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Speaking of Nuclear Energy

Highlights of Proceedings from IAEA Public Information Regional Seminars

Fall 1992

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Introduction

At the 1989 International Atomic Energy Agency (IAEA) General Conference, the Japanese Government pledged an extra-budgetary contribution for a three-year enhanced public information programme. With this funding and the support of cost-free experts from the United States and Japan, we have been able to develop such a programme centering on a series of two-day regional media seminars.

It was felt there was a dearth of basic information available on the facts about nuclear power, which contributes to an inadequate understanding of this subject among members of the general public. Many people receive most of their information through the media. Therefore, the best way to reach the public at large, we determined, was through dialogue with the media. These seminars were the chosen vehicles for doing so.

At the very outset, it was determined that these seminars were to be informative and educational, and provide balanced, honest background material on the subject of nuclear energy. We felt that since the Agency's scope is limited, the seminars would have a seed effect: we would demonstrate to Member States that this type of seminar could be done; show how it could be done; provide the stimulation and the materials for them to use as templates for their own publications; and help them to expand such a dialogue with their local media.

The key message of the seminars was basic: nuclear power is a complex technology that can be managed safely and economically through high standards of excellence. Such excellence can be achieved worldwide by observing international standards and maximum openness.

Regional media were the primary audience for the seminars. However, local and regional authorities also have attended. The topics discussed included explanations of radiation, nuclear waste, non-proliferation, nuclear applications including power generation, nuclear safety and the environmental impacts of the various energy sources.

The speakers chosen were a mix of IAEA and outside experts from around the world who gave their time and energy to making each seminar a success. Overall, the response was most positive. About 500 participants from 20 countries took part over the initial three years of the programme. Seminar sites included Bombay, India; Canberra, Australia; Aomori, Japan; Budapest, Hungary; Tokyo, Japan; Bangkok, Thailand; Cairo, Egypt; Hong Kong; Jakarta, Indonesia; and Kuala Lumpur, Malaysia.

As the current phase of the enhanced programme draws to a close, we felt that other IAEA Member States might benefit from the presentations and material from these seminars. Therefore, we have made a selection of speeches and topics that we believe captured the essence of the information presented during our regional seminars. They are published here, in the hope that the information they contain will continue to be of value beyond the seminars themselves and may also inspire others to attempt similar ventures in the future.

Hans Blix
IAEA Director General

Public Attitudes and Nuclear Power
The Question of Nuclear Power

Rita Scott
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Cairo, Egypt
3-4 March 1992

This year marks the 50th anniversary of the Atomic Age. It began with the first nuclear chain reaction at the University of Chicago in the United States. This "propagation of atomic fire," as one observer called it, took place in deepest secrecy; its purpose was military and it was years later before the world was told about it. By the time the secret was out, everyone living knew this mysterious force had changed the future and that our world would never be the same.

Scientists and engineers had gained access to the immense reservoir of energy in the atomic nucleus. The splitting of the atom would release "enormous quantities of usable energy." Bertrand Goldschmidt, a scientist from France who participated in this event, recalls that most people believed atomic energy opened for mankind the door to a new world full of hopes—and threats.

For almost 20 years, the optimists' view of the nuclear potential prevailed. High energy hopes were based on this new fuel which was 3 million times more powerful than coal. Nuclear powered ships, electricity plants, airplanes and submarines were envisioned and planned. Fifteen years to the day after the first chain reaction, a commercial nuclear power plant opened in the United States.

During the past two decades, however, the public focus has seemed to settle on nuclear energy's threats. Monotonously, reports on nuclear energy's potential and use grew pessimistic, as downbeat as a dirge. Repeatedly, we heard that nuclear energy was an option few countries in the world would ever choose again. Detractors claimed that nuclear energy's golden promise had turned into leaden fears of unsafe reactors and long-lived nuclear waste.

Only recently, as we approach the half-century anniversary of Chicago, do we see other concerns beginning to take precedence in the public mind. And now, in a number of countries, the news about nuclear energy is more positive. The Gulf War, the turmoil in the former Soviet Union, and the threat of greenhouse gases are causing some nations to take another look at the use of nuclear energy for electricity generation.

Today, nuclear power appears to be at a crossroad and the question asked is will this energy source continue to be developed and used, or is it slowly dying a technological death?

Supporters and opponents alike respond: Nuclear power will revive and grow only if and when the public accepts it.

At the bright beginning of the Atomic Age, someone made a prophesy "that nuclear energy will be too cheap to meter" and the public embraced this vision of an unlimited, inexpensive energy source and enthusiastically supported it. In the midst of this technological euphoria, the United States, the United Kingdom, and much of Western Europe began to develop nuclear power programmes, followed by the former Soviet Union, Eastern Europe and, more slowly, Asia and South America.

At this time, there are about 420 reactor units operating in 26 countries including Taiwan, providing electricity to more than two billion people. Five other countries, including China, with populations totalling nearly one billion, had plants under construction as of December 1990.

Five countries, France, Belgium, Hungary, the Republic of Korea and Sweden, generate about one half of their total electricity requirements with nuclear energy. Altogether, 12 countries in the world rely upon nuclear power to supply at least one-fourth of their total electricity needs. Nuclear energy is the single largest source of electricity production in Western Europe, accounting for 32 percent of all supplies in 1990. In the United States, 111 nuclear plants produce more than 20 percent of that country's electricity.

But, in the years since nuclear energy's buoyant beginning, the world has been battered by a series of events, including two accidents in nuclear power plants. The 1950's were followed by two decades during which the public seemed to revolt against technology in general, with specific debates about the desirability of nuclear power.

Today, nuclear power usage worldwide provides few clues to its future. In countries where nuclear plants are either operating, under construction, on order, or planned, the use of nuclear energy is still the subject of intense controversy. In most of these countries, public attitudes are clearly directing the energy choices made and the actions taken, indicating nuclear power may have lost public support even in countries fairly dependent on it.

For example, Belgium, which receives almost 60 percent of its electricity from nuclear power, has no new nuclear plants under construction nor are any planned. In Switzerland, where nuclear power provides 42 percent of its electricity, a referendum in September 1990 mandated a moratorium on new nuclear plant construction until the turn of the century. Sweden, with almost half of its electricity produced by nuclear energy, voted in 1980 to phase out nuclear power plants by the year 2010. Finally, in Canada, where Ontario Hydro had planned to build 10 new nuclear plants in the next 25 years, a recently elected government put a 3 year hold on those plans, while allowing a plant under construction to be completed.

Another country that appears to be turning away from this energy source is the United States, where no new plants have been ordered since 1979 and none are under construction that were not ordered before 1973. Of all the OECD countries, only France and Japan have firm plans to install new reactors after 1995.

What has happened since those days in the early 1950's when this technology was expected to vastly improve the quality of life on our planet?

Clearly, nuclear power has made a contribution to the economic growth of the industrialized nations, for statistics in these countries indicate a direct connection between the growth of the gross national product and the industrial use of electricity. In Canada, for example, the demand for electricity has grown nearly 4 percent per year in the last 10 years. It is expected to grow at over 2 per cent annually for the next 25 years.

In the United States, for the past 17 years, economic growth and electricity use ran virtually parallel—nearly one to one. In France, domestic product and consumption of electricity have grown at faster rates than expected.

Obviously, a growing economy requires increased supplies of electricity.

Nevertheless, a number of countries with a strong industry based on technological development appear to be retreating from a technology, namely nuclear, that has supported that growth. Public opposition came at the very time nuclear power began to offer real benefits to society; and because of the public attitude toward nuclear power in these nations, governments responsible for providing adequate supplies of energy for economic health and faced with a money drain from energy imports, have hesitated to support nuclear power, or have withdrawn from it all together.

