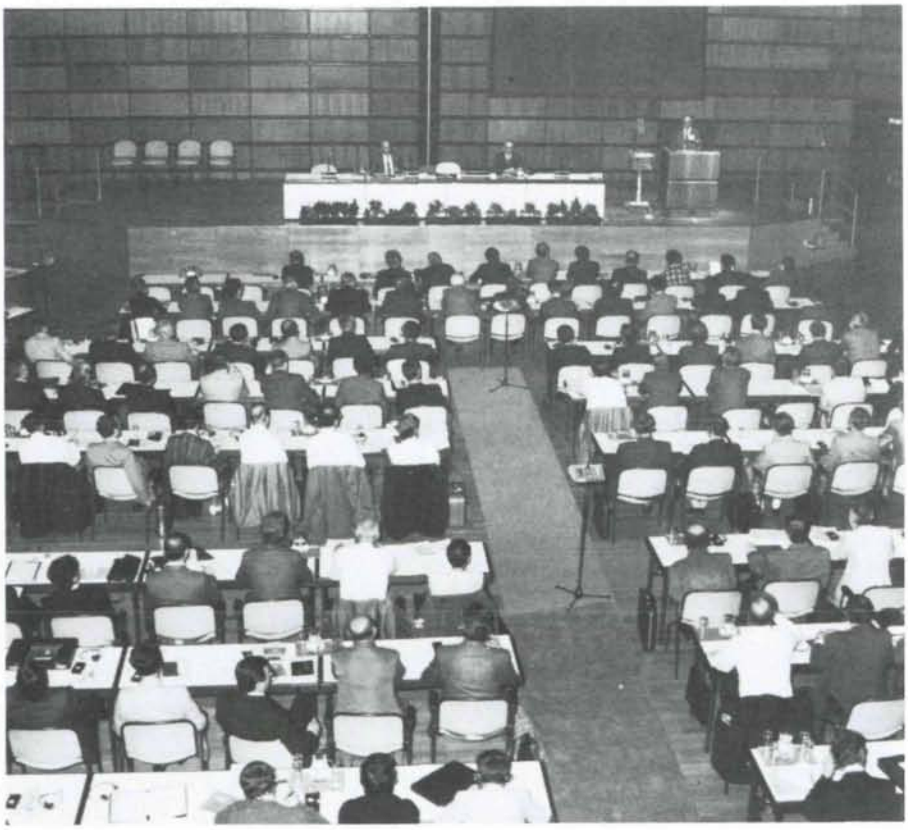
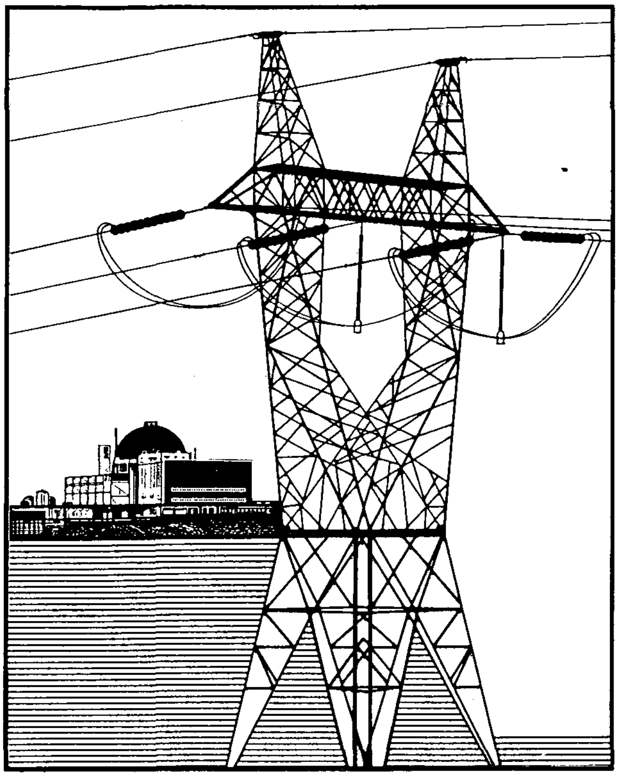


The IAEA's International Conference on Nuclear Power Performance and Safety from 28 September to 2 October in Vienna was attended by experts from about 40 countries. In conjunction with the meeting, the Soviet Union held a press conference on 30 September regarding aspects of its nuclear power programme. Soviet officials who participated included (from far right) Mr N. Lukonin, Mr A. Petrosyants, Mr V. Malyshev, Mr A. Abagyan, and Mr L. Ilyin. (Credit: Katholitzky for IAEA).



