One effective way to reduce human error and thus improve plant performance and safety is to provide nuclear plant personnel with appropriate training according to the type of work. The NEA has just completed a survey of approaches to plant personnel training in its member countries which addresses various phases of training programmes. The cover photo shows a training simulator at the Paluel nuclear facility in France.

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Perspectives on nuclear safety after Chernobyl

F. Cogné

On 26th April 1986, at 1:23:44 a.m. (local time), the reactor in Unit 4 of the Russian RBMK nuclear power plant at Chernobyl exploded. This accident, by far the most serious ever to occur in a civilian nuclear installation, was to expose some 200 persons to severe irradiation (of whom 30 were to die shortly thereafter), lead to the evacuation of 135,000 people and contaminated large areas of Russian territory.

But the rest of the world was to learn of this accident only after abnormal dose rates were recorded outside the Soviet Union; first in Sweden, 48 hours after the explosion. In fact, it was only gradually that the world was to realise the scale of the catastrophe, and it would be three months before the causes and consequences of the accident would be really understood in detail.

In most Western European countries, the situation was difficult to manage because of the lack of detailed information; above all, it was impossible for the experts to respond adequately to public concerns. The result was an appreciable loss of public confidence in nuclear energy and a shot in the arm for the anti-nuclear movement; in some countries, the very utilisation of nuclear energy has been called into question.

It was at the International Conference organised in Vienna by the IAEA, from 25th to 29th August 1986, that experts from participating countries were at last able to discuss the different aspects of the accident with the Soviet authorities, who provided a great deal of information about the events leading up to the explosion, the measures which made it possible to bring the situation under control, and the steps taken to deal with the situation created by the accident.

We now know that the accident was one of reactivity caused by the carrying out, at whatever cost, of an electrical test which was badly prepared and finally undertaken in quite abnormal reactor operating conditions after deliberate breaches of the safety rules. The particular neutronics and thermohydraulic features of RBMK reactors then allowed a nuclear excursion to develop, releasing enough energy to break through the reactor's structures, leading to the ejection of 3 per cent of the fuel and the release, over some ten days, of considerable quantities of fission products (including 100 per cent of the rare gases, 20 per cent of the iodine and 12 per cent of the caesium present in the reactor core).

What is important now is to glean all relevant information from the Chernobyl disaster. Nuclear energy's safety record, it should be noted, remains positive when compared to other energy sources. But it is vital that the public realise this fact, failing which the pressure of public opinion could lead the political authorities to take decisions the consequences of which would bear no relation to the reality of the risks. Various measures have already been taken in some countries to better educate the public. We must go further still, and the task of educating and informing the public has to be considered by all those involved in the use of nuclear power as a vital part of their duties. In this respect, it is essential to avoid public airing of disputes among experts and dissemination of incomplete information. It is absurd, for example, to announce a given number of latent cancers resulting from Chernobyl, thereby transforming into certain victims of the accident figures which are simply the result of hypothetical calculations intended to indicate a maximum range of risks. The debates on the fixing of maximum contamination limits for vegetables and milk were also particularly unfortunate in that they were of little relevance from the public health standpoint. An effort must be made to reach international consensus on these subjects, based on objective scientific data as opposed to emotional arguments, bearing in mind that the presentation of the results obtained will be as important as the results themselves.

At a technical level, it must first be stressed that while the particular features of RBMKs make them a special case as compared to the reactors in use in the rest of the world, this does not mean that there are no lessons to be learned from a consideration of the sequence of events in question. One of the first points to consider is whether the methods of calculation we use in studying the accident sequence progression make it possible to reconstruct, on the basis of the Soviet data, a more or less accurate picture of what happened, particularly with regard to the steam explosion, dispersal of fuel and dissemination of radioactive substances. Calculations will certainly be made by different countries and a comparison of the results obtained at the international level would be extremely valuable.

Another technical point involves one of the most striking aspects of the Chernobyl accident, namely that of the deliberate breaches of the safety rules, which makes one wonder to what extent the operators were aware of the risks involved. This touches on questions of the training, and continued training of operators, an aspect which is of concern to us all: we must ask ourselves whether our operators really do possess the necessary understanding of the workings of the reactor and of safety questions. And, since account must be taken in this sphere of

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national differences, it is clear that the reply to this question must be given at the national level, responsible as each country is for protecting persons and property from the risks presented by the installations it operates. It would, nonetheless, be helpful if exchanges of information could be organised on this topic.

The safety of an installation relies largely on an in-depth defense against its failures, both material and human. Every country should reconsider the question of its installations' in-depth defenses with respect, naturally, to reactivity accidents but also to other possible accident situations. The setting-up of a containment barrier for water reactors so as to allow filtered releases before the pressure within the barrier exceeds a dangerous level is a measure advocated by some countries, and already widely discussed on the international scene: it is towards this type of development, rather than a fundamental rethinking of the design of installations, that our efforts should be directed.

It is, however, in the field of the management of post-accident situations that the most important lessons can be drawn from Chernobyl. All of the experts have been impressed by the scale and efficiency of the measures undertaken by the Soviet Union after the accident, not only bringing the fire under control in a highly radioactive environment, but evacuating populations at risk, treating seriously irradiated victims, preventing wider dissemination of radioactivity, and decontaminating large areas. After the Three Mile Island accident, the different countries concerned had already considered what measures should be taken in the event of a serious accident, but probably no country had, as yet, really prepared for an accident on the scale of Chernobyl both as regards emissions and duration. It is of course highly unlikely that an accident in an installation in an OECD country would ever be as serious as Chernobyl, but the experience acquired in this field, and especially the Soviet experience, should be widely publicised as should the results of the programmes to monitor the food chain and track the health of individuals.

In this connection, it is encouraging to note the work already undertaken under the auspices of the IAEA to draft, first, a Convention providing for the dissemination of information in the event of an accident occurring in a nuclear installation, and secondly, a Convention providing for international assistance in such an event. These are of course positive measures, highly relevant in an international context, even if there already exist bilateral information Conventions between neighbouring countries with respect to power plants situated near frontiers. The accident at Chernobyl clearly showed that radioactive substances may be widely dispersed well beyond the borders of the country in which the accident occurred.

For their part, the OECD countries, whose nuclear facilities conform to a different safety approach, should spare no effort in maintaining the highest level of operational safety while pursuing co-operation within the framework of the NEA.

It may be asserted that the accident at Chernobyl does not call into question the foundations on which the safety of power plants in OECD countries has been based. Thus, there is no reason to abandon either nuclear energy or the safety prerogatives of individual countries in favour of an international structure. The Chernobyl accident, on the other hand, constitutes an invitation to us to further strengthen technical co-operation among countries, be it on a bilateral, multilateral or international basis. The results of research and development work must be widely disseminated and discussed, and operating experience must be widely shared so as to increase still further the safety of our installations. In this way, on the initiative of international organisations, perhaps the singular occurrence at Chernobyl will provide the opportunity for taking another step in this direction.
The impact of the Chernobyl accident in OECD countries
A first assessment by the NEA Committee on Radiation Protection and Public Health

On 1st and 2nd September 1986, some four months after the Chernobyl reactor accident, the NEA Committee on Radiation Protection and Public Health (CRPPH) met in special session in order to make an independent assessment of the situation, consider the lessons to be learned from the accident and identify those follow-up actions which are of more immediate concern to NEA Member countries and which could more efficiently be carried out by the NEA in a co-ordinated effort with other international organisations. The following is a summary of the discussions at this special session and of the current position of the CRPPH on the Chernobyl issue.

