. (SPE-39521).
San cuier, A.
Scaling properties of disordered multifractals.
Siberg, J.P. et al.
Fission track thermochronology applied to late Proterozoic and Phanerozoic thermal and tectonic events in Sweden.
Throntsen, T., Hidde, S., Unander, A., Huang, J.
A practical concept for effective utilisation of basin modeling results in exploration.
Meeting in Organic Geochemistry, Bergen, 1996.
Wangen, M., Hahovsen, G.
The interaction of a rectangular fracture with the host rock.
Åberg, G.
Naturally occurring isotopes: A dynamic approach to the understanding of environmental processes.
Int. Symp. on Acidic Deposition and its Impacts. Tsukuba (Japan), 1996.
Åberg, G., Stiftbohm, D., Loevendahl, R.
Weathering and conservation depth determined by carbon isotopes released by laser ablation.
Int. Symp. on Acidic Deposition and its Impacts. Tsukuba (Japan), 1996.

MULTIPHASE FLOW AND CORROSION TECHNOLOGY, EXPERIMENTAL FLOW-TECHNIQUE

Brandt, I., Lande, L.
Multiphase flow: A strategic technology for offshore development.
Seminar and Workshop on Norwegian and Indonesian Science and Technology for Sustainable Development, Jakarta, 1996.
Espedal, M.
An experimental investigation of stratified two-phase flow in near horizontal pipes at atmospheric pressure.
European Two Phase Flow Group Meeting, Gronsvold, 1996.

PROTECTION MODELLING AND CONTROL

Harre, K., Skogstad, S.
Zoned of EHP areas and rules on performance in multivariable systems.
Control 96, Exeter (England), 1996.
Harre, K., Skogstad, S.
Input output control and partial control. 15th IFAC World Congress, San Francisco, 1996.
Harre, K., Borg, P.
Harre, K., Morard, J., Skogstad, S.
Selection of feedback variables for implementing optimal control schemes.
Control 96, Exeter (England), 1996.
Harre, K., Skogstad, S.
The use of RQA and condition number as robustness measures.
Sira, T., Lundstrom, P.
Real time simulation of a VCM cracking plant.
SIMES 96, Trondheim, 1996.

RENEWABLE ENERGY

Gaudernack, B., Lyrum, S.
Hydrogen from natural gas without release of CO2 to the atmosphere.
Institutt for energiteknikk
Institute for Energy Technology