Nuclear power performance & safety

Highlights of the IAEA's international conference

by L.L. Bennett, J. Fischer, and A. Nechaev

National and international efforts to improve the performance and safety of nuclear power plants were among a wide range of technical and economic issues addressed at the IAEA's International Conference on Nuclear Power Performance and Safety, which concluded in Vienna in early October 1987.*

In his statement opening the conference, IAEA Director General Hans Blix noted that the meeting was the latest in a series that have marked major milestones along the course of nuclear energy's development. The series includes the four Geneva Conferences (the last two of which had programmes under the IAEA's responsibility), the 1977 Salzburg Conference on Nuclear Power and its Fuel Cycle, and the 1982 Vienna Conference on Nuclear Power Experience. Each of these conferences marked an important stage in the development of nuclear power and served to summarize the collective knowledge by pulling together information from many countries. This last conference also proved to be timely and important in providing a useful overview of recent experiences and information about goals and objectives in countries with nuclear power programmes, and in giving information on the sometimes painful reassessment of nuclear power programmes which has been undertaken in some countries during the past year.

Nuclear power development

Energy and nuclear power needs

In his summary statement at the closing session, Mr W. Kenneth Davis, consultant to the Bechtel Group Inc. and former US Deputy Secretary of Energy, stated his conviction that energy (including electricity) is one of the fundamental *requirements* for economic growth and social improvements, and not just a *consequence* of such growth.

Mr Davis concluded that the need for nuclear power is clearly related to the need for electric power, as well as to the availability of options for producing it. The need for electric power is generally related to the need for total energy but it is not, as was made clear in several papers presented at the conference, directly dependent on it. The rate of growth in demand for electric power generally exceeds substantially the rate of growth in demand for energy. The result is that the proportion of primary energy used for production of electric power increases in almost all countries. In the developing countries the rate of growth of demand for energy and electricity, as related to economic growth, is much higher than in developed countries. This leads to serious financial problems when the cost of energy is high.

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* Held from 28 September to 2 October 1987 in Vienna, the conference was attended by about 500 participants from 40 countries and 12 international organizations. Nearly 200 papers from 26 countries and six international organizations were presented and discussed. Proceedings are available from the IAEA.

These points were supported by the presentation given by Prof. H.J. Laue on behalf of the World Energy Conference.

In a paper presented by the IAEA, it was reported that nuclear power capacity in developing countries is expected to increase more than twofold up to the end of the century, corresponding to the addition of about 40 gigawatts-electric (GWe) of nuclear power capacity. During the same period, installed nuclear power capacity in industrialized countries is expected to grow by 65%, an increase of 170 GWe. Thus, 25% of all new nuclear power capacity to be placed in operation up to the year 2000 will take place in developing countries.

In spite of this achievement, the share of the world's nuclear capacity located in developing countries is likely to remain at modest levels for the foreseeable future. Therefore, up to the year 2000, the major share of electricity requirements of the developing countries will be supplied from conventional thermal and hydropower sources.

Economics and performance

The future growth of nuclear power capacity is closely related to the question of the economics of nuclear power as compared with other alternatives. In many countries further hydro development is not economic nor practicable, oil and gas are expensive for power generation, and possibilities for substantial economic contributions from other sources such as solar or wind are minimal. This generally leaves coal or nuclear as the choice — many countries either have coal or the opportunity for importing it, but not necessarily at favourable prices. Papers from India and China presented results from studies showing the high total investment requirements for large-scale expansion of coal-based electricity generation as compared with the same expansion based on nuclear power plants.

Based on the presentations, there seems to be universal agreement that nuclear power plants built and operated as well-managed projects will continue to be competitive with coal for large central station plants in most areas of the world, except where coal is available locally at favourable prices on a long-term basis. One important point raised was that, once they are built, nuclear power plants provide a stable cost for electricity generation that is affected very little by inflation.

Sustained record of excellence

In his opening remarks, Dr Blix stated, "I believe that we have to assume that only a sustained record of excellence in performance and safe operation of nuclear power plants worldwide can help to overcome the fears which exist among the public due to its unfamiliarity with the phenomenon of radiation and which have been exacerbated by the accidents which have occurred. It will not suffice to explain that any industrial activity — including energy production — entails some risk. We have to accept that safety standards for nuclear plants will need to be set at higher levels than for any other industrial plants. This is recognized by the nuclear power industry everywhere and forms the basis of the programmes of both industrial and governmental authorities.

"Fortunately," he added, "safety and good economic performance go hand in hand. There is an economic incentive to achieve a smooth, reliable running of nuclear power plants."