Preliminary assessment of the radiological impact of the release

The specific features of the release of radioactive material from the Chernobyl accident, particularly its relatively large duration (more than 10 days) and the altitude reached by the radioactive plume, favoured a widespread distribution of activity, mainly across Europe. A contributing factor was the variation of meteorological conditions and wind regimes during the period of release. Activity transported by the multiple plumes from Chernobyl was measured in Northern as well as in Southern Europe, but also in Canada, Japan and the United States.

The distribution of radioactive contamination was extremely uneven in the OECD area and within each country. This was due in part to the varying distances from the source of release, and the long duration of the release which gave rise to different plumes transported in different directions by the fluctuating wind regime. However, a major contribution to the unevenness of ground and foodchain contamination was the presence in Europe of an unusually variable meteorological situation, characterised by frequent and localised heavy precipitation.

As a consequence, the concentration of activity in air varied in space, as well as in time; the ground deposition was also very uneven in space, differing sometimes by one or two orders of magnitude between localities situated few tens of kilometres apart. At the level of the foodchains an additional factor of diversity, besides the population dietary habits, was that in some parts of Europe cattle were still being fed on stored fodder, while in other parts animals were already grazing on fresh grass outdoors. The resulting differences of contamination in milk and other dairy products, particularly for radiiodine, were very large.

In these circumstances, the radiological impact of the accident in terms of doses to individuals in the various countries covered a wide spectrum. In several countries the doses to the individuals of the critical groups may well be higher by an order of magnitude or more than the average individual dose over the whole population. In view of all these elements and the fact that the long-term contamination by long-lived radionuclides and its radiological impact are still being assessed, it is not yet possible to draw a comprehensive map of the distribution of individual and collective doses committed by the Chernobyl accident in OECD countries. Nevertheless, a first assessment of the situation can be made based on the dose calculations carried out in Member countries so far.

From these data, it appears that the average individual effective dose equivalent to citizens of OECD countries in Europe committed from the first year of exposure/intake would range between 0.04 and 1.1 millisieverts. The average thyroid dose equivalents have been estimated to range between 0.04 and 2.9 millisieverts. As far as the maximum doses are concerned, they appear to range between 0.1 and 6 millisieverts in terms of effective dose equivalent, and between 1 and 20 millisieverts in terms of thyroid dose equivalent. The corresponding values assessed for the OECD countries outside Europe, such as Canada, Japan and the United States, are much lower, on the order of microsievers or tens of microsievers.

The above ranges of values refer to the present estimation of doses actually committed, including the application in some countries of protective countermeasures concerning particular items of the diet or other aspects of the radiation exposure. From assessments made in such countries of the expected effectiveness of the countermeasures taken, it would seem that they resulted in a reduction by a factor of 1.2 to 10 in the doses to individuals of the critical groups and by a factor of 1.1 to 3 in the weighted average individual doses and the corresponding collective doses. These reduction factors were dependent not only on the type and duration of the countermeasures but also on the radionuclides, pathways and groups of population involved.

Finally, it can be estimated that the total collective dose equivalent resulting in the European OECD Member countries from the accident should be on the order of $10^5$ man sievers in terms of effective collective dose equivalent and of $4 \times 10^5$ man sievers in terms of thyroid dose equivalent.
After Chernobyl

Based on the information available to date, it can be concluded that although the radiological consequences of the accident have been serious in the area surrounding the Chernobyl site, on the whole, these consequences do not raise any major concern for the health of the population in the OECD area. The radiological consequences on individual members of the public in OECD countries have been minor. In particular, no individual in those countries is likely to have been subjected to a radiation dose greater than a few times that received every year from natural background radiation. Thus, the lifetime average risk of radiation-related harm for the individual members of the public has not been changed to any significant extent by the accident. The impact on the OECD countries' population as a whole, in terms of the potential collective detriment that can be theoretically calculated from the collective dose, is unlikely to lead to a detectable addition to the natural incidence of cancer and cancer mortality rates during the next few decades.

Emergency response in OECD member countries

The progressive spread of contamination at large distances from the accident site has caused considerable concern in Member countries, and the reactions of national authorities to this situation have been extremely varied, ranging from a simple reinforcement of the normal environmental monitoring programmes without adoption of any countermeasures, to compulsory restrictions concerning the commerce and use of foodstuffs. This variety of response was accompanied by large differences in the duration of application of the countermeasures.

The most widespread countermeasures were those which could be taken without a significant disturbance of normal life or a significant economic burden, at least for a short period. They included the recommendation to wash fresh vegetables and fruit before consumption, not to use rainwater for drinking or cooking, as well as the monitoring of citizens (tourists, students, workers) returning from Ukraine and Belorussia.

Other countermeasures having a more significant impact on the population's dietary habits and involving a relatively important economic and regulatory burden, included restrictions on the sale and use of milk, dairy products, fresh leaf vegetables, and some types of meat, as well as keeping milk-producing cows from grazing outdoors in a few countries. Other countermeasures, adopted for variable time durations, concerned limitations in travelling to the region most affected by the accident and restrictions on imports of some foodstuffs from Russia and other Eastern countries. Restrictions of this kind were even adopted by some countries with reference to food items imported from other OECD countries.

It is difficult to establish a clear relationship between the nature, amplitude, timing and duration of the countermeasures adopted and the pattern of radioactive contamination being measured. Actions taken in some countries differed even when similar contamination levels were being experienced. In a few cases of bordering countries, decisions were totally different with reference to population groups living only a few kilometres apart on the two sides of a border. Also, the countermeasures were issued and implemented in different ways, ranging from simple advice or recommendations to the public, up to the adoption and legal enforcement of compulsory measures.

Another aspect which contributed to the complexity and lack of clarity of the overall picture resulting from the emergency response in OECD countries was that the derived intervention levels for the various exposure pathways, existing or adopted at the moment, were found to be identical in certain countries and significantly different in others, even when environmental and socio-economic conditions were not dramatically different. For example, the reference values for radioactive iodine known to have been associated with the consumption of milk varied between 185 and 2000 Bq/l; in one country a level as low as 10 Bq/l was adopted for restricting import of milk, whilst in another country a value of 100 000 Bq/l was reported in terms of instantaneous peak concentrations. For cesium-137 and 134 in milk, reference values between 300 and a few thousand Bq/l were reported.

Part of the reason for these discrepancies might be found in a diversity of radiation protection criteria adopted by the different national authorities in establishing primary intervention levels in terms of dose, which are the basis for the definition of the derived intervention levels. This may be due to specific national policies, or traced back to the differences between international recommendations. Another part of the explanation for the differences

The basic International Commission on Radiological Protection (ICRP) recommendations of 1977 (ICRP Publication 26) and the Basic Safety Standards for Radiation Protection issued by IAEA/WHO/ILO/NEA in 1982 stipulate that the establishment of intervention levels for particular circumstances, including nuclear emergencies, is the responsibility of national authorities, due to the large variety of administrative, social, and environmental conditions existing in various countries. At the same time, a common basis for a reasonably coherent approach to emergency management has been agreed upon internationally. This comprises the definition of a range of intervention levels in terms of radiation dose between two levels — a lower level below which introduction of a countermeasure is not warranted and an upper level at which its implementation should almost certainly be attempted. However, discrepancies exist in the guidance given by the different international organisations for the establishment of this range. Further clarification and better harmonisation of the general criteria recommended by international organisations would contribute to reducing the disparities in criteria and protective actions that was observed during the Chernobyl accident. One question which should be explicitly addressed is that of criteria for the management of accidents having transfrontier consequences.
between derived intervention levels is certainly to be found in the objective diversity in contamination levels, environmental features and population habits and diets, as well as in different ways and scope of their application.