Why? Opponents of nuclear power claim "Chernobyl drove a stake through the heart of nuclear power." Its advocates strongly disagree. They point to the fact that nuclear power supplies 17 percent of the world's electricity and that during 1991, four nuclear reactors were connected to the electricity grids in Bulgaria, China, France and Japan. There are 77 nuclear plants being built, including three that started construction last year—two in India and one in Japan. France has five reactors coming into service to add to the 56 operating plants that provide three quarters of that country's electricity with the lowest per capita CO_2 emission in the OECD countries. They note that worldwide, 29 countries in 1991 were operating or building a total of 497 nuclear plants for electricity generation. The sum of these figures does not point to a dying technology.

However, this question of what is perception and what is reality confuses people's understanding of the issue at a time when major energy concerns must be resolved, in a world whose population will be 60 percent larger by 2025, when at least 50 percent more energy will be needed. Like the Red Queen in the book *Alice in Wonderland*, the world will have to run faster and faster simply to stay in place.

The Chernobyl accident in the former Soviet Union aroused public fears about radiation and its effects on human beings as nothing ever has. The accident heightened the fears of a large faction of the public worried about the dangers associated with this unfamiliar energy source. But this is not the single reason for the decline of nuclear power. We are learning that those groups who oppose nuclear power appear to do so for a number of reasons starting with the very name of this energy source which ties it forever to the specter of the bomb and the mushroom cloud. Radiation, disposal of nuclear waste, the specter of cancer—all of these can be and are misunderstood by a large part of the public.

Safety is clearly the public's foremost concern regarding nuclear power, and the nuclear community does not yet seem to have made a convincing case that the Chernobyl and Three Mile Island accidents were the exception, not the rule, for nuclear power plant operation. Some groups charge the nuclear community worldwide with contributing to their fears by being secretive, and by implying the technology is too technical and complicated for the public to understand.

There are other concerns, pocketbook concerns, about nuclear power that are held by large sections of the public. The significant increase in costs of nuclear plants in a number of countries is seen as a major factor in the withdrawal of public support. In some of the industrialized countries during the 1970's, when a large number of nuclear power plants were being planned and or constructed, inflation rates rose to close to 20 percent, so that original cost estimates of the plants doubled and tripled. One-of-a-kind design plants, inexperienced utilities and bad management led to serious and costly delays. After the Three Mile Island reactor accident in the USA, regulatory reforms and safety lessons learned required extensive retrofitting of plants, both under construction and in operation. All were catastrophically costly.

France was exempt from these problems by the nature of wise planning in the beginning. The country chose and stayed with one reactor type, built in a series of standardized units and consistently improved.

Worldwide, a number of nuclear plants were canceled in the late 1970's and early 1980's. Often, these canceled plants were part of a planned series of three or four units that a utility was building. When only one plant of the series was completed, the design and engineering costs that would have been spread over all the plants in the series had to be borne by the single remaining unit, adding substantially to its expense.

Needless to say, the forecast about cheap nuclear power has come back as a taunt to haunt the nuclear industry. Actually, it was based on the relatively small amount of fuel required, compared to fossil fuels. Indeed, nuclear fuel or uranium, remains the least cost aspect of this energy source, even when compared to the price of coal. Over a 30 year period of construction and operation, coal and nuclear energy costs are quite comparative. Charts are available that show recent cost experiences in five countries, Canada, Hungary, Korea, Spain and the USA. The construction costs and the capital investment is higher for nuclear than for coal plants. Operation and maintenance is also a little more expensive. But, the fuel prices bring both type of plants into the same price range over a period of 30 years.

The size of nuclear units currently is being evaluated, for once it was thought that there were great savings in size. But as one utility operator lamented, "every large nuclear project costs twice as much and takes twice as long to build." A country's uncertainty over future energy needs may make building large reactors questionable in today's economic environment, so there is renewed interest in smaller, modular units that can be more easily tailored to the needs of an area.

This question of economics is often misunderstood. These cost concerns, as well as the fears about safety and radiation, are frequently capitalized on by another group known as environmentalists in the USA and the Greens in Europe.

This group appears to be part of an anti-technology movement that is seeking an alternative society with alternative sciences. They want safe, decentralized technologies and energy sources that are simple and labor intensive. They are knowledgeable and skilled in the manipulation of information, especially in talking to those persons who are so unsure of what to be afraid of in nuclear power, that they simply oppose it on general principles. Popular movies, television shows and novels all add to this fear by making nuclear energy a sinister force, or an evil to be combatted.

The actual numbers of opposing groups is difficult to determine. Researchers of public opinion report that actual opposition is not that widespread as recent polls show in countries such as Finland, Sweden, Japan and the USA. More than half the public of those countries believe nuclear power will provide electricity in the future and that it is necessary to meet electricity demands. Poll figures also indicate the public is slowly recognizing the environmental advantages of nuclear power. Spokesmen on both sides of the issue admit that probably 30 percent are for and 30 percent are against nuclear power, and the middle 40 percent are the ones that make the difference in elections and referenda. Within this group, shifts in opinion occur easily and quickly.

This is the public that will ultimately decide the fate of nuclear power.

At first glance it would seem that the energy choices made by a country are the business of that country only. Unfortunately, all of us have seen that the effects of a country's energy choice are not limited by national boundaries. In 1986, Europe discovered that the fallout from the Chernobyl accident in the former Soviet Union had no respect for borders. On the other hand, Europe is also learning, as each day passes, that carbon dioxide, sulphur dioxide and nitrous oxides also violate many a nation's atmospheric borders. And during the Gulf Crisis, we learned, once again, how the vital linkage between a country's economic growth and access to energy supplies can contribute to a war affecting people the world over.

The public is waking up to the reality of global energy effects, as it has had to recognize that supplies of fossil fuels are finite while energy needs are unending.

As Robert Franklin, CEO of Ontario Hydro, pointed out, "There is no benign technology for producing electricity. Nuclear electricity produces waste, so dc fossil fuels. Burning coal creates fly ash, acid rain and greenhouse gases. Oil gives off the same gas, and the relatively cleaner burning natural gas also contributes to acid rain and the greenhouse effect. Even hydro electric dams are not without their problems, such as flooding and river bank erosion. "I'm afraid," he conlcuded, "when it comes to choosing technologies, it's a choice between necessary evils."

A Spanish proverb tells us, "Take what you want", said God, "and pay for it."

Conservation can reduce the demands somewhat. Solar and renewable energy sources can be used in specific locations in small increments. But until new energy sources are tapped or developed, every nation must meet its base load, round-the-clock power needs from this short list—coal, oil, natural gas, nuclear and to a lesser extent, hydro power. This is a fact of life that the publics of countries with or without nuclear plants in operation must address, sometime soon.

There are several countries that are beginning to face the problem sooner, rather than later. Perhaps the most dramatic example can be seen in Sweden.

Sweden has no fossil fuels, but plenty of rivers, so about two thirds of their water resources have been used to produce 45 percent of their electricity needs. However, by the 1960's it was clear that hydro power would not meet the growing demand for electricity. In order to reserve some of their rivers, they decided to build nuclear power plants. At the time the decision was made, there was no opposition; but as the first plant came on line, the debate began over waste management and the safety of the reactors. The debate heated up in 1979 after the accident in the USA. In 1980, the Swedish people voted to complete the reactors under construction and use a total of 12 reactors for their life span. They predicted nuclear power to begin phasing out by the year 2010.

Then a new government in 1988 decided that the phasing out of the reactors should begin earlier, with the shutting down of two nuclear plants in 1995 and 1996. However, during the 1980's, Sweden also had prohibited further large development of the country's hydro potential and mandated that there would be no increase in fossil fuel emissions from the 1988 level. Theonly alternatives were energy conservation, biomass and the wind.

In spite of a government-supported programme for energy conservation, the demand for electricity continued to grow about four percent per year during the last ten years, with a number of energy intensive industries, such as paper pulp, iron and steel mining and chemicals, which generate a great deal of export revenues.

An investigation into the environmental and economic cost of taking two reactors out of production 15 years earlier than calculated was estimated at US $8 billion and that included building fossil fuel plants. Otherwise, shutting the two reactors would lead to massive unemployment which could be expected to rise up to 30 percent.