He also noted the performance improvement since the Conference on Nuclear Power and its Fuel Cycle in 1977. At that time, the average energy availability factor for the 137 nuclear power reactor units reported to the IAEA Power Reactor Information System (PRIS) was only 64.7%; in 1982, at the time of the next major conference, the number of nuclear reactor units had increased to 200 but the average availability factor remained around 65% — a figure which gave cause for concern. By 1986, the most recent year for which complete data are available, that figure had improved to 70.4% for the 288 nuclear power reactor units listed in PRIS. It is even more significant that 55% of these nuclear power units are operating with an energy availability of 75% or better. Indeed, since 1984 some 40% of the units are consistently reporting an availability of more than 80%.

These data clearly show that lessons can be learned through international conferences and other means, by improving the exchange of information and highlighting the standards of performance which can be achieved.

Targets for the 1990s

Cost reduction. It was reported that a 35% reduction in the fore cost (also called "overnight construction cost") can be achieved by extensive plant standardization. Further cost savings can result from reductions in time-related charges, due to shorter construction periods.

Beyond the well-established industry trend in France, there are clear signs of further moves toward standardization policies — the Convoy concept in the Federal Republic of Germany (FRG) and the future standardization programme embodied in the Advanced Light Water Reactor Program of the US Department of Energy (US DOE) and Electric Power Research Institute.

Based on the Convoy concept, the engineering manhours required for a plant started in the early 1980s would be reduced by about 38% as compared with a non-standardized plant begun in the late 1970s. Extending standardization to all but site-specific plant components will allow 70% of all engineering documents to be available when the conceptual design is completed, and it will allow 90% of the engineering effort to be completed prior to the start of construction. This thus provides electric utilities greater confidence in the cost and schedule estimates and in meeting plant economic goals. Also, costs are minimized and construction lead times are shortened because of increased scope for preassembly and prefabrication of civil structures, and computerized project management and work-control procedures.

Operating performance improvements. A longer operating cycle for better plant availability is a central goal of the nuclear industry, and improved core-design concepts are being developed to achieve longer in-core residence times of fuel assemblies. (The conference summation on the nuclear fuel cycle in the following section provides further information on this topic.)

Regarding plant availability, planned outages for refuelling, maintenance, and repairs account for some 70% of the overall unavailability for a light-water reactor (LWR); hence, it is important to shorten these times. Achievements in reducing total planned plant downtime have been good so far, with reduction from an average duration of 70 days in 1982 to 41 days at present; however, there is still room for further improvement in outage management.

With a view to using planned outage time more effectively, the nuclear industry is exploring ways to remove some outage activities from the critical path so that parallel jobs can be performed. For example, the use of special pressure vessel nozzle plugs makes it possible to drain the loops with the reactor flooded, thereby allowing simultaneous testing and inspection of the pressure vessel, primary pumps, and steam generators. Also, the use of special manipulators and development of new service equipment helps reduce time requirements and radiation exposure of the maintenance personnel.

Stabilized licensing. The resolution of the institutional aspects of a standardization effort and the establishment of a stabilized regulatory regime are important targets of the nuclear industry for the 1990s. The aim is to introduce stability and predictability into the plant licensing process and to remove the open-ended nature of the present process. In some countries, the present regulatory uncertainty is still regarded as too high-risk for investors, which may discourage public utility investments in new nuclear plants, regardless of their safety, reliability, or economic merit. In the USA, changes are now being proposed which would allow one-step combined construction and operating licenses, preliminary and final plant design approvals, and the implementation of a plant design certificate license which would be a reference basis for a 10-year period. In the mid-1990s, an electric utility should be able to select a design-certified plant concept and combine it with a pre-approved site in order to obtain a combined construction and operating license within a relatively short regulatory review period.

Nuclear power safety

Essentially all countries with nuclear power plants have carefully analysed the Chernobyl accident in relation to the safety of their own nuclear power plants and have concluded that the type of accident occurring at the Chernobyl RBMK reactor would not happen in other types of power reactors. Nevertheless, issues of nuclear power safety, in particular for RBMKs, were the focus of more than 70 conference papers.

Severe accidents

High interest was expressed in papers presented by the Soviet Union on actions taken in response to the Chernobyl accident and on its health effect. *(See the article on this subject in this edition.)* They updated the information available at the time of the IAEA's Post-Accident Review Meeting in 1986. The experience with entombing Chernobyl Unit-4 was reported, and it was noted that no problems arose during this first year of entombment. The reported drops in temperature and in the level of radioactive material released clearly showed the stabilization of conditions.