Although it seems clear that the general radiation protection principles which served as a basis for the emergency actions taken in the various OECD countries were very similar, it would appear that the variance in of radioactive materials have been progressively adopted in Member countries, although some residual cases of use of the old units are still being observed. The relationships between the new SI units and those previously used are shown in the following table:

### Quantities and Units

For many years special measurement units for quantities of interest in radiation protection were used, which were not coherent with the International System of Units (SI). These old units, röntgen, rad, rem and curie, have been superseded in the last few years by a new set of units which are coherent with the SI system.

These new units, the gray for absorbed dose, the sievert for dose equivalent, and the becquerel for activity

<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI Unit</th>
<th>New Name and Symbol</th>
<th>Old Unit and Symbol</th>
<th>Conversion Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Ckg⁻¹</td>
<td></td>
<td>röntgen (R) 1</td>
<td>Ckg⁻¹ = 3876 R</td>
</tr>
<tr>
<td>Absorbed dose</td>
<td>Jkg⁻¹</td>
<td>gray (Gy)</td>
<td>rad (rad)</td>
<td>1 Gy = 100 rad</td>
</tr>
<tr>
<td>Dose equivalent</td>
<td>Jkg⁻¹</td>
<td>sievert (Sv)</td>
<td>rem (rem)</td>
<td>1 Sv = 100 rem</td>
</tr>
<tr>
<td>Activity</td>
<td>s⁻¹</td>
<td>becquerel (Ba)</td>
<td>curie (Ci)</td>
<td>1 Bq = 2.7x10⁻¹¹ Ci</td>
</tr>
</tbody>
</table>

In addition multiples and sub-multiples of the above units are frequently used. The most common ones are the following (with correspondence to old units):

<table>
<thead>
<tr>
<th>Activity</th>
<th>Dose Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Becquerel (1 Bq)</td>
<td>1 Sievert (1 Sv) = 100 rem</td>
</tr>
<tr>
<td>1 kiloBecquerel (1 kBq)</td>
<td>1 millisievert (1 mSv) = 0.1 millirem (0.1 mrem)</td>
</tr>
<tr>
<td>1 Mega Becquerel (1 MBq)</td>
<td>1 microsievert (1 μSv) = 0.1 millirem (0.1 mrem)</td>
</tr>
<tr>
<td>1 Giga Becquerel (1 GBq)</td>
<td></td>
</tr>
<tr>
<td>1 Tera Becquerel (1 TBq)</td>
<td></td>
</tr>
</tbody>
</table>

countermeasures and in intervention levels that has been pointed out was larger than could be explained and justified by the above-mentioned national and local differences. Hence it is felt that differences in methodological approach, including environmental and dosimetric models, as well as the influence of non-technical and non-quantifiable factors, must have played a major role in creating this confused situation.

Lessons learned and needs for the future

There is no doubt that the Chernobyl accident, its development and the way in which its consequences have been managed offer a number of lessons and an in-depth reflection on these lessons will be necessary in order to draw indications and, hopefully, international consensus, for further improvement of emergency preparedness and public protection.

One major issue is that of emergency response criteria. A comprehensive and detailed review of the countermeasures adopted, their rationale and their effectiveness will be included in a report that will be issued by NEA in early 1987. However, it can already be concluded that on the whole, the emergency response criteria and approaches in the various countries seem to be very divergent, even beyond the natural diversity deriving from local situations and requirements. There is therefore a feeling that an effort should be made towards a more consistent approach to emergency response, taking into account national diversities.

In the field of data acquisition and reporting, the observed variety of data handling and reporting systems and formats caused confusion and contrasting interpretations and statements. Although some differences in the measurement methods and in the data handling and reporting may be justified in view of local specific requirements, for the most part they are unwarranted and...
there appears to be no reason why better harmonisation in the technical formats for data acquisition, processing and reporting could not be achieved. It is the opinion of the CRPPH that this should not present great technical difficulties, although it will require substantial co-operation between Member countries. This harmonisation is extremely important for the transmission of data from one country to another, in order to enhance decisions about protection actions during the course of an accident.

Finally, there is also a clear need for improvement in the communication with the public. The systems and the amplitude of the information given to the public in the various countries varied considerably, and significant difficulties were experienced by national authorities in explaining the features and magnitude of the risks and the meaning and rationale of the countermeasures adopted, or not adopted. This is, therefore, another area where a collective international reflection would be warranted.

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**Explanation of terms**

Some technical terms used in the text are explained in the following:

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>Quantity of a radionuclide. It describes the rate at which spontaneous decays occur in it. It is measured in becquerels (Bq) = 1 nuclear transformation per second.</td>
</tr>
<tr>
<td>Dose</td>
<td>A general term denoting a quantity of radiation. It can be qualified as absorbed dose, dose equivalent, effective dose equivalent.</td>
</tr>
<tr>
<td>Absorbed dose</td>
<td>Quantity of energy imparted by ionising radiation to the unit mass of matter such as tissue. It is measured in grays (Gy) = 1 joule per kilogram. One Gy produces different biological effects on tissue depending on the type of radiation.</td>
</tr>
<tr>
<td>Dose equivalent</td>
<td>The quantity obtained by multiplying the absorbed dose by a factor representing the different effectiveness of the various types of radiation in causing harm to tissues. It is measured in sieverts (Sv). One Sv produces the same biological effect irrespective of the type of radiation.</td>
</tr>
<tr>
<td>Organ dose equivalent</td>
<td>Dose equivalent imparted to a given organ or tissue. It is measured in sieverts (Sv).</td>
</tr>
<tr>
<td>Effective dose equivalent</td>
<td>Weighted sum of the dose equivalents to the various organs and tissues. The weighting factor for each organ or tissue expresses the fractional contribution of the risk of death or serious genetic defect from irradiation of that organ or tissue to the total risk from uniform irradiation of the whole body. It is measured in sieverts (Sv).</td>
</tr>
<tr>
<td>Collective dose equivalent</td>
<td>Total dose over a population group exposed to a given source. It is represented by the product of the average dose equivalent to the individuals in the group by the number of persons comprising the group. It can be expressed as collective organ dose equivalent or collective effective dose equivalent. It is measured in man-sieverts (manSv).</td>
</tr>
<tr>
<td>Critical group</td>
<td>A homogeneous group of population representative of the persons receiving the highest dose among all the population exposed to a given source.</td>
</tr>
<tr>
<td>Maximum individual dose</td>
<td>Average dose to the individuals of the critical group.</td>
</tr>
<tr>
<td>Committed dose</td>
<td>Total dose (expressed as organ dose equivalent or effective dose equivalent) gradually delivered to an organism during a given period of time by the decay of a radionuclide fixed in the organism following its intake into the body. The integration time is usually taken as 50 years for workers and 70 years for members of the public.</td>
</tr>
<tr>
<td>Intervention level</td>
<td>The value of a quantity (dose, activity concentration) which, if exceeded or predicted to be exceeded in case of an accident, requires the application of a given protective action.</td>
</tr>
<tr>
<td>Primary intervention level</td>
<td>Intervention level in terms of projected or estimated dose to individuals.</td>
</tr>
<tr>
<td>Derived intervention level</td>
<td>The activity concentration in a given environmental matrix (air, soil, water) or foodstuff which, under certain assumptions, corresponds to a dose to individuals equal to the primary intervention level.</td>
</tr>
</tbody>
</table>
Radiological aspects of Chernobyl in Western Europe

R.H. Clarke

First indications

The first information about the Chernobyl accident strongly suggested the release of radioactive material would cause no great problem for Western countries and that the accident, while serious, fell short of a disaster. By the morning of 29th April, three days after the explosion, it was clear that the accident was much worse than at first thought, although the impact still seemed likely to be small for most of Western Europe and Scandinavia.