Last year, Sweden's political parties met and agreed that, first of all, there will be no early phasing out of nuclear reactors, and when that phasing out begins will depend on the results attained in energy saving and in the supply of electricity from (new) environmentally-acceptable power plants. Many in Sweden do not expect to see the reactor phased out at the agreed upon date.

Furthermore, public opinion in Sweden now seems to have taken a more relaxed attitude towards nuclear energy. A public opinion poll last year indicated that about 65 percent of the population want to see the Swedish nuclear plants running even after 2010. Most believe the Swedish plants are safe and that nuclear waste is being handled responsibly. After the facts about the need for nuclear power were published, a nuclear waste poll was taken and the majority of the Swedish public agreed they would accept waste storage in their neighborhood if it proved to be the best site for it.

There are other examples of countries responding to the difficult energy choices that must be made. In the Republic of Korea, the economy is dynamic, consumer demands are constant, but natural resources are in chronically short supply, and most of the primary energy is imported. The Republic is a perfect example of a country in which energy consumption and power generating capacity have doubled in the last decade. It also has large energy needs, such as I discussed earlier. However, unlike Belgium, or Switzerland, the Republic of Korea has turned to, not away from, nuclear energy. The government, working to reduce its dependence on imported oil, announced this past summer the planned construction of two new nuclear power units.

China, with the world's largest population also has had to make a serious study of available energy resources, in order to provide the energy needed for continuous stable economic growth, and to reduce severe environmental pollution. As a result, China has committed to building nine nuclear power plants, with a combined generating capacity of six million kilowatts before the year 2000. This country's long range plans are to actively develop nuclear power and wherever possible substitute nuclear sources for coal. China hopes to have thirty 1 000 MW(e) reactors operating by the year 2020.

In the USA, the Department of Energy's 1991 National Energy Strategy promotes the ability of nuclear power to meet electricity needs, and suggests a plan whereby this can be done by reducing costs and increasing safety and reliability.

Indonesia has announced nuclear power is an indispensable part of its long range energy plan, as the available supplies of oil, gas and coal are predicted to run out in the next 20 to 200 years.

In Denmark, a former member of Parliament, now the head of the Danish Nature Conservancy and a leader in the trade unions, announced there were good arguments for nuclear power plants, especially in light of the CO_2 emissions avoided by their operation. They supported reconsidering the 1985 decision to exclude nuclear power from future energy plans.

And Finland is preparing its public to make a decision on the construction of a new fifth nuclear power plant, which was planned to begin during the mid-eighties. The project had to be canceled after the Chernobyl accident, but now polls indicate support for the project. More than 40 percent of Finland's electricity comes from nuclear power plants which have an excellent safety record. Finland also has found a way to deal with its nuclear waste.

These examples demonstrate that public attitudes towards nuclear power are not inflexible and will change if certain conditions are in place. These conditions include: the continuous, safe operation of the nuclear power plants;

responsible handling and storage of nuclear waste; the availability of open, honest and immediate information; a clear understanding of the energy choices, their hazards and benefits; as well as early and full public involvement in the decision-making process.

For the past ten years, accelerated by the Chernobyl accident, the international nuclear community has been making a concerted effort to resolve safety and waste issues and to develop enhanced public information programmes. A worldwide self-monitoring body, the World Association of Nuclear Operators, or WANO, was formed to keep nuclear safety performance at the highest level by helping plant operating staff around the globe to share experiences. The IAEA also has expanded its nuclear safety programmes.

In all the countries with nuclear power plants, public information centers have sprung up with a multitude of diversified activities. For the last two years at our IAEA Public Information Forums, experts from around the world have come together to learn from each other how to better do their jobs, and to share experiences gained in their efforts to provide honest, accurate information to their publics.

Clearly the pro and con debate about nuclear energy will continue, especially in the light of the growing environmental concerns, and the increasing demands for energy for growing economies. The winners of the debate will decide whether or not the "immense reservoir of energy" will be tapped. Only then will we see if nuclear energy will finally fulfill its golden promise. ❐

Energy, Economics, Environment and Nuclear Power

Dr. Hans Blix
Director General
International Atomic Energy Agency

Bombay, India
18 December 1989

We have lived through a remarkable period in the political world in the last few years and especially this year. The Cold War between East and West seems to be over and its most striking symbol, the iron curtain, is being dismantled. Some armed conflicts have been terminated. In other cases, there are hopes for solutions.

All this is very exciting and is occurring at a breath-taking pace. But economics do not, in most cases, develop at such a pace, neither in the industrialized nor in the developing world. One might perhaps hope that the expensive armament programmes both in industrialized and in developing countries will wind down. This ought to free resources for the capital-intensive but vital sector which I am to discuss, namely energy.

Raising the standard of living in developing countries requires efforts on many fronts, including education, health, agriculture, industrialization. In addition, external and internal peace is needed. A greater use of energy for transport, industry and domestic use is a vital ingredient. The three quarters of the world's population who live in developing countries consume only about one third of the world's energy.

We hear a great deal these days about the need for more efficient use of energy. These recommendations are valid everywhere. There is no good reason why one should consume one liter of petrol for ten kilometers driving if one can get away with 0.6 liter for the same distance. This is true both in developing and industrialized countries. However, given their present low levels of energy use, there is no doubt that even with very strong efforts to achieve a discriminating and efficient use of energy, developing countries will need to use more primary energy.

Electricity is a very special form of energy. It cannot yet be used on a large scale to drive cars and trucks, or ships and airplanes, but it has wide use in industry; it is vital for light and as an energy supply in electronic communications and home appliances. It is, of course, used extensively in large industries, but is particularly convenient for the small scale cottage industry. You just plug in. It is clean and relatively safe.

Our statistics show that even after the oil shocks of the 1970's and the recession, when the consumption of primary energies—coal, oil and gas—was stagnant in industrialized countries, they continued to increase their use of electricity. Indeed, the greater use of electricity—often generated by nuclear power—was part of the reason for the stagnating use of oil. Should environmental concerns prompt a greater reliance on trains, trams and trolley buses, and should electrically driven cars become economic, the demand for electricity would become even stronger.

Current Levels of Electricity Consumption

Let me give you some idea of the present level of electricity consumption in different countries. The world's highest per capita consumption is in Norway, with 23 000 kwh per person and year; in Sweden that figure is 15 000; in France, 6 400; in the USSR, 5 600; and in Japan, 5 500. The developing countries on the average have a per capita electricity consumption of only 1/14th of that of the industrialized countries. In Indonesia, the figure is 200 kwh per person and year; in China it is 400; in India, 270; and in Bangladesh, only 50.

It is not surprising that all developing countries are planning for a greater generation of electricity as a central element of their economic and social development agendas.

How are the increasing quantities of electricity to be generated? There are numerous ways: such as through the burning of fossil fuels, such as coal, oil and gas, through hydro power, nuclear power, through renewable sources such as wind, sun and biomass, and geothermal power. All these sources will be used, but the proportions in which they come into play have relevance, from an economic as well as from an environmental point of view.

Traditionally, planning took only the economic aspect into account. The cheapest energy was the best energy. It was only after the oil embargo that countries began to consider energy independence as a significant factor. We failed to include in our calculations the cost of air pollution, e.g., corrosion, destruction of land, lakes and forests. It is, of course, difficult to put price tags on some of these things.

Nevertheless, today it is evident that we must take into account not only the costs of generating and distributing energy, but also the costs in terms of life and health as well as the environmental costs. A gradual warming of the earth's atmosphere through a continuous increase in the carbon dioxide level due to the accelerated use of fossil fuels is a price we don't want our grandchildren to pay.

It is important to explain at the outset that the discussion of the merits and demerits of an energy option become meaningful only when this option is compared with others. Let me therefore go through and comment on the various options for electricity generation.

I shall begin with fossil-based power generation, i.e., the burning of coal, oil and gas. Currently, about 63 percent of the world's electricity is generated by this method. The technology is not very complicated. From the point of view of cost, generation by coal is about equal with nuclear in many places. Oil— even at current prices—is a much more expensive fuel for electricity production than coal. The price of gas used to be linked to that of oil, but we have seen recently how it has instead been linked to the price of coal, at least for electricity generation. If this becomes common, gas will become an economically viable fuel for electricity generation in many places.