The treatment of the reactivity control problem, which is typical for RBMKs, was of particular interest to safety specialists. According to the Soviet papers, the Government's intentions (as previously expressed during the 1986 Post-Accident Review Meeting at the IAEA) have been slightly modified with respect to the question of backfitting plant control and shutdown systems. The rod insertion speed has been increased (by a factor of approximately 1.7). Changes also have been made in the number of rods, in the positioning of rods and water displacers in the core, and to the monitoring capability. Further modifications are under development. Another important change is to gradually introduce 2.4% enriched fuel in all RBMKs, in conjunction with leaving a larger number of control rods in the core, in order to reduce the void coefficient of reactivity. As a result of all measures, the void coefficient still remains positive and a certain economic penalty has to be borne, but the safety characteristics are considerably improved. In the context of this discussion, a Canadian paper extensively presented the features introduced a long time ago in the Candu reactor to operate it safely, even under the assumption of accidents with rapid voiding.

There were several papers dealing with the radiological situation after Chernobyl. The USSR reported on the measurements and evaluations of the fallout from Chernobyl.

One value may be quoted for orientation: The expected collective committed dose to the USSR population over 50 years due to the Chernobyl accident will be less than 330 000 man-sievert. On average, this is approximately 2% of natural background exposure during this 50-year period. *(See the related article in this edition.)*

Other papers concerned the radiation consequences in the agro-industrial production sector of the USSR, and the environmental consequences of Chernobyl in Western Europe, specifically, in countries of the European Community (EC). This paper estimated a dose commitment for the EC population of approximately 80 000 man-sievert. It further estimated an average individual effective dose due to Chernobyl of a few hundred micro-sievert during the first year in countries that were most affected.

Although no changes in safety features are considered necessary in pressurized-water reactors (PWRs) or boiling-water reactors (BWRs) as an immediate consequence of Chernobyl, the discussion of severe accidents has received greater emphasis during the last year, a fact reflected in many papers. A presentation on behalf of the IAEA's International Nuclear Safety Advisory Group (INSAG) concluded, among other things, that accident management is a fruitful path to risk reduction, and that another important goal must be to protect the containment function. Developments related to these two topics started before Chernobyl, but it is probably not pure coincidence that formal licensing decisions on containment venting have been made in some countries since the accident.

While there was no comprehensive coverage of all countries with nuclear power plants, it seems that accident assumptions, acceptance criteria, and necessary containment modifications are not uniformly accepted, resulting in different approaches. As an example of one new acceptance criterion, Sweden and Italy have introduced the concept of ultimate land use after an accident. This has led to establishing maximum release targets of 0.1% of the caesium and iodine in the core inventory. Various ways of venting the containment in a controlled manner are under discussion and there seems to be a rather strong tendency for introducing some kind of vented containment into LWRs. Gradually, the classical definition of a design basis accident (DBA) is being abandoned or amended.

Safety assessment

Much attention was directed to various aspects of safety goals on the basis of probabilistic methods. Apart from quantitative methods to improve the precision of probability analysis, there are some fundamental points of terminology and criteria needing clarification and agreement. Papers provided some insight into the problems rather than presenting solutions for them. How the relevant parameters should be combined and limited for individual and societal (collective) risks (such as mortality, low dose effects, land use, and capital loss) is still very much debated and it is likely that a somewhat uniform international approach remains many years away. For some time to come, decisions (in regard to DBA) will continue to be made on the basis of deterministic engineering judgement (which includes some probabilistic judgement) supported by quantitative probabilistic analyses. One overview paper took a more optimistic position, at least regarding a more formal use of probabilistic risk criteria at the level of safety systems. It also evaluated other advantages of probabilistic safety assessments (PSAs); for example, the possibility to evaluate uncertainties arising from statistical variations of hardware behaviour. This is not possible in a deterministic approach.

In the discussion of safety goals, one consideration is the comparison of risks. One paper addressed safety approaches in non-nuclear hazardous industries and noted that large-scale accidents nearly always have a political significance because of the uneven distribution of benefits and risks among groups of people. The licensor thus has the obligation to justify his standards to the public in order to maintain their confidence. The author clearly stated his opinion that it is "a great mistake to suppose that the public as a whole can be educated about risk", which in turn requires strong efforts by the industry and the regulator to inform people adequately. Another obstacle is the fact that safety is not an easily measurable quantity, and risks that are numerically equal may not mean the same thing for different industries. In the UK, the Sizewell-B public inquiry has re-emphasised the conclusion that, for the public, it is not only necessary that plants are safe but also that this message is made evident to them. Several other papers addressed aspects of public communication. They noted that one prerequisite to clarifying the risks of nuclear power is the routine availability of factual and objective information. However, since this information is passed to the public through the mass media, it may be reported in different ways.