External dose rate measurements in Finland rose from a normal background of about 0.1 μSv hr⁻¹ to 3 μSv hr⁻¹ during 29th April and decayed with a half life of about 4 days(1). In West Germany external dose rates increased from normal background levels to some 1.1 μSv hr⁻¹ on 1st May, reducing with about an 8 day half life(2). The differences between these results are explained by the movement of the cloud of radioactive material over Europe, complicated by the fact that the release appears to have continued over a number of days. The plume arrived over Italy at about the same time as it did over Germany and it later moved across France, arriving over the United Kingdom on Friday 2nd May 1986. Total doses received from external γ-dose from the plume have been estimated at about 10 μSv in the UK(3), and about 35 μSv in West Germany(4) and in Finland (5).

Measurements were made of the radionuclide activities in air in all of the countries. The nuclides readily identified were:

\[ {^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103}Ru, ^{106}Ru, ^{131}I, ^{132}I, ^{132}Te, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{141}Ce, ^{144}Ce, ^{239}Np} \]

Some measurements of actinides were made which identified \(^{239}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, ^{242}Cm\), but at very low levels and having little radiological impact. The highest actinide activities in Finland(1) were for \(^{242}Cm\) at about 0.3 Bq m⁻³, with \(^{239}Pu\) at less than 0.01 Bq m⁻³.

The concentrations of these radionuclides in air were representative of fuel irradiated for around 400-500 days(6). The levels of \(^{131}I\) in air in Finland were as high as 200 Bq m⁻³ on 28th April, rapidly falling to between 1 and 5 Bq m⁻³ over the next few days(1). For most of Europe, air concentrations were up to about 10 Bq m⁻³ of \(^{131}I\) but the duration varied, concentrations remaining between 1 and 5 Bq m⁻³ for about a week over West Germany and Italy(2,7), but only for about a day over Western France and the UK.

Generally, levels of \(^{137}Cs\) in air were similar to those of \(^{131}I\) in much of Western Europe, although the earlier Scandinavian data had a greater proportion of \(^{131}I\).

Inhalation doses have been estimated in terms of the committed effective dose equivalent from the passage of the plume and values of 10 to 40 μSv are reported(1,3), there not being a great difference between doses to children and adults.

The need for action

In most countries in Europe, emergency plans provide for monitoring of the environment out to considerable distances from the plant at which the accident occurred. It is invariably assumed, however, that there is a "source" from which activity disperses and becomes more dilute. In the case of Chernobyl, a large mass of contaminated air moved over countries leaving a mottled pattern of deposition. As a consequence, most countries' emergency plans had to be used in reverse — that is, instead of monitoring most intensely near the source and looking further afield mainly in a limited way for information to reassure the public, "information monitoring" was required to identify parts of the country with high deposition where intense monitoring was then needed to decide whether action was necessary. This proved extremely difficult because of the lack of pre-existing monitoring effort in the areas that needed it.

While the radioactive material was passing over Europe, activity was deposited on the ground by the action of dry deposition. In addition there was sporadic heavy rainfall over Europe while the contaminated air mass was drifting westwards and northwards. This led to greater deposition of \(^{131}I\) by about a factor of 10 and of \(^{137}Cs\) by about a factor of 100 as compared with dry deposition(3). But the absolute levels depended very much on the intensity of rainfall and position of peak concentrations of activity in the plume. This led to localised high levels of ground deposition of \(^{131}I\), \(^{137}Cs\) and \(^{140}Cs\) which were not easy to find.

The high deposition in rainfall led to the first need for action. Often, in remote areas where there is no main supply of drinking water, fresh rainwater is collected for drinking. In Scandinavia and some other European countries, advice was given by 2nd or 3rd May that fresh...
rainwater should not be drunk. These decisions were generally made on the basis of the recommendations by the International Commission on Radiological Protection (ICRP) for levels of dose at which action should be taken in a radiological emergency. Levels of activity in rainwater were such that if it were consumed, the ICRP accident dose levels could be reached within a day.

There was of course a high level of activity on grass. This was expected to be transferred into cows’ milk, which thus became the second area of concern. In Scandinavia and some parts of Northern Europe, cattle were still on winter feed and were not out grazing the grass. Advice was given in some countries that cows should not be let out to pasture. When cows were outdoors, and there had been heavy rainfall, if the cows were on supplementary foodstuffs there was less activity in milk than would be predicted from the deposition. The most acute situations arose in Southern and Central Europe, where the grass was growing and the cows grazing. In Italy, a ban was introduced on the consumption of fresh milk for about the first three weeks of May 1986.

Levels of $^{131}I$ in milk in Scandinavia only rose to about 30 Bq l$^{-1}$ compared with an action level of about 2000 Bq l$^{-1}$ — the figure which led to the dose limit for the thyroid of a member of the public. In West Germany levels in bulked milk were around 1500 Bq l$^{-1}$ on 4 May and in the UK the figure was about 50 Bq l$^{-1}$ in the (dry) south and 400 Bq l$^{-1}$ in the (wet) north. In Italy figures up to 2000 Bq l$^{-1}$ in cows’ milk were reported and where the levels of iodine were high the levels of $^{137}Cs$ and $^{134}Cs$ were also high.

Growing vegetables were an immediate concern where these were close to harvest. It also became clear that goats’ milk had high levels of iodine and caesium, although the highest levels were measured in sheep’s milk. This was because sheep did not have supplementary feed and tended to be grazing the grass high on hills where deposition was likely to be higher than on lower ground, where cattle graze.

The fact that three isotopes, $^{131}I$, $^{134}Cs$ and $^{137}Cs$, were appearing in milk meant that their contributions to dose had to be summed. Thus, once it was clear that the dose limit for the thyroid was not going to be reached from $^{131}I$, in each country protection experts began looking at the effective dose equivalent limit and sum from all nuclides. The “action level” for any one nuclide was therefore reduced from that applied to it in isolation.

Additionally, over much of Europe the contaminated air mass had moved backwards and forwards over a week, continually depositing fresh activity onto growing grass. Therefore the mean duration of iodine and caesium in milk was going to be longer than for the previously identified scenarios of a single deposit from an accident. Again this meant that “action levels” for this accident situation were lower than for a single deposit for the same level of dose.

The different dietary intakes in European countries presented another problem, so that although all countries were working to essentially the same levels of dose, the activities per unit mass of foodstuff were different.

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**Deposition on Ground by Cs-137**

$[\text{MBq/km}^2] 
\times 10^3$

The deposition of radioactivity from Chernobyl was uneven, especially over mountainous areas in Europe. This map shows the deposition of $^{137}Cs$ over Austria.
In the end, there was much confusion about why different action levels were used by different countries. Political expediency had, in some cases, overridden radiological protection.

The overall estimates of doses received indicate that ingestion was the major pathway in the short term although external doses will be received over the next few years from $^{137}$Cs on the ground. Average population dose estimates for the first year vary between 700 µSv in Finland$^{(1)}$ and West Germany$^{(2)}$, 70 µSv in the UK$^{(3)}$ and 80 µSv over Italy$^{(7)}$. Infant doses could be up to ten times these values$^{(3-7)}$.

Lessons learned

Lesson number one was that the demand for monitoring was overwhelming. This included monitoring of the environment, monitoring of people returning from Russia and Eastern Europe, monitoring of aircraft flying across Europe, monitoring of foodstuffs and other cargoes at ports. Had the accident occurred in Western Europe, the level of these demands might have exceeded available resources.