From the view point of safety, all three fossil fuels are accepted by the public, although the number of casualties is high in accidents related to coal mining, offshore drilling and gas transportation. Looked at from the viewpoint of the world's resources, one might regret the burning of finite oil and gas resources, which could have more valuable uses. Coal is more plentiful.

The most serious concerns about generating electricity through the burning of fossil fuels are environmental. Acid rains and dying forests and lakes have been linked to the accelerated use of coal and oil in several industrial areas and the gigantic resulting emissions of sulphur dioxide and nitrogen oxides. It is now technically feasible—at a cost—to reduce these emissions drastically when coal and oil are burned, and gas burning does not give any SO_2. However, the burning of fossil fuels at present levels is viewed with increasing alarm, because of the so-called greenhouse effect. Let me briefly explain what this is.

Certain gases, released into the world's atmosphere—primarily chlorofluorocarbons (CFCs), methane and carbon dioxide (CO_2)—trap the heat in the atmosphere. It is calculated that the increases in these gases is leading to a higher temperature in the world's atmosphere—with consequent climate changes. Further research can be expected to give us more definite knowledge about the threat, but many are convinced that we have already experienced a minor warming and that further warming is inevitable. The question seems only to be whether, through determined action, we are able to slow this development and stabilize it. The governments of the world are jointly focussing upon this issue in a special international forum—the Intergovernmental Panel on Climate Change—established by the World Meteorological Organization and the United Nations Environment Programme.

Action is already being taken to phase out the CFCs which are used in modern refrigerators and in foam plastic production because, apart from being a source of greenhouse gases, they also are destructive to the world's ozone layer.

Methane gas gets into the atmosphere from animals, rice paddies and leaks during the production of natural gas. It is not easy to reduce these emissions.

There remains CO_2, which results from the burning of all fossil fuels and all organic material, including wood. There is no viable way in which CO_2 emissions can be avoided in such combustion. All fossil fuel burning—in cars, in heating and in electricity production—is thought to contribute about 50 percent of the greenhouse effect. The current burning of rain forests is deemed to add some further 10-20 percent. The different fossil fuels do not, however, contribute CO_2 in equal measure. Counted per unit of energy generated, the burning of gas yields about half as much CO_2 as does coal. The amount of CO_2 produced by burning oil lies between those of coal and gas.

If the current global levels of burning of fossil fuels are too high for the health of our planet, it is easy to see that increased levels are even more dangerous. A conference that was held at Toronto last year urged that the current emission of about 20 000 million tons of CO_2 per year should be reduced by 20 percent by the year 2005. Others have suggested even more drastic reductions. It is also urged that the burning of rainforests and the heavy logging be halted and that reforestation be undertaken everywhere—to increase the biosphere's capacity to absorb CO_2.

How could the burning of fossil fuels be reduced? Non-controversial—but in my view totally inadequate—answers are: a switch where possible from coal to gas, which emits less CO_2 and/or conservation and development of renewable, non-CO_2-producing energy sources. A controversial additional answer is: use of more nuclear power. Let me comment on the various possibilities.

There is a tendency toward greater use of natural gas. This has fewer consequences in the form of acid rain and dying forests. As the burning of gas results in half as much CO_2 as does coal, there is a net advantage to replacing coal by gas in terms of the greenhouse effect. Where gas is burned for additional energy generation, there will, of course, be additional CO_2—though less than if coal had been used to generate that additional electricity.

Let me turn next to conservation. This concept covers both a more discriminating and more efficient use of energy. The difference between the two ways of saving energy is easily seen when we consider that we can save petrol by driving less or by using a more fuel efficient engine. The latter form of saving is easily accepted. To renounce reliance on energy is mostly harder. Environmentalists are fond of saying that no energy pollutes less than the energy you don't use. They may have a point in the rich, energy-squandering countries, but a famous Indian nuclear scientist, Homi Bhabha, coined the expression "no energy is more expensive than no energy." Developing countries can testify to the human costs of an absence of energy.

It is very difficult to calculate how much energy we can save. The quantities are significant, but no serious energy experts believe that one can achieve more than a partial off-setting of the increasing demand for energy. What we can clearly see today is that current energy plans in the world do not point to a reduced use of fossil fuels. China, which is already the world's biggest user of coal, plans to double its coal production from the levels of the mid-1980's by the year 2000. India plans to triple its coal production in the same period. If the plans are carried out, these two countries together—with more than one third of the world's population—will then use more coal than the whole of Western Europe, North America, Japan and Australia.

Developing countries in general, starting from a low per capita level of use of fossil fuels, can be expected to expand their use of these fuels. For most of them nuclear power is at present not a practical proposition because their grids are too small, or because they lack adequate manpower or infrastructure —or all of this.

The most important renewable and non-CO_2-producing source of electricity is hydro power. At present, it generates some 20 percent of the world's electricity. In the industrialized world, most hydro potential already has been exploited, but in some developing countries resources remain and will undoubtedly be used, where it is economical and where the example of a huge electricity-producing hydro power installation which has also had very severe environmental consequences.

In China, a hydro project on the Yangtze river has been contemplated. It would yield enormous quantities of electricity, but would also, apparently, require the resettlement of large numbers of people.

There is much talk about the use of biomass in the industrialized countries. Rapidly growing, harvesting, and burning trees and the planting of new ones would be a fuel cycle without any net contribution of CO_2. However, the economics of this source have not yet been established and so far it has not really been relied upon on a large scale anywhere.

In many developing countries, biomass in the form of non-commercial fuel wood and animal dung is a dominant fuel. With a growing population, the reliance on this source has become much too heavy in many places, with deforestation and desertification as a result. In such areas, a more efficient use of fire-wood, replantation and greater use of other fuels is desirable.

In conclusion—as far as we can see today, a greater global reliance on biomass is not likely to become a very significant method of substituting for fossil fuels.

Solar power is making a substantial contribution in isolated locations and on a small scale. Heating of water by solar energy is practical and economic in many places. However, solar cells for large-scale economic electricity production are still deemed to be far away.

Windmills have a long tradition, but despite considerable experimentation and promotion, wind power has not become economic, nor does it yield the large quantities of energy we need.

Taken together, solar power, wind power, biomass and other commercial renewable sources yield today less than 0.3 percent of the world's energy. Most of it is actually geothermal—in the United States, Iceland, Italy and New Zealand.

I turn now to discuss nuclear power, and my comments on fossil fuel-based electricity and the use of hydro power, biomass, solar and wind power may serve as background and comparison.

Nuclear Power Today

Although the use of nuclear power is the subject of controversy in many countries, it has demonstrated its capacity to generate electricity on a large scale, economically and in an environmentally benign way. It has expanded fast. Seventeen percent of the world's electricity is now produced by nuclear power plants. That is only three percent less than the 20 percent we get from hydro power in the world. That is no small quantity even though it corresponds to only about five percent of all the primary energy consumed in the world today.

Of the 430 nuclear power reactors operating around the world today, 26 are in eight developing countries in Asia, Latin America, and the Mediterranean region. Some developing countries are constructing new plants and a few are contemplating initiating nuclear power programmes.

Some comments about the cost of nuclear power: There are certainly cases of nuclear power plants that have turned out to cost many times what was originally calculated. However, it is nevertheless true to say that nuclear power plants in general have proven their long-term economic benefits.

The Nuclear Energy Agency and the International Energy Agency of the Organization for Economic Co-operation and Development (OECD) have recently completed a study which shows that nuclear-generated electricity from new plants will be cheaper than coal-generated electricity in many OECD countries and in five developing countries, in spite of the current low international market price of coal. India has presented a convincing case that even small nuclear power plants of 200 MW(e) can compete with coal-fired plants if the whole infrastructure for coal mining and transport is taken into account.

Nuclear plants have proved to be reliable as well. In Europe, for example, nuclear plants are showing about the same performance data as their oil- and coal-fired counterparts in all size ranges.