Probabilistic methods for safety analysis are in principle an established way to assist safety decision-makers. These methods are widely used, in particular for the detection of weak points during the design stage and for ensuring a well-balanced defense strategy. The problem of uncertainties in bottom-line results makes it difficult to use them as absolute figures. Two major areas are under careful investigation, and benchmark calculations reveal subtle differences in methodology and their effects on the end result: Human errors, as well as failures having a common cause, are difficult to model, and their treatment requires experience, systematic analysis of the individual situation, and further development. One approach being explored is extensive systematic analysis of actual operation experience. It should give deeper insight into the behaviour of operators under various conditions, and it may allow adjustment of parameters in model equations. There are national and international systems of operational feedback. They have partly different objectives: either to collect a large amount of information to be evaluated statistically, or to collect and evaluate a selected number of incident reports in order to develop lessons to be learned. The Incident Reporting System (IRS) of the IAEA and Nuclear Energy Agency of the Organization for Economic Co-operation and Development (NEA/OECD) is emphasizing the latter case. One paper addressed this point by specifically dealing with lessons to be learned from degradations unconnected with significant events. An example (Bugey-5 loss of instrumentation-and-control power supply, 1984) demonstrated the problem of predicting certain events; it also provided feedback on how to prevent such a case from happening again. International bodies, such as the

Commission of the European Communities (CEC), can serve as a vehicle for operations feedback and its use for modelling in probabilistic analyses, as well as for bringing scientists together to investigate such problems in a concerted effort.

There is another problem of safety assessment (not restricted to probabilistic methods): It is not possible to present conclusive mathematical proof that none of the event sequences that could lead to accident conditions has been overlooked. Most authors stress the necessity of using a prudent combination of probabilistic and deterministic methods. The deterministic approach — which has a tendency to look at the plant "atomistically" ("wholeness is the sum of its parts") — must be counterbalanced by probabilistic methods — which provide a more synthetic view ("wholeness is more than the sum of its parts").

Safety technology

In parallel to such fundamental and theoretical investigations of the safety of nuclear power plants as a complex machine, much research is being done on specific topics of plant design and operation.

While it is generally acknowledged that nuclear power production has reached maturity, it is also recognized that a typical feature of maturity is the problem of plant ageing. This area has received increasing attention within the last few years and will grow in importance in the 1990s. *(See related article in this edition.)*

The human factor has drawn more attention because of the accidents at Three Mile Island and Chernobyl. Analysing, modelling, and using operations feedback is one side of the picture. The other side deals with control and instrumentation, computerized operator aids, improved information systems, training, and operating procedures. This field — comprehensively addressed at IAEA's conference on the man-machine interface in the nuclear industry (February 1988 in Tokyo) — is gaining importance.

At a panel discussion on the topic of "operational safety in the 1990s", several interesting points were raised. The conviction was expressed that future plants will not change the safety concept in a revolutionary way; rather, more emphasis will gradually be given to the development of passive or inherently safe features that will be introduced into operating plants to the extent considered reasonable. The ongoing advances in operator aids, the improved man-machine interface, automated controls, and operator training were noted as examples of important trends.

International co-operation

At the plenary session on international co-operation, the USSR re-emphasised its interest in international co-operation supplemented by international laws and agreements in the field of nuclear safety. Also noted as one of the most significant achievements in the last year was the quick agreement on the *Convention on Early Notification of a Nuclear Accident* and the *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.* National early-warning systems (by means of electronic on-line monitoring) are in operation or under development in various countries, it was further noted. Even without on-line monitoring, bilateral arrangements for information exchange, such as the one in force between the CSSR and Austria, may be considered as models worth following. In the area of operational safety, the Agency's IRS was mentioned as a very important international link, one that should gradually be able to raise confidence and the level of frank information exchange.

Nuclear fuel cycle

Considering that the nuclear fuel cycle is an inseparable part of nuclear power performance and safety, it is not surprising that about one-third of the papers presented during the conference dealt with topics in this area. However, as was pointed out by Mr P. Jelinek-Fink in his summary statement, the presentations were most interesting but did not bring up any basically new approaches. This fact is a natural consequence of the industrial maturity of the nuclear fuel cycle.