Second, there is a need for better communication with the public. It must be explained why people are expected to continue living in an enhanced radioactive environment; the doses may be small, but the activity is measurable. The radiological protection assumption of linear non-threshold dose-response means there is no level of zero risk and there is a need to argue the acceptability of the assumed risk.

Third, it is important to consider whether there can ever be unified “action levels”. Decision-making had to move from an acute irradiation situation of $^{131}$I in milk or fresh vegetables, to a chronic exposure situation, as it was realised that the high levels of $^{137}$Cs and $^{134}$Cs in processed foodstuffs, e.g., powdered milk produced in May or June, tinned or frozen vegetables, or meat from animals slaughtered in May/June (particularly lamb), could be a source of dietary intake over a year. This results in lower “action levels” for these products than for fresh items giving short term intakes of radionuclides.

Finally, radiological protection concepts proved to be difficult and confusing for politicians and administrators. The radiological protection community must decide which way to go in the future: either we work hard to educate people to understand our philosophy, or we accept that it is politically expedient, albeit expensive, to choose single, simple numbers.

NEA action

At the NEA Committee on Radiation Protection and Public Health meeting on 1st-2nd September 1986 to discuss the radiological impact of Chernobyl in Member states, data on the levels of radionuclide deposition and the pathways of exposure were presented and individual and population doses estimated. In estimating doses, countries described the effectiveness of any actions that had been taken and quoted the reduction in dose that had been achieved.

Average doses received in NEA Member countries from Chernobyl

<table>
<thead>
<tr>
<th>Committed effective dose equivalent (µSv) May 1986 - April 1987</th>
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<tbody>
<tr>
<td>Australia</td>
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<td>Austria</td>
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<td>Turkey</td>
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<tr>
<td>UK</td>
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<tr>
<td>USA</td>
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</tbody>
</table>

Natural background 1900

* No deposition as of September 1986. Some dose may be received from importation of contaminated foodstuffs, but it is expected to be small.
** Estimated from total deposition.
The per caput doses estimated for each of the Member states, based on their own submissions, are shown in the table. These data are representative averages for each country although there was very non-uniform deposition, especially over mountainous areas in Europe. In some countries some of the most highly exposed individuals could receive doses perhaps 10 times the average for that country; however, the general effect of countermeasures appears to have been to keep maximum doses below the annual dose limit for members of the public, 5000 µSv. The doses are better estimates than those in earlier publications(1,2,3,7) because of additional monitoring information. Thus, the doses shown here for Finland, UK, and FRG are lower than those from initial publications. For comparison, the average figure for natural background radiation is also given.

This information, which constitutes the first comprehensive assessment of the radiation consequences in Western countries of the Chernobyl accident, will be made widely available with the publication of the CRPPH report in early 1987.*

References


* For a summary of this, see “The impact of the Chernobyl Accident on OECD Countries: a first assessment” in this issue.
Improving the safety of reactor operations

K. Morimoto

The importance of learning from the day-to-day operation of nuclear power plants and of feeding the experience back into their design and operation was again underscored by the accident at Chernobyl. For the last six years the NEA has sponsored the Incident Reporting System (IRS), which gives Member countries access to information on safety-related operating experience collected on an international basis, and which has triggered a variety of activities relating to operating experience and human factors.*

General overview of recent incidents

Generally speaking, incidents relating to design deficiencies or shortcomings have decreased in number, while those involving operational problems are becoming more frequent. Steam generator tube failures and problems in emergency diesel generators, for example, had been plaguing Member countries for some time. The exchange of experience and knowledge on a bilateral and multi-lateral basis through the international network has allowed most countries to overcome these problems.

On the other hand, with the increase in the number of reactor-years of plant operation, incidents caused by operational problems, such as degradation of components or equipment, human error or inadequate maintenance and testing, have a growing significance. In order to prevent these types of incidents, it is essential to identify hidden problem areas in the stages of design, construction and maintenance. In particular, the following aspects are worth noting:

- The necessity of assessing the adequacy of testing programmes, including post-maintenance testing.
- The need to perform root-cause analyses to identify effective countermeasures.
- The crucial role of operator training and improvement in their understanding of procedures, design and equipment operation.
- The usefulness of plant process computers in recreating the abnormal conditions for assessment after the incidents.

Of course it is necessary to continue to focus on the recurrent problems, such as the reliability of safety or relief valves, stress corrosion cracking (SCC) on reactor internals and piping, etc.

Generic report on major safety issues

To allow for better use of the information exchanged through the NEA-IRS, a generic report on major safety problems experienced in plant operations has been compiled. A first international attempt to integrate the information on operating experience into a comprehensive report, is intended to enable readers to have a concise overview of and insight into the issue. The first topic for this pilot study, “Loss of Safety System Functions”, was selected because this type of failure can significantly degrade plant safety.

Apart from the specific findings relating to respective safety system functions in LWRs and PHWRs, the following aspects have been observed:

- Operating experience shows that a substantial number of losses of safety system functions have occurred, although none of them resulted in releases of radioactive material.
- In some cases timely interventions by operators to restore system functions were important contributions to coping with the incidents.
- The duration of system unavailability was normally short, as in most cases failures were successfully detected through testing and maintenance activities.
- Problems which occurred repeatedly at different systems include:
  - component common cause failures
  - insufficient administrative control
  - interdependencies between redundant systems.

On the basis of the results of this study, it is proposed that further studies be performed on more specific subjects, such as residual heat removal systems (RHRs) or containment leaktightness.

Reducing reactor scram frequency

The frequency of reactor scrams, which are defined as manual or automatic actuations of the reactor protection system resulting in the most rapid possible insertion of

* For a related article, see “Learning from Experience: the NEA’s Incident Reporting System”, NEA Newsletter, No.2 (June 1984).
Analysis of incidents in nuclear power plants has underlined the need to focus closer attention on the importance of human factors in reactor operations.

the control rods, is widely recognized as an indicator of the health of the plant. In spite of their vital importance as a safety function to bring the plant to a safe and stable shutdown condition in case of an emergency, negative side effects of too-frequent scrams on plant operations have been a matter of concern for OECD Member countries. Reactor scrams not only challenge the safety systems but also result in undesirable thermal and hydraulic transients; in general they are indicative of deficiencies in the operation of the plant. At the same time, unplanned shutdowns of reactors have considerable economic implications for electrical utilities.

Efforts are being made both by regulatory bodies and industry organisations in OECD Member countries to reduce the frequency of reactor scrams. However, statistical data on recent operating experience have shown that there are wide differences in the frequency of reactor scrams between plants in different countries. As a step towards gaining a clearer understanding of the underlying reasons for the differences in the observed scram frequencies, a symposium on reducing reactor scram frequency was held in April 1986 in Tokyo (Japan) under the auspices of the NEA and at the invitation of the Japanese government.
The NEA cause or aggravated by human error during operations are treated in the same way as other types of incidents under course of maintenance and testing activities. The importance of human factors in reactor operations. Apart from this serious case, statistics have not been remarkable. However, exchange of such topics as approaches to training and regulatory practices; instructional methods; evaluation of personnel, performance and training; and diagnostics and team training techniques. With the participation of experts both inside and outside of the nuclear community, the meeting will provide a timely opportunity to discuss measures by which the approach to training for nuclear personnel can be improved.

Another important area in the context of preventing human error is the interface between the operators and the computers in the control room. Computer systems generally collect data concerning plant status and present them to the operators as raw or processed information. In some applications they may also have such functions as providing operator aids, entering operator commands, issuing control signals, automatic controllers, data logging, etc. For a number of years, the OECD Halden Project in Norway has been active in the study of man-machine interface, particularly the development of control room systems and displays to better help reactor operators understand the status of their plant. These efforts now include studies of operator training techniques: hybrid display systems; prototype control room design and development of expert systems to aid the operators in accident diagnosis.