Nuclear power provides some countries with a measure of energy independence. Even when nuclear fuel has to be imported, it is easy and relatively cheap to stock several years' supply of fuel. For energy-poor countries like Japan, the Republic of Korea and France, this is an important factor.

Lastly, in this era of concern over acid rain, dead forests and the greenhouse effect, nuclear power plants in normal operation are environmentally benign electricity generators. They do not emit any SO2, NOx, or CO_2.

The Environmental Threat

Some anti-nuclear writers have tried to belittle the help which the world could have from nuclear power in restraining the use of CO_2-emitting fossil fuels. To such comments, the reply is firstly that no one contends that an expanded use of nuclear power alone would be enough to reduce CO_2 emissions to acceptable levels; secondly, that no one has dreamt of anything so unrealistic as the closing of all coal-, oil- or gas-fired electric power stations; and lastly, already today's nuclear power avoids the emission of very large quantities of CO_2 which would have resulted from an alternative generation of electricity through fossil fuels.

The Toronto Conference which I mentioned recommended that the annual emissions of CO_2 be reduced by 4 000 million tons by the year 2005. The current use of nuclear power avoids the emission of about 1 800 million tons of CO_2 per year which would have resulted from the alternative generation of electricity by coal. This is not insignificant. Moreover, it does not take any imagination to realize that an expanded use of nuclear power could help us to avoid more fossil fuel burning.

Many environmentalists would argue that money should be put neither in nuclear nor in fossil power but in conservation measures. However, as I said earlier, serious energy experts do not hold it possible for conservation measures to keep pace with increasing energy demands by a long shot. In reality, we also see highly developed countries like Belgium, the Netherlands and Finland planning for expanded electricity capacity.

If nuclear power is so good, why then is there not a worldwide consensus about an expanded use of nuclear power? Three main objections are raised, and I shall discuss them one by one. They relate to safety, waste disposal and the risk of proliferation of nuclear weapons.

Nuclear Safety

Our increasingly urbanized societies are vulnerable. Energy installations which can have an impact on the lives and health of many people must operate at a very high level of safety. It is generally understood that hardly any human activity can be totally without risk, but there seems to be very real difficulties in conveying to the public a perception of risk that corresponds to the reality.

It is not my contention that there are no risks in using nuclear power, but these risks must be compared with the risks and damage to health and environment connected with fossil fuel-based generation of electricity from the extraction of the raw material to the waste disposal. Comparisons must include the mining of both uranium and coal, the transportation of each, the fission of uranium and the burning of coal, and the emissions from coal and the disposal of nuclear waste.

Taking these figures into account, the number of casualties and health injuries and the amount of environmental damage resulting per giga-watt hour of electricity should then be calculated and compared. That would be a fair comparison. Although difficult to make, such examinations are underway and we have seen, so far, that they point to a very positive picture for nuclear power.

Such systematic studies apart, we cannot ignore Three Mile Island (TMI) or Chernobyl. Yet, they too must be accurately described. TMI was a big economic catastrophe, but no one was injured and there were no significant radioactive releases. Due to the Chernobyl accident, 29 persons died from radiation exposure and two more died from burns. Several hundred others received high radiation doses, but many of these have returned to normal working lives.

We might never ascertain whether any additional cancer cases occur as a result of the radioactivity released, because the number of cancer cases from other causes is so high that a small addition may not be visible. It must also be noted, however, that more than 100 000 people were evacuated because of radioactive contamination caused by the Chernobyl accident.

One must compare these figures with accident statistics for other types of energy. Recently, a gas leak in the USSR caused an explosion and fire and many hundred deaths. Last year, an oil platform exploded in the North Sea killing 165 people. An explosion in a coal mine in the Federal Republic of Germany left 57 people dead. A fire in a coal mine in Yugoslavia recently claimed some 100 lives. The worst dam accident was in 1979 in Morvi, India, where some 15 000 people were killed when a dam burst.

These statistics remind us that the production of energy by any means entails some risk of accidents.

It is hard to tell exactly what it is about nuclear energy generation that evokes so much fear. Personally, I think that part of the reason is that it is new to us—we have not tucked it away in our minds, we are not used to it. There is a need to demystify it. We are used to explosions in coal mines and we know that people die when a dam bursts.

I am not suggesting, of course, that we should be complacent about the risk of any accidents. In the nuclear field, as in others, we must actively strive to reduce the existing risks further and take steps to ensure that the consequences of accidents such as radioactive releases are minimal.

One further action is needed. We should strive to produce as correct a picture as possible of the risks and of damage that has occurred. Engineers, scientists, planners, and politicians should contribute facts which can help the public make realistic comparisons between the advantages and risks of various types of energy.

Nuclear Waste

Nuclear power use is opposed by many people because of fear of nuclear waste. In many places people protest against plans to dispose of high-level waste in their vicinity. Their fears that nuclear waste cannot be adequately disposed of are unfounded.

If waste from other industries were disposed of in as safe a manner as is the case with nuclear waste, the world would look a lot better. If I were to be a bit provocative, I would say that the wastes are one of nuclear power's great assets—compared to other fuels. Above all, the quantities we deal with are small.

Secondly, these wastes decay with time. It must be remembered that part of the waste resulting from the burning of coal on the other hand, namely, the toxic heavy metals such as arsenic, cadmium, lead, vanadium and mercury, remains dangerous forever. The toxicity of these stable elements does not decrease over time as does the toxicity of radioactive materials.

If you take the whole world's nuclear-generated electricity in 1988, it gave rise to a quantity of about 7 000 tons of spent fuel which is highly radioactive. If the same amount of electricity had been generated by coal, you would have had a hundred thousand tons of heavy toxic metals alone.

There are also the large quantities of gases emitted into the atmosphere—tens of millions of tons of sulphur dioxide and nitrogen oxides, even with the best cleaning equipment available, and 1 700 million tons of carbon dioxide.

Non-proliferation

The third concern mostly raised about nuclear power is that it might contribute to the risk of proliferation. The risk of the spread of nuclear weapons to further countries is certainly real, and significant efforts are made to reduce it. However, that risk would not be reduced significantly by a moratorium on further nuclear power. Rather, it should be noted that transfer of nuclear technology, hardware, and fuel for the peaceful production of electricity through nuclear power has been and remains one of the principal methods of obtaining legally binding—and verified—commitments to an exclusively peaceful use.

When the IAEA was established 30 years ago, it was authorized to set up a safeguards system with on-site inspection to assure that any assistance it provided would not be used for military purposes. This safeguards system is now a fundamental element in the present non-proliferation regime. Governments understandably attach great importance to assurances that hardware, fuel or nuclear technology which they sell do not promote prolifer- ation of nuclear weapons. And governments importing the nuclear technology have normally an interest in demonstrating in the most convincing manner—i.e., through outside independent inspection—that they are using it only for peaceful purposes. If they don't, local or regional nuclear arms races may result.

The cornerstone of the non-proliferation regime still remains the Non-proliferation Treaty, but nuclear weapon free zones established under the Tlatelolco Treaty and the Treaty of Rarotonga also contribute to this regime. Substantial nuclear disarmament ought to increase the prospects for further adherence to the Non-proliferation Treaty.

Let me conclude.

The Nuclear Option and IAEA Assistance

The decision to go for electricity generation through nuclear power is one made by each sovereign government. Nuclear power, however, is a very exacting technology and many developing countries do not have grids which can accept a big nuclear power plant or the trained manpower that is needed to operate it. Additionally, the initial investment in the hardware is a large one. It is very expensive to build a nuclear power plant even though during its lifetime it becomes economical because the fuel is so cheap.

By contrast, the construction cost of a coal-, oil-, or gas-powered station is lower, but the fuel is expensive. For developing countries that are short of capital, however, the lower initial capital needed for a fossil fuel plant may be an advantage.