Front-end of nuclear fuel cycle

Joint studies of the IAEA and NEA/OECD clearly show that the present favourable situation in the uranium industry may be called "metastable". Although known uranium resources in the low-cost category are sufficient to meet expected uranium demand through the year 2000, operating and committed uranium mines and mills in WOCA countries will apparently be insufficient to meet production requirements from about the 1990s. (WOCA is the acronym for World Outside Centrally Planned Economies Area.) This supply gap (which is about equivalent to total current uranium stocks) will increase sharply from 1990, and by the year 2000 may reach more than 26 000 tonnes uranium annually or 44% of the annual demand. Considering only supplies from existing and committed production centres, the cumulative deficit would reach more than 130 000 tonnes uranium by the year 2000. It must therefore be concluded that new production centres have to be constructed and put in operation in the early- to mid-1990s. The estimated capital investments needed to construct these mines and mills would be about US $ 1200 million in 1995 and US$ 1800 million in 2000. Such a sizeable investment will be made only if reasonable returns on invested capital are expected, which can be achieved only through higher uranium prices. However, the projected rise in uranium prices is expected to be partially compensated by lower enrichment costs and improved fuel management in reactors.

World enrichment services are provided primarily by four suppliers: US DOE, Eurodif, and Techsnabexport, which all use gaseous diffusion technology, and Urenco, which uses the centrifuge process for isotope separation. According to the IAEA and NEA/OECD, annual enrichment requirements in WOCA may increase from about 24 million separative work units (MSWU) in 1985 to about 38 MSWU in 1995 and about 46 MSWU in 2000. The existing enrichment capacity is more than adequate for demand up to 1995. No difficulties in enrichment services are expected at least for a further 5 years, considering plans of Urenco to expand enrichment capacity and the additional domestic capacity planned in Brazil, Japan, South Africa, and some other countries.

Thus, now and up to the end of this century, the security of supply is no longer an issue. Today the question is rather how the supply industry is to master the problem of a market in which there is strong competition because of over-capacity. Looking beyond the year 2000, it is important to keep in mind the necessity to be ready for the replacement of some of the existing gaseous diffusion plants. According to the prevailing opinion, gaseous diffusion cannot be considered as a basic technology for the enrichment industry in the future. This means that intensive research and development (R&D) on alternative methods of uranium isotope separation should be finalized in the 1990s.

The papers presented by all main suppliers reflected very clearly two dominant tendencies in world enrichment activity: (1) the aspiration to strive by various means for a stable position in the enrichment market; and (2) development of advanced technologies to allow the production of enriched uranium more economically, and to adequately meet increasing requirements and changing needs, such as re-enrichment of reprocessed uranium.

Concerning advanced enrichment technology, deployment of the atomic vapor laser isotope separation (AVLIS) method receives most attention in France, the Federal Republic of Germany (FRG), Japan, the Netherlands, the UK, and the USA. Although it is difficult to predict exactly when and in which countries AVLIS will be realized, active R&D gives reason to expect that the new enrichment technologies will positively influence the situation in the front-end of the nuclear fuel cycle, and could change the positions of the main suppliers in the world enrichment market.

Reactor fuel design, performance & utilization

Notwithstanding the positive experience in operating water-cooled nuclear power plants with uranium oxide fuel and the good performance of existing schemes of fuel utilization, R&D continues on improvements in reactor fuel design, performance, reliability, and utilization. The aim is to make nuclear energy more competitive.

Increasing the capacity factor of a 1000-MWe nuclear plant from 70% to 75% could, in principle, save US $5 million per year, if this additional production replaces oil-fired electricity generation. To achieve the same savings from any of the nuclear fuel components, it would be necessary to reduce their costs as follows: uranium by 40%, or enrichment by 35%, or fabrication by 75%.

Assessments reported during the conference show that advanced fuel management schemes (including extended burn-up, low-leakage loading patterns, fuel assembly reconstitution, etc.) can reduce uranium consumption for light-water reactors by about 20% and enrichment requirements by 10–14%. Utilization of slightly enriched uranium in heavy-water reactors (Candu) can reduce total fuel cycle costs by 25–50% relative to natural uranium fuel. Thus, one can conclude that, in the field of reactor fuel technology and utilization, there remains considerable potential for enhancement of economic competitiveness for nuclear power over conventional sources of energy.

In reviewing the main trends in reactor fuel improvements, it is also necessary to mention other important tasks, including load-following operation; extension of the fuel cycle length; and increasing (by changing the lattice) the water/fuel ratio. It was reported that a change from the 2-year to a 3-year refueling cycle is well justified. Other improvements in fuel design are linked to further technical improvements in related areas.

Another steady trend in a number of European countries, Japan, and Argentina is the development of plutonium recycling in thermal reactors. Although some additional investigations are needed, the mixed-oxide (MOX) technology, as it was reported, is at an adequate level of development to permit immediate industrial-scale use. In Europe, the marketing capability has been set up in form of the Commox Joint Venture created by Cogema and Belgonucléaire, backed up by the designer Fragema, and the manufacturing plants of Belgonucléaire (Dessel, 35 tonnes/year as of 1988), CEA (Cadarache, 15 tonnes/year as of 1989) and Cogema (Melox factory at Marcoule 100 tonnes/year as of 1995). R&D programmes are aimed at determining the real possibilities for the practical introduction of MOX fuel in the LWR fuel cycle.