Human factors

Analysis of incidents in nuclear power plants has clearly underlined the need to focus closer attention on the importance of human factors in reactor operations. In fact, the Chernobyl accident last April was caused by a remarkable range of human errors and violation of operating rules, in combination with specific reactor features which compounded and amplified the effects of the errors. Apart from this serious case, statistics have shown that a significant portion of incidents have been caused or aggravated by human error during operations under normal or accident conditions, as well as in the course of maintenance and testing activities.

In most countries incidents involving human factors are not currently analysed with a special methodology, but are treated in the same way as other types of incidents with equipment failures. However, if deemed necessary, on-site reviews are conducted both by the electrical utilities and regulatory bodies to determine the root cause of the event. This has proved to be effective in identifying whether the error was a result of a cognitive error of the plant personnel or a deficiency in the procedures they followed. Other contributing factors such as unusual characteristics of the physical environment (e.g. heat, noise, etc.), communication or managerial problems and adequacy of personnel knowledge and experience, are also assessed with a view to taking appropriate countermeasures to prevent recurrence of similar incidents.

One effective way to reduce human error and thus to improve plant performance, is to provide plant personnel with appropriate training according to the type of work. In an effort to review Member countries' approaches to training programmes for plant personnel, the NEA conducted a survey during 1985 which addressed various phases of training programmes, including their analysis, design, development, implementation and evaluation.

In spite of the wide differences in approaches to training, the survey revealed that at least some training programmes are standardised at the utility level in a majority of countries. In most cases, training is based on a combination of regulatory guidance and utility practices and compliance with regulatory guidance is monitored through inspection by government authorities. In order to train instructors and trainees, organisations outside of the utility and site specific facilities are often used, applying such methods as on-the-job training, lectures, simulator training, etc.

As a follow-up to this, a specialist meeting on "Training of Nuclear Reactor Personnel" will be held in April 1987 in Orlando, Florida (U.S.). The discussions will cover such topics as approaches to training and regulatory practices; instructional methods; evaluation of personnel, performance and training; and diagnostics and team training techniques. With the participation of experts both inside and outside of the nuclear community, the meeting will provide a timely opportunity to discuss measures by which the approach to training for nuclear personnel can be improved.

The NEA Newsletter, fall 1986
Re-thinking severe reactor accidents

H.J. Teague

Following the Three Mile Island incident the NEA launched an examination of then-current approaches in NEA countries to dealing with severe accidents. The objective was to provide guidance on the implications of TMI-2, particularly for future research, and on the need, if any, for additional reactor design or operational measures. In May 1986 the Agency published Severe Accidents in Nuclear Power Plants, a report by a senior group of experts of the Committee on the Safety of Nuclear Installations that has studied these issues over the last six years.

Membership of the group was drawn from NEA countries pursuing, or contemplating, major programmes of LWR reactors and consisted of senior specialists with extensive experience in safety research, who in most cases were also engaged in regulatory activities. Their discussions ranged over all aspects of reactor safety technology, including design, operating procedures and safety assessment techniques. The general ideas of probabilistic safety analysis permeated the group's systematic approach to evaluating the relative significance of the complex and interrelated technical issues.

One important conclusion to emerge is that the past development of LWR technology, incorporating general safety concepts such as defence in depth and searching analyses of safety provisions, has produced a generation of designs which stand up well to modern safety analysis. Although designers worked essentially towards coping with "design basis accidents" defined within specific limits, in general the designs they produced are capable of withstanding accidents of significantly greater severity.

A closely related point is the importance of management in relation to severe accidents. There is a strong need to ensure that all plant personnel are equipped with knowledge and understanding of all aspects of severe accidents relevant to their individual functions in the running of the plant. That need applies to all phases including early preventive actions which anticipate and avert accident initiation, exploiting the capability of the plant to survive challenges beyond the design basis by intercepting at an early stage the development of an accident, and "last ditch" mitigation measures. It may turn out that advanced simulators will in due course play a big part in equipping plant personnel with the desired depth of understanding of severe accident progression.

The scientific understanding of the basic physical processes important in accident progression is considered good, although work on improving this understanding is likely to continue for some time. Development is needed particularly in computer codes which enable the basic knowledge to be applied in circumstances that are highly plant-specific or where phenomena hitherto treated in isolation interact strongly. A typical example arises in the transport of fission products within the plant. The principles are well understood but proper account must be taken of the detailed geometrical configuration. Furthermore, the convection currents which determine the transport of fission products result from the heat they generate and thus depend on their distribution.

The study places strong emphasis on containment performance and on the current progress in studying source terms. For both, there is again the need to apply the existing good fundamental understanding in a way which adequately takes account of detailed plant geometry and conditions, which can vary from stage to stage of an accident.

Overall, no substantial design changes, major new research facilities or programmes were identified as necessary for dealing with severe accidents. On-going studies should be maintained, however, in order to confirm current projections and to provide computing capabilities for plant-specific applications. Attention should be paid to potential weaknesses, such as inadvertent by-pass, which might jeopardise containment performance, and to the extension of operating capabilities of vital equipment beyond the range of design basis conditions.

H.J. Teague is Deputy Director of the Safety and Reliability Directorate at the United Kingdom Atomic Energy Authority and Chairman of the NEA Senior Group of Experts on Severe Accidents.
The Nuclear Energy Agency’s Committee on the Safety of Nuclear Installations (CSNI) has initiated a Three Mile Island (TMI) Unit 2 Programme. The charter of the Joint Task Group (JTG) formed for this programme is two-fold: first, it is to collaborate with the U.S. Department of Energy (DOE) in establishing participation of interested OECD countries in the DOE’s TMI Unit 2 Sample and Acquisition and Examination Programme; and second, the JTG is to establish an analytical programme along the lines of an international standard problem exercise, wherein interested countries will analyse various periods of the TMI Unit 2 accident in an effort to assess and improve the relevant severe accident computer codes.

G.D. McPherson is Manager of the US Department of Energy’s TMI-2 Accident Program and Chairman of the NEA’s Joint Task Group on TMI-2.

Expanding the US programme

When the NEA initiated this programme, the DOE's TMI Unit 2 Accident Evaluation Programme had reached a point where much new information on the accident sequence had been discovered by close examination of computer and strip chart records in the reactor control room; and inspection of the core debris showed that the core had undergone much more serious damage than had first been estimated.

As a result of these developments, the DOE concluded that a standard problem type of analysis could be performed to the benefit of computer codes used in the analysis of severe accidents. It also concluded that an international effort in performing some examinations of core and reactor debris would serve to expand the resulting base, and this in turn would improve the statistics.
of the information to be gained from this unique study. For these reasons, the DOE responded positively to the NEA and the TMI Unit 2 JTG was quickly formed.

The programme of work

The first meeting of the JTG on the TMI Unit 2 was held in the Idaho Falls Offices of the Idaho National Engineering Laboratory (INEL) in April 1986, with the participation of 11 countries*, plus the Commission of the European Communities. In connection with the sample examination programme, the DOE offered to make available samples from the core and reactor components from the reactor coolant system and from areas within the reactor building. Of these, the unanimous choice for a first delivery was core bores that were soon to be drilled from the core. In fact, drilling was done during the summer of 1986 and the INEL technicians are now preparing core bore samples for selection by an expert sub-group of the JTG in early 1987. The selected samples will then be delivered to each participant's hot cells by April 1987. It is expected that two more shipments of samples will take place at annual intervals. While each participating country will fund the preparation, shipment, and examination of its samples, the DOE is to integrate and share in the interpretation of all results. The benefits of this exchange will be enhanced by the distribution of all relevant documents produced under the DOE's TMI Unit 2 evaluation.