Since environmental concerns are likely to make expansion of fossil fuel based power more and more questionable, and since there are simply no other options visible to generate the power that our energy-hungry world demands, I think the nuclear option is indispensable and we must make the best of it. A nuclear safety culture must be maintained worldwide. Developing countries, too, will need to prepare themselves for entering the nuclear age.

The difficulty in obtaining financing is certainly a major constraint. Where a nuclear power programme is undertaken, it must be an integral part of an overall development programme and the government must have a strong commitment to the nuclear power programme.

This means that:

- Qualified manpower must be made available at all levels;
- Organizations must be created for the planning and implementation of projects, for operating and regulating the safety of the plants;
- Industrial support must be made available; and
- In many cases, the electric grid must be developed, also taking into account future nuclear plants.

When a country has decided to make the necessary commitment to choose the nuclear option, the IAEA has a duty to give all the assistance needed that is possible within its resources. ❐

Applications of Nuclear Science and Technology

Professor Richard E. Collins
Chairman, Australian Nuclear Science
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As a scientist, I like to do experiments. I have a particular affection for very simple experiments, without complicated equipment, in which something fundamental and important is learned. I would like you to share some of the excitement that we scientists experience in our work—I want you to perform an experiment for yourselves. In keeping with my preferences, it is a very simple experiment, but I believe that you will find the results quite profound, and thought provoking. Once again, as with my own experiments, it requires practically no apparatus—no fancy equipment—certainly no computers! In fact, all that you need is a pencil and paper.

The experiment—Ask two questions of ten people, chosen at random from the general public, and record the answer.

The questions—Is nuclear technology good or bad for the world? Why?

Now it just so happens that I have performed this experiment myself, many times, with many different people. The answers that I have received are very revealing. The vast majority of people say that nuclear technology is bad for the world, and they emphasize things like:

- the dangers of radiation,
- the disposal of radioactive waste,
- Chernobyl, and
- bombs.

Only a few people mention the beneficial impacts of nuclear technology such as, in electric power generation:

- no greenhouse gases,
- containment of wastes, and
- outstanding safety record.

Practically no one talks about the other, non-power applications of nuclear technology in medicine, agriculture and industry, nor of the spin-offs from nuclear power technology into other areas of benefit to society.

These are the things that I will discuss here. I will touch on just a small part of the enormous range of beneficial applications of nuclear science and technology in several diverse areas which, along with the beneficial aspects of nuclear power, are essentially unknown by the general public.

At the end, I will return to this theme and ask my own question—Why is the public perception of nuclear matters so negative?

Nuclear Medicine

The medical area is perhaps the one where the benefits of nuclear technology are the most obvious. Nuclear techniques permit a doctor to learn what is happening inside a person's body in a non-invasive way—without incisions or operations. The medical applications rely on two unique features of radioactive materials:

- The ability of nuclear particles (usually gamma rays) to pass through quite large amounts of materials; and
- The possibility of detecting minute quantities of nuclear material (in fact, individual atoms) and identifying the atomic species of that material uniquely.

As an example, nuclear techniques can be used to identify regions of a patient which contain cancerous growths. An image is obtained by injecting a tiny amount of radioactive material into the person—the material is chosen to have a chemical affinity for cancer cells and so it accumulates in these diseased areas.

The radioactive material most commonly used for this diagnostic procedure is technetium 99-m (^{99m}Tc). This element does not exist in nature—it is, in fact, quite unstable, decaying in a few hours. Technetium 99-m is made in a nuclear reactor by bombarding other atoms with neutrons. In fact, usually another material, molybdenum-99, is made in the reactor which is also unstable, and which decays to ^{99m}Tc with a half-life of a few days. The molybdenum is located in a shielded container which forms the core of a technetium generating system. This container can be shipped from the reactor and processing facility to the hospital, or doctor's rooms, where the isotope is used. In Australia, Ansto makes technetium generators and supplies them to all parts of the country, and to other countries.

The instrument used in this procedure is called a gamma camera. It detects the gamma rays emitted by the decaying technetium atoms, and forms the images that enable doctors to perform their diagnosis.

Many internal organs can be imaged by this method, including lungs. In one very interesting and useful adaptation of this technique, a moving picture is reconstructed of the operation of a heart during its full pumping cycle. This permits a quantitative measurement of the pumping capacity of the heart, and enables the operation of internal parts, such as valves and chambers, to be observed. Much of the software for this imaging technique was developed in Australia at the Royal Prince Alfred Hospital, Sydney.

The gamma camera is the work horse of nuclear medical imaging and is very widely used. Some new medical imaging techniques are emerging, however, which permit more information to be obtained by the doctor. One technique is PET—Positron Emission Tomography. PET utilizes a range of isotopes which are produced in a cyclotron. A cyclotron is simply a machine which accelerates charged particles to high energy and uses them to bombard other materials to produce radioactive isotopes. Cyclotron-produced isotopes are particularly useful because they can be very short-lived and because they can be used to image the function, or operation of internal organs, rather than the structure. For example, the operation of the brain in response to an external stimulus can be observed. Other applications include studies of thyroid, lung, heart, and epilepsy.

Another novel diagnostic technique using radioisotopes involves the measurement of the total amount of body protein in an individual. This technique was also developed at ANSTO. The method involves making a measurement of the ratio of the quantity of two elements—nitrogen and hydrogen—in the human body. The tissue is irradiated with neutrons from a low activity source, and the decay products from separate reactions with nitrogen and hydrogen atoms are measured. The technique is very useful for the diagnosis of sufferers of illnesses which cause malnutrition, including anorexia nervosa, AIDS, cancer and trauma associated with surgery.

These three examples are just a few of the many diagnostic applications of nuclear techniques in the medical area—techniques which provide information about a patient's condition. In addition to diagnostic procedures, nuclear techniques can be used therapeutically—that is, to treat illnesses.

The principle of nuclear therapy is quite simple. The diseased part of the body is subjected to high levels of radiation in order to destroy the tissue. Irradiation by an intense source of gamma rays is a quite common therapeutic treatment. Other, more sophisticated procedures are being developed. In one, boron neutron capture therapy, the patient is injected with a material containing boron which is preferentially absorbed by the cancer. The diseased region is then irradiated with neutrons from a reactor. Neutrons interact much more strongly with boron than with other elements in body tissue. As a result, a local nuclear reaction occurs in the cancer cell which causes local destruction of that cell with less damage to the surrounding healthy tissue.

Patients who require nuclear therapy are, of course, usually very ill indeed. Any high level nuclear irradiation is a somewhat hazardous procedure and not to be undertaken lightly. Nevertheless, irradiation therapy can significantly prolong the life of patients, and improve the quality of that life. The inherent risks of the procedure are, in most cases, more than balanced by the benefits. The simultaneous occurrence of risks and benefits is a feature of all nuclear technologies and, indeed, of all technologies, as we shall see.

Agriculture

A second area when nuclear techniques are widely used is in agriculture.

The atmospheric nuclear weapons testing which occurred in the 1950's and 1960's is, thankfully, no longer taking place. This testing resulted in a very small increase in the background radiation in which we all live. There is one isotope, however, caesium-137, which is generated in nuclear testing and does not occur naturally. This isotope can, therefore, be used as a marker which indicates the position of the surface of the ground during the period of nuclear testing. By measuring the amount of caesium-137 at different depths in soil, it is possible to determine the rate at which material is accumulating as a result of erosion from other regions. This quantitative technique is extremely valuable in helping to determine strategies to combat soil erosion—one of the most serious problems facing farmers in many parts of the world.

Another nuclear technology of importance to agriculture is the determination of the age of groundwater. Australia, for example, has a large underground water resource, called the Great Artisan Basin. Over the past 200 years, this resource has been used indiscriminately, on the assumption that it is essentially limitless. We now know that this is not the case. Measurements of naturally occurring radioisotopes—tritium, carbon-14 and chlorine-36—permit an estimate to be made of the age of the water. In many cases, it is found that the water in the Great Artisan Basin is extremely old indeed—greater than 40 000 years. It is not a renewable resource as had been commonly thought. Such information has profound implications on the way in which this resource is managed.