Back-end of nuclear fuel cycle

The back-end of the nuclear fuel cycle is the focus of the nuclear community not only because of its impact on uranium requirements (reprocessing and recycling can reduce natural uranium requirements by up to 40%), but also because serious political, environmental, socio-economic, and technical problems remain. It is impossible to find simple solutions which would be acceptable for all countries. But today there is reason to affirm that reprocessing is an established technology, whereas spent fuel disposal has not been demonstrated yet. There is already considerable experience in Europe and Japan in fabrication, transportation, and irradiation of MOX fuel, and in the re-enrichment and use of uranium for thermal reactors. In other words, the closed nuclear fuel cycle is an objective reality, and the scope of reprocessing and recycling of fissile materials will increase significantly in the years to come.

Countries such as China, France, the FRG, Japan, the UK, and the USSR are committed to continuing reprocessing of spent fuel or to start it once plants are available. They are further committed to the utilization of MOX fuels in thermal reactors and, eventually, in fast-breeder reactors. Economics seems to be one main factor in favour of reprocessing in these countries, especially due to large investments which have already been made (e.g., 50 billion francs in France). These countries also consider separation of high-level waste (HLW) from bulk spent fuel as an advantage in waste disposal.

Other countries, such as Canada, Spain, Sweden, and the USA are following the long-term storage of spent fuel as a necessary step before direct disposal into deep geological formations. In the USA, such storage (until it is accepted by US DOE after commissioning of monitored retrievable storage sites) is the responsibility of utilities. Thus, as before, two main concepts dominate the back-end of the nuclear fuel cycle, but there is a clear trend to a rapprochement of positions. Countries, such as the USA, which in previous years were very strong in supporting the once-through fuel cycle today observe a more flexible policy which does not in principle exclude the possibility of accepting the reprocessing strategy in the future.

Policy decisions for waste management have already been taken in many countries and the 1990s should be a period of demonstration and implementation. As illustrated by data presented from various countries (the USA, France, and the FRG) many years of experience have been achieved in radioactive waste management and the technology exists to implement national plans and policies.

The USA has a well-defined programme mandated by the National Waste Policy Act (NWPA) of 1982 (as amended) which sets forth specific goals for the disposal of spent fuel and HLW. By the year 2000, it is anticipated that about 40 000 tonnes of uranium in spent fuel will have accumulated in the United States from over 100 nuclear power plants. The NWPA mandates that site characterization, selection, design, and construction start of the first repository site must be achieved during the 1990s. In countries pursuing the reprocessing option, important goals have also been established. France plans to soon commission two waste vitrification facilities for HLW at the La Hague complex. Each facility will be capable of producing 90 kilograms per hour of a borosilicate glass-waste matrix which is sufficient to solidify the HLW output of the La Hague reprocessing plants. Reprocessing of spent fuel on a commercial scale is planned to begin in the FRG in the 1990s. HLW from reprocessing operations will be vitrified based on technology demonstrated at the Pamela vitrification plant at Mol in Belgium.

The establishment of criteria, development of safety performance methodology, and site investigation work are key activities essential to the successful selection, characterization, and construction of geological repositories for the final disposal of radioactive waste. Considerable work has been done in these areas over the last 10 years and will continue into the 1990s. However, countries that are considering the geologic disposal of HLW now recognize the need for interfacing the technical aspects with public understanding and acceptance of the concept and with decision-making activities. The real challenge of the 1990s in waste disposal will be to successfully integrate technical/technology activities within a process which accommodates and satisfies institutional and public concern.

Regarding treatment and disposal of low- and intermediate-level radioactive waste, Mr Jelinek-Fink noted correctly in his summary statement that this technology obviously seems to be regarded as routine, so that many countries did not report about it at the conference at all. Additional R&D work is underway only to improve these techniques and to make their operation more economic, he said. However, the problems of disposal strategy of these wastes, selection criteria for disposal sites, and licensing of selected sites are not finally solved in most countries.