Benefits expected to be far-reaching

Understanding of the details of the TMI Unit 2 accident has already grown considerably. Several countries which originally thought that there was insufficient information to proceed with a standard problem are now convinced of the contrary and have become active participants in the programme. Others are willing to accept severely damaged samples to perform measurements with which they have no experience. However, a free and open transfer of procedures and other skills will ensure that all the needed examinations will be performed and, incidentally, that before this programme is over, there will be a worldwide network of hot cells with a common base of capabilities in the severely damaged fuel area. In the end, this OECD TMI Unit 2 programme will serve three vital functions:

- it will permit a comparison and assessment of severe accident codes in a realistic, large scale accident situation;
- it will assist the DOE in its overriding goal to understand the TMI Unit 2 accident; and
- through the international character of the programme, it will extend the benefits of these results far beyond the boundaries of the United States.

* Canada, France, the Federal Republic of Germany, Finland, Italy, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom, and the United States. Together with the CEC, half of these countries will participate in one or the other of the sample examination and standard problems, and half will participate in both.
Disposal of radioactive waste: using codes for probabilistic systems assessment

S.G. Carlyle and P. Diaz Munoz

The NEA Probabilistic Systems Assessment Codes (PSAC) User Group was established in early 1985 by the Agency’s Radioactive Waste Management Committee as part of a concerted effort to develop performance assessment methodologies for radioactive waste management applications. The PSAC User Group provides an international forum for:

- exchanging information and experience
- comparing and verifying codes
- mutual peer reviews
- carrying out joint code development activities
- discussing topical technical issues

Only those Member countries actively developing probabilistic systems assessment codes are invited to take part in the Group. Currently, the 15 Group members are drawn from organisations in Belgium, Canada, the Federal Republic of Germany, Finland, Japan, Sweden, Switzerland, the United Kingdom and the United States, as well as the Joint Research Centre of the CEC.

Improving classical approaches to consequence prediction

Over the last few years it has become increasingly evident that the classical approaches to the prediction of radiological consequences of potential nuclear accidents and radioactive waste disposal systems can be improved by the use of formal uncertainty analysis techniques. It was considered sufficient in the past to deal with uncertainties by using expert judgement, with pessimistic assumptions to give the worst cases, or by generally placing caveats on the predictions. However, recent advances in calculating uncertainties in predictions may mean that more definitive and quantifiable information can be produced to indicate the level of confidence that can be given to the results. In addition, these techniques can be used to assess the risks associated with the long-term performance of a radioactive waste disposal facility by predicting the probabilities of occurrence of certain events in combination with the concomitant consequences.

The NEA Radioactive Waste Management Committee has been directly involved in advances made in applying uncertainty analysis techniques to assessments of the performance of radioactive waste disposal systems. An expert report entitled Long-Term Radiation Protection Objectives for Radioactive Waste Disposal, which was published in 1984, recommended inter alia the use of risk as an indicator of the performance of a waste repository. Risk was defined as the product of the probability of occurrence of an event, or sequence of events, and the predicted consequence of this event, i.e., potential harmful effects. This concept was introduced in order to systematically account for extremes in performance. At one end of the spectrum, it is possible to envisage high consequence/low probability events such as intrusion directly into a repository (e.g., by an inquisitive archaeologist in 12,000 AD). On the other hand, low consequence/high probability events may have greater frequency, such as minute discharges to lakes of radionuclides that have been subjected to dilution and dispersion along tortuous paths through confining geological media. A representation of the balance between events of varying probability and consequence within a given systems description can be achieved by using probabilistic uncertainty analysis techniques that take account of parameter uncertainty. These are called Probabilistic Systems Assessment Codes.

Figure 1. Schematic representation of natural and engineered barriers to the migration of radioactive waste.
The main features of PSA codes

Probabilistic systems assessment codes are being developed in several NEA Member countries to take account of uncertainties arising from predictions of the radiological impact of potential radioactive waste disposal systems; in particular, uncertainties arising from the variable quality of data used. Figure 1 gives a schematic representation of the natural and engineered barriers present in a typical disposal system for high-level radioactive waste. PSA codes attempt to simulate all the relevant processes which operate within the system in order to predict the radiological impact of disposal. A schematic representation of one such code, developed by Atomic Energy of Canada Limited (AECL) and called SYVAC, is shown in Figure 2. SYVAC contains a set of sub-models representing the major components of the disposal system: the vault, geosphere and biosphere. Uncertainty and variability in the data needed to drive the models are taken into account by using probability distributions to define the input parameters, rather than single 'best estimate' or 'worst case' values. SYVAC selects a simulation (defined as a possible state of the system) by randomly sampling a value for each parameter from its pre-specified distribution. This set of parameter values is then used deterministically within the sub-models to estimate the radiological consequence. SYVAC repeats this procedure many times (typically several thousand runs are made) and the results are combined, for example, as a histogram of predicted consequences versus their frequency of occurrence. It is then possible to evaluate the total risk associated with the disposal facility.

The Data Bank's contribution

One of the Group's objectives — to exchange codes and develop an inventory of PSA codes — is being met in large part by the NEA Data Bank. Effort is concentrated on the acquisition of fully developed and documented codes including SYVAC 1 and 2 from AECL, SYVAC A/C from the UK Department of Energy, and LISA from the CEC Joint Research Centre. These codes have been made available to the Data Bank and have been fully tested, documented and packaged, ready for distribution on request to other members of the Group.

Work has also begun at the Data Bank on the development of a library of computer modules used in the various PSA codes. The aim is to allow members of the Group to exchange specific pieces of code. Under discussion is the development of a standard interfacing system so that particular modules may be easily exchanged. This is particularly important as it will help avoid duplication of effort, reducing development time and therefore costs.

Finally, the use of standardized output files would simplify the analysis of the results of code intercomparison exercises and the Data Bank is collaborating with the PSAC User Group in the design of standard output specifications for PSA codes.

Verifying the codes

Confidence is an essential element in the development of new computer codes, especially where they are to be applied in the regulation of radioactive waste disposal systems. For this reason the Group has devoted considerable effort towards the verification of codes — i.e., confirming that the codes adequately represent the system being modelled. The primary means for doing this is to compare a number of similar codes by running a test case and to identify and explain or correct any differences that occur. The Group is in the process of conducting an exploratory (Level 0) intercomparison exercise to examine the possible pitfalls and benefits of comparing PSA codes, and the intention is to develop a structured series of intercomparisons to test different aspects of the codes.

Topical technical meetings provide peer review

Another important activity of the group is to hold topical technical meetings on subjects identified as meriting detailed discussion. The format is simple and straightforward. A subject is chosen, a few speakers 'volunteer' to prepare keynote papers and very informal meetings are held where everyone has an opportunity to freely express their views on problems arising and possible solutions on a specific aspect of PSA code development. This kind of mutual peer review has proved a very successful means of exchanging ideas.

As the PSAC User Group continues to develop, the NEA will play a key role in the development of what will probably become one of the major tools for assessing the safety of potential radioactive waste disposal systems.
Techniques for exploiting the fluctuations of signals from the wide variety of instruments and sensors used in nuclear reactors have been developed over the last 15 years to supply complementary information to characterise the status of a plant under normal or abnormal operation. It is possible with these inherent signal fluctuations—or, "noise"—to monitor reactor component behaviour such as core barrel motion, pump vibration or coolant leaks. Analysing the noise information with respect to expected patterns can improve both the safety and the availability of nuclear power plants.

Noise information can be analysed off-line—or nowadays on-line—using cheap microcomputers. Currently, expert systems are being developed which can alleviate the problem of false alarms and provide helpful displays for operators. The simplicity and low cost of providing for continuous and undisturbed monitoring of the plant by supplying a means of obtaining early warnings of possible reactor malfunctions is a major advantage of this approach. Further complications can be prevented by alerting operators to a problem and aiding in the diagnosis of that problem—before it demands major repairs.

Assessing today's techniques

As the reactor noise analysis field has reached a level of maturity for widespread industrial implementation, the NEA felt it was timely to issue a state-of-the-art report.* A group of experts from national laboratories involved in the field of reactor noise analysis has produced an assessment of where these techniques are today, including an analysis of trends, together with recommendations to utilities, manufacturers and research organisations.

The report covers the following main areas of applications for PWRs, BWRs and LMFBRs:

- Loose parts detection and acoustic monitoring
- Thermal hydraulics surveillance
- Flow measurements
- Vibration monitoring
- Surveillance systems
- Dynamic performance monitoring

In analysing the state of the art of noise techniques, the authors describe the various types of sensors available, what physical quantities can be extracted from specific categories of sensors and the possible anomalies which can be detected. The table gives a summary of these surveillance systems for PWRs.

In order to improve plant safety and availability, utilities are encouraged to establish improved communications (e.g. through workshops) regarding their noise analysis experience. This could serve to both improve their ability to perform correct diagnoses and provide a forum for encouraging all plant owners to utilise the best available technology.

It is also recommended that plant manufacturers integrate noise analysis into plant design by providing specifications on sensor locations and built-in capability for proper sensor mounting. In this respect, it would be useful to establish guidelines and standards, possibly through national or international co-ordinating organisations.

R & D establishments are encouraged to continue improvements of theoretical aspects of acoustic signal transmission and to develop automated on-line diagnosis using schemes based on artificial intelligence techniques. Surveillance methods for secondary systems (steam turbines, condensers, etc.) should also be included in R & D programmes.

NEA activities

The activities of the NEA in the field of reactor noise analysis include the sponsoring of a symposium on noise analysis techniques about every 3 years. The purpose is to provide a forum where users and researchers can take stock of the progress made and discuss problems that remain to be solved. The fourth in the series of symposia known as SMORN (Specialist Meeting on Reactor Noise) was held in 1984 in Dijon, France.* SMORN-V is currently being organised by the Gesellschaft für Reaktorsicherheit (GRS) of the Federal Republic of Germany and will be held in Munich in October 1987.

In conjunction with the SMORN series, the NEA Committee on Reactor Physics (NEACRP) organises benchmark exercises on well-defined problems involving

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* See also "SMORN-IV - Analysis of Nuclear Reactor Noise", NEA Newsletter, No.3. (December 1984).
the processing and interpretation of noise measurements. Laboratories in various countries participate in these benchmarks to validate their noise analysis methods. Two benchmarks are currently under way involving the detection of a) an artificial anomaly from a simulator and b) a real anomaly from an operating commercial reactor. Results of these benchmarks will be presented at SMORN-V.

### Summary of Surveillance Systems for PWRs*

<table>
<thead>
<tr>
<th>Sensors used</th>
<th>Physical parameter</th>
<th>Physical phenomena monitored</th>
<th>Type or example of anomaly</th>
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<tbody>
<tr>
<td>Ex-core neutron detector</td>
<td>Mechanical position of internal structures</td>
<td>Vibrations of structures</td>
<td>Loosening of hold-down spring</td>
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<td>Thermal-shield flexure broken</td>
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<tr>
<td></td>
<td>Primary water temperature</td>
<td>Temperature fluctuations</td>
<td></td>
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<tr>
<td>In-core detections</td>
<td>Mechanical positions of fuel assemblies</td>
<td>Vibrations of fuel assemblies</td>
<td>Baffle jetting</td>
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<tr>
<td></td>
<td>Mechanical position of control rods</td>
<td>Control rod vibrations</td>
<td>Cross flows</td>
</tr>
<tr>
<td></td>
<td>Void fraction in subchannels</td>
<td>Boiling</td>
<td>Abnormal boiling</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>(local overpower or flow reduction)</td>
</tr>
<tr>
<td>Outlet thermo-couples</td>
<td>Primary water temperature</td>
<td>Temperature fluctuations</td>
<td>Anomaly of flow</td>
</tr>
<tr>
<td>Pressure sensors</td>
<td>Primary water temperature</td>
<td>Temperature fluctuations</td>
<td>Natural circulation</td>
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<tr>
<td></td>
<td>Pressure waves</td>
<td>Vibration of internal structures</td>
<td>Presence of gas (steam or incondensable gas)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Primary pumps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>working conditions</td>
<td></td>
</tr>
<tr>
<td>Vibroacoustic Sensors</td>
<td>Displacements or accelerations</td>
<td>Vibration of mechanical waves</td>
<td>Abnormal vibrations</td>
</tr>
<tr>
<td></td>
<td>Mechanical waves</td>
<td>Impactings</td>
<td>Loose parts</td>
</tr>
<tr>
<td></td>
<td>Acoustic waves</td>
<td>Acoustic emission due to leakages</td>
<td>Leakages</td>
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</table>

* Taken from the report.
New publications from the NEA

Uranium: Resources, Production and Demand (Red Book)
ISBN 92-64-12842-5
Price: £ 21.00 US$ 42.00 FF 210.00

Nuclear power generating capacity can continue to expand only if there is a steadily increasing supply of uranium. This report presents compilations of uranium resource and production data, compared with the nuclear industry's future natural uranium requirements. In addition, it reviews the status of uranium exploration, resources and production in over fifty countries.

1986 Statistical Update of the Red Book
Free on request

Nuclear Spent Fuel Management: Experience and Options
ISBN 92-64-12883-2
Price: £ 15.00 US$ 30.00 FF 150.00

Spent nuclear fuel can be stored safely for long periods at relatively low cost, but some form of permanent disposal will eventually be necessary. This report examines the options for spent fuel management, explores the future prospects for each stage of the back-end of the fuel cycle and provides a thorough review of past experience and the technical status of the alternatives. Current policies and practices in twelve OECD countries are surveyed.

Assessment and Recording of Radiation Doses to Workers
(A report by an NEA group of experts)
Free on request

This report considers the assessment and recording of occupational exposure to external and internal radiation sources and attempts to identify practical problems in complying with current radiation protection standards.

Epidemiological Studies of General Population Groups Exposed to Low-Level Radiation
Free on request

The purpose of this report is to provide a simple description of the different types of epidemiological study involved, of how they are carried out, and of their potential, limitations and problems.

International Intercalibration and Intercomparison of Radon, Thoron and Daughters Measuring Equipment — Part I : Radon Measurement
Free on request

The variety in design of new radon measurement methods has led to a concern about the quality of the data produced. There is a need to determine their accuracy and comparability. This report provides the results of a joint NEA/CEC programme to determine how the calibration procedures used in different countries compare.

Decommissioning of Nuclear Facilities : Feasibility, Needs and Costs
(Report by an Expert Group, 1986)
ISBN 92-64-12894-8
Price : £ 11.00 US$ 22.00 FF 110.00

This report describes experience in the decommissioning of nuclear facilities to date and assesses current technology as a basis for decommissioning large commercial plants in the future. It compares several national estimates of the costs of decommissioning and examines the impact on the cost of generating electricity.

NEA Activities in 1985: The 14th Activity Report of the OECD Nuclear Energy Agency
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Newsletter No.12 on Radionuclides Migration in the Geosphere
Free on request

The OECD Nuclear Energy Agency
An information booklet
Free on request