One of the significant successes of nuclear technology in the agricultural field is the use of nuclear techniques to control the fruit fly. This has been done by using irradiation to sterilize large numbers of male fruit flies which are then released. The sterile males reduce the proportion of matings by fertile males, thus significantly decreasing the number of fruit flies in the next generation. This technique has been very successfully applied in programmes supported by the IAEA.

Finally, it is worth mentioning the technique of food irradiation as a method with enormous potential to increase the storage life of food. It is well known that a significant proportion of the food grown in the world is lost to spoilage before it can be brought to market. The use of irradiation by intense gamma rays has been shown to increase significantly the storage life of many types of food. Despite the promise of this technique, it has not been used widely because of opposition from people concerned about the potential dangers of consuming irradiated food. The vast majority of scientific opinion formed after many extensive testing programmes, is that irradiated food is safe. Despite this, its introduction is still delayed. Opponents of food irradiation appear to have no difficulty making their arguments heard, despite the fact that they have no scientific or technical validity. These arguments have raised public and political concerns which have resulted in the technique being largely unused.

Nuclear Technology in Industry

Nuclear technology has also found widespread application in industry.

In a very successful programme, the movement of very small amounts of radioisotopes have been traced through a blast furnace. This provides information on the time for which material resides within the blast furnace. From this information, the efficiency of the furnace can be optimized. It will be appreciated that the conditions within a blast furnace are so severe that it is impossible to use conventional sensors to obtain this type of information. A similar technique has been used to determine the efficiency of electrolytic cells used in the smelting of aluminum.

Radiotracer techniques are also useful on a much larger scale. A small quantity of the isotopes gold-198 or iridium-192 are used to trace the movement of sand on the floor of the ocean. The tracer is released at a particular place, and samples are subsequently taken at different locations. Results of this type of study can be used to assist in the development of a management plan for estuaries and ports. These methods also are being used to trace the movement of sewage in ocean outfalls. It is worth emphasizing that the actual amount of radioactive material released in such procedures is very small, and it has a negligible effect on the level of radiation already present.

Nuclear thickness gauges are extensively used in many industries. These very simple devices operate by measuring the intensity of a beam of gamma rays after they have passed through the material under test. The attenuation of the beam is dependent on the mass of material through which it passes.

An important and fascinating industrial application of nuclear technology is an adaptation of the ancient alchemist's dream—to turn lead into gold. In this case, however, it is to turn silicon into phosphorous. The silicon is in the form of large single crystals of extremely pure material, utilized in the manufacture of electronic components. Irradiation of silicon by neutrons can be used to convert a small proportion of the atoms to phosphorous. In small quantities, the presence of phosphorous modifies the electrical properties of the silicon in a way which permits the application of certain specialized processing schedules. Irradiations of this type are performed in a research reactor. Considerable care is needed to achieve uniform conversion throughout the silicon, and to control the amount of conversion. At ANSTO, we currently process many tons of silicon each year in our research reactor, HIFAR.

Spin-offs from Nuclear Technology

As in any area of science and technology, research in a particular area of nuclear science often results in benefits in a totally unrelated area. As an example, ANSTO has for some years conducted research and development on Synroc—an advanced concept for the storage of radioactive waste from the nuclear power industry. Synroc is a man-made material which has a crystallographic structure similar to naturally occurring rocks which are known to have existed for millions of years. The radioactive atoms can be incorporated into the Synroc structure, and are therefore isolated from the environment for their lifetime. The technology of Synroc essentially involves the development of ceramic composites. ANSTO has built up a large body of expertise in this field. We are now applying this knowledge in other fields. For example, a porous ceramic piece has been made for use in a cardiac pacemaker. The pores contain a drug which inhabits the formation of adverse reactions in the heart tissue close to the active tip of the pacemaker electrode.

Another important spin-off from the nuclear power programme is the discipline of risk and reliability analysis. Methods of quantifying the risks associated with complex technologies were developed by the nuclear industry specifically to assist in the analysis of safety of plant and the choice of cost-effective design strategies. These techniques are now being widely applied in non-nuclear industries, and resourcebased projects, to optimize investment decisions and assess the remaining life of operating plants.

Finally, the mining of uranium has necessitated extensive analysis of the environmental and health implications of the operations. At ANSTO, for example, a high level of expertise has been developed to analyze the stability of tailings, dams and the movement and uptake of waste materials, such as heavy metals, in the environment. This expertise is now being widely applied in non-nuclear mining industries and will significantly reduce the negative environmental impact of such activities.

Summary

It is clear that the impact of nuclear technology is far broader than simply in the generation of nuclear power. It has important implications in many, diverse aspects of our society. In the discussion of these applications, one continuing theme has emerged. The application of nuclear technology brings direct benefits—but it also carries with it certain risks.

For example, nuclear medicine applications permit improved diagnosis of patients, but there is a mild exposure of the patient and, to a lesser extent, of the medical staff, to radiation. In addition, the radioactive material must be produced, protected, transported and disposed of in a safe way. Such operations have risks of their own. The important point, however, is that the benefits and risks go together. This is a feature of every aspect of human endeavor—benefits are always associated with risks:

- electricity generated from coal results in emissions of waste gases which cause acid rain and contribute to the greenhouse effect;
- hydroelectricity requires large areas of land, and there are risks associated with failure of dams; and
- automobiles provide convenient transport, but they pollute, and road accidents kill people.

Seen in this light, the question that I put to you at the beginning is meaningless. There is no such thing as a "good" or a "bad" technology. In making choices about any technology, society must weigh the benefits and the risks. The ability of society to do this is directly dependent on the availability of information about the technology to the experts, to the politicians and to the public.

If the public is consistently provided with information about the negative, hazardous aspects of a technology, they will form the view that this technology is "bad." The political process, as a vehicle for implementation of public opinion, will reflect that view.

There is no doubt that nuclear science and technology has many benefits to offer society, just as it is equally obvious that there are risks associated with it. The benefits are in nuclear power and the host of other applications in medicine, agriculture and industry. The risks are probably evident to us all and are addressed in many ways such as, for example, through procedures for safe handling and disposal of radioactive materials, redundancy in plant design and adoption of appropriate codes of practice.

It is fundamentally important that the media adopt a balanced approach to the reporting of issues, and in particular, of nuclear-related issues, in order that the public can be adequately informed about the relative benefits and risks of nuclear technology. Only through proper public information can rational debate occur, and balanced decisions be made.

The media have an awesome responsibility in ensuring that the extensive benefits from nuclear technology are made available to our society. ❐

Radiation and Health
Some Facts about Radiation

Björn Wahlström
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Loviisa Nuclear Power Plant, Finland

Bangkok, Thailand
14-15 November 1991

Mr. Chairman, Ladies and Gentlemen,

You are radioactive. Each one of you is radioactive. You have

- radioactive radium and polonium in your bones,
- radioactive potassium and carbon in your muscles, and
- radioactive noble gases and tritium in your lungs.

It is possible, with a sensitive radiation meter, to measure radiation directly from your body. Also your relatives are radioactive, and your car, your house, the food you eat and the air you breath.

Everything is Radioactive

There is no place on Earth, or in the Universe, where you can hide from radiation. This is true, and this is how it has always been. This fact has nothing whatsoever to do with anything that mankind has made right or wrong. This simply is how nature is.

It has been said that radiation is something that all people are anxious about—except for the experts.

It's easy to see why—radiation cannot be detected by the human senses, so the man in the street cannot sense when he is at radiation risk. Furthermore, the laymen do not understand radiation information, because they are not familiar with the units and concepts, the microGrays, the milliSieverts, the Becquerel (Bq), the Megas, the Gigas and the Teras.

We have seen in Hiroshima and Nagasaki that radiation can kill.

We also know from medicine that radiation saves lives.

We don't know exactly the effects of low level radiation.

The possible effects of small radiation doses are too small to be observed. This means that they are close to zero. Still, many people would rather choose a larger conventional risk than a smaller radiation risk.

Why is radiation so controversial?

You have about 4 000 quadrillions of atoms in your body. That figure consists of 28 digits. The number is bigger than the number of water droplets in all the oceans put together. So the atom has to be very small.

Still, even the atom has its internal structure. It has a nucleus in its center with electrons spinning around. The nucleus houses two kinds of particles, protons and the neutrons. The number of protons defines the name of the element. One proton gives us hydrogen; two, helium; and three, lithium. Four protons give us beryllium; five, boron; and six, carbon.

The number of neutrons may vary. For instance, the carbon nucleus may have three to ten neutrons. But only if the neutron number is six or seven is the carbon nucleus what we call stable. Then it lives its entire life in peace with everybody, forever.

But, attention! Warning! Look out if the nucleus has too few or too many neutrons! Because then it isn't stable anymore, but excited. It doesn't feel comfortable with itself. It has excess energy, which it has to get rid of. Sooner or later, it will discharge its extra energy by emitting a particle and/or an electromagnetic pulse of energy. The nucleus is said to decay. After the decay, the nucleus normally feels satisfied and stays stable for the rest of its life. This is nothing special for just carbon. It's the same with all elements.

The time an excited nucleus can exist before it decays depends on how wrong the ratio between neutrons and protons is. This time may range from fractions of a second to billions of years. The time it takes for half of the total number of excited nuclei to decay is called the half-life of that nucleus.

A piece of material that houses excited nuclei is called radioactive. That's the definition of radioactivity.

The fact that a material is radioactive doesn't tell us anything about the risk. Remember that you are radioactive yourself. To be able to measure the potential risk we need to introduce a new concept which describes the decay rate. This concept is the activity and its unit is the Becquerel. The unit was given this name to honor the French scientist, Henry Becquerel, who was a colleague of the famous couple Marie and Pierre Curie. The definition of the Becquerel is simple—Becquerel tells us the number of excited nuclei which decay in a second.

If 10 000 excited nuclei decay per second in a barrel of radioactive waste, we would say that the activity content of that barrel is 10 000 Bq. If the contamination level of some food stuff is said to be 200 becquerel per kilogram

(Bq/kg), this means that 200 excited nuclei decay per second in each kilogram of that food stuff.

The activity of your body is a few thousand becquerel. A normal value for sea water is 15 000 Bq/m^3 and for soil 30 000 Bq/ton. The activity of most construction materials is 50 000-200 000 Bq/m^3.

Because the becquerel is an extremely small unit, all activity data looks large. The figure in front of the unit is large. This has caused much confusion in the dialogue between nuclear experts and the public.

How can the public realize and trust that both of the following statements are true at the same time:

- The nuclear opponent says that "the release of off-gas from a certain nuclear power plant is 20 000 Bq/s."
- The information officer of that plant tells that "the off-gas does not contain more radioactivity than the normal breathing air in many homes does."

But, both of these statements are true at the same time. As the becquerel is such a small unit, even an acceptable activity value looks large and dangerous.

Another example—the expert may want to tell the public that "the release of contaminated water doesn't really cause any harm by saying that the activity concentration is only a few million becquerel/ cubic meter."

The normal reaction to that statement would be that it is completely unacceptable. However, the water in our example is clean enough to be classified as drinking water.

The particles and/or electromagnetic radiation emitted by excited nuclei are called ionizing radiation. The radiation emitted from natural radioactive substances in our environment and from the cosmos has a special name and is called background radiation.

The value of background radiation is not stable. It may vary widely from place to place and from time to time, depending, for instance, on the structure and the wetness of the soil, the seasons, changes in weather and wind direction, and the level above sea.

Many of the natural radioactive substances are so long-lived that they were formed at the time when the world was born and, though part of them decayed, there are still more left. Others are short-lived. The reason that we also have those all around us is that they are continuously produced in natural processes.

The first time mankind added radiation to the natural amount was in 1895, when the X-ray tube was discovered. The X-ray tube emits the same kind of electromagnetic radiation as radioactive material does. However, the radiation stops when you disconnect the power.

Artificial radioactive substances were produced for the first time in 1934, by shooting neutrons into stable nuclei. By changing, in an artificial way, the ratio of protons and neutrons, a stable nucleus could be turned into an excited state, i.e. non-radioactive material was made radioactive! Artificially produced radioactive substances have since then been widely used in industry, medicine and research.

In 1938, an astonishing discovery was made. It was observed that when neutrons were caused to hit the nucleus of Uranium, not only was the nucleus excited in the expected and well-known way, but it was so upset by the event that it broke into two parts! In this way, two lighter nuclei were formed from the heavy uranium nucleus. And these two new nuclei were normally excited, because the proton/neutron ratio was formed more or less by chance. The event, when a heavy nucleus breaks into two parts, is nowadays called a fission, and the two new nuclei are called fission products.

This new skill of mankind, to split the uranium nucleus, has later been used in the service of good as well as bad.

The world has seen more than 1 000 nuclear detonations.

Two of them killed 100 000 people.

Today, 17 percent of the global demand for electricity is produced by nuclear power, which doesn't affect the atmosphere in the way that its alternative, fossil power does, and it doesn't accelerate the feared greenhouse effect.

In a nuclear reactor, artificial radioactive substances are produced as by-products, both by neutron activation and by fission. In all normal cases, most of these substances never get into contact with living nature. They will stay in the waste to be treated and finally deposited in a safe way.

The radioactive releases during operation are kept so small, that they really are of no significance. In most cases, their effect is smaller than the fluctuations in the natural background radiation caused by changes in weather and seasons.

In many cases the release of radioactive substances into the atmosphere from a nuclear power plant is smaller than that of a coal fired plant. Yes, I really mean radioactive releases. Coal fired plants release from their stacks long-lived radioactive substances, which were dug from the coal mine together with the coal. When burning the coal, those radioactive substances, such as uranium, thorium and radium, which earlier were captured deep in the earth, are released to the atmosphere.

Normal releases from properly operating nuclear power plants do not have any impact on the health of the public or nature in the vicinity. A major reactor accident, such as the one in Chernobyl in 1986, does have an impact.

To understand the health effects of radiation we must again introduce a new concept and its unit. Health hazards cannot be expressed in becquerel, because the same amount of becquerel can kill a man (if injected into his body), or have no effect at all (if deposited in a safe way). It all depends on where the emitted radiation energy is going to be absorbed.

Without going into details, we can say that when radiation hits a person, all or part of its energy is absorbed by the tissue. The energy absorbed by each kilogram of tissue is called the absorbed dose. When this is multiplied by a factor, which takes into account the relative biologic effect of different kinds of radiation, we arrive at a concept called dose equivalent or merely dose. The unit for radiation dose is called sievert. The Swedish radiation protection expert Rolf Sievert was a great man; and the unit sievert is a big unit, too big to be used in everyday life. That's why we mostly prefer to use the unit millisievert (mSv).

Background radiation normally causes a dose per person of 1-5 mSv per year. An X-ray examination may cause some 10-20 mSv. An annual dose limit of 50 mSv in one year is recommended for occupationally exposed persons, with the additional limitation at the average for each five year period may not exceed 20 mSv per year. Doses of this magnitude can never cause any acute health effects.

A few tens of mSv cannot cause any acute effects.

Doses of a few hundred mSv received in a short time can cause temporary radiation illness.

A few thousand mSv received in a short time could be fatal.

Doses causing acute health effects can be received only in accidents or in radiotherapy.

In Chernobyl, some tens of people were killed by high radiation doses and a few hundred were acutely affected, but survived. Ever since that accident, estimates have been made of how many late cancer cases, outside the high dose area, the accident may have caused for the future. All kinds of estimates, ranging from zero to millions, have been published and will be published in the future, too.

The reason that the estimates may differ so much is simply that those late effects have not been observed, and probably will never be. You may try to calculate a figure, but the result is never better than the mathematical model you choose to use.

Increases in cancer incidence was observed among the Japanese bomb victims who received high, instant doses. The increase was not high, but it was statistically significant. No hereditary effects have been observed in the offspring of the survivors or in any other exposed population.

On the basis of the