In the USSR, the treated waste is stored intermediately on site, until the central or regional repositories are installed. Geological barriers are considered the main ones against the release of radioactivity. In Czechoslovakia, final disposal will be performed at regional shallow land repositories in 200-litre drums. Geological surveys are being done to confirm the possibilities of underground disposal. In the USA, three burial grounds are in operation. Owing to legal obligations under the "Low Level Radioactive Waste Policy Act" (1980) and its amendment in 1985, the individual states are responsible for the disposal of the waste generated within their borders. Today it seems questionable that the 1990 milestone for licensing new burial grounds will be met. In the FRG, low-level waste has been stored in the Asse salt mine up to 1978. Since then, a total of about 25 000 drums of conditioned waste have been produced and stored on site. Another 5000 drums per year are expected. The final disposal site Konrad (a former iron ore mine) is expected to start operation in 1992, if the licensing procedure continues successfully. The European Community mainly concentrates on promotion of R&D work concerning waste treatment and quality assurance, radiation protection, and environmental protection. In the future, it intends to promote work for the development of an "international market" for treatment and storage of radioactive wastes in order to install comparable and reliable specifications for waste treatment, transport, and disposal and to enable a more economic operation of final repositories.

Decontamination and decommissioning

From the systematic point of view it is not clear today which place decommissioning of nuclear facilities occupies in the general scheme of nuclear power and its fuel cycle. However, this is undoubtedly essential and a very important part of the nuclear business. Decommissioning of nuclear facilities, realized in three stages, produces both waste materials and equipment for which no further use exists. It has been estimated that during the next 25 years, three million cubic metres of radioactive wastes will arise from decommissioning of nuclear power plants only in OECD countries, where the equivalent of about 200 reactors of 1000 MWe each will be decommissioned during the period 1996-2010 (an average of 14 reactors per year). Decommissioning of nuclear fuel cycle facilities other than reactors is expected to contribute less than 4% to the total amount of decommissioning waste.

As emphasized at the conference, decommissioning needs careful planning, cost estimation, and funding. The costs of decommissioning an 1100-MWe PWR and BWR are shown respectively as US $220 million and $264 million. At the same time, financial problems should not overshadow the problems of health risks. It is necessary to elaborate and establish balanced decommissioning criteria, and relevant studies are in progress in some countries. According to the nuclear decommissioning philosophy in Japan, 5 to 10 years of mothballing, followed by dismantling, has been recommended. Development of a dismantling technology needed for larger reactors is one of the main focuses of the programmes undertaken by the Japan Atomic Energy Research Institute (JAERI). Of particular importance is the development of a computerized data acquisition system to aid future decommissioning planning. The European Community's R&D emphasizes large industrial decommissioning projects. In the UK, progress was reported in decommissioning the Windscale reactor, with emphasis on the development of a special remote dismantling machine and manipulators. The USSR presented two papers on entombment of Chernobyl-4, including several technical innovations on equipment and decontamination practices which are particularly suited for long-term use in highly radioactive fields. The unique experience gained at Chernobyl should contribute to technical and planning provisions for future emergency planning.

In conclusion, decontamination and decommissioning are going on smoothly, safely, and economically. However, this field of nuclear technology has not yet reached its industrial maturity, and the 1990s and beyond should see active development of corresponding technical, economic, and political concepts.

Two of the three nuclear units at Forsmark in Sweden. (Credit: Naturfotograferna)

OSART missions (as of December 1987)

Country	Total no. of reactor units	Missions	Reactor type	Year
Brazil	1	1	PWR	1985
Canada	18	1	PTR	1987
Finland	4	1	BWR	1986
France	50	1	PWR	1985
Germany, Fed. Rep.	21	3	BWR,PWR	1986,1987
Italy	3	1	BWR	1987
Korea, Rep. of	7	2	PWR	1983,1986
Mexico	—	3	BWR	1986,1987
Netherlands	2	3	BWR,PWR	1986,1987
Pakistan	1	1	PTR	1985
Philippines	—	2	PWR	1984,1985
Spain	8	1	PWR	1987
Sweden	12	1	BWR	1986
USA	103	1	PWR	1987
Yugoslavia	1	1	PWR	1984

BWR = Boiling-water reactor PWR = Pressurized-water reactor
PTR = Pressure tube reactor

National participation of experts, or scientific visitors (observers) in OSARTs (as of October 1987)

Argentina	3	Japan	4
Belgium	6	Korea, Rep. of	2+9SV
Brazil	4 + 5SV	Mexico	3SV
Bulgaria	2SV	Netherlands	2
Canada	9	Pakistan	5SV
China	2SV	Philippines	2SV
Cuba	3SV	Portugal	1SV
CSSR	2SV	Romania	2SV
Finland	6	Spain	6
France	20	Sweden	12
German Dem. Rep.	3	Switzerland	4
Germany, Fed. Rep.	17	UK	5
Hungary	4SV	USA	19
India	1	USSR	2+2SV
Italy	5	Yugoslavia	5+3SV

SV = Scientific visitors (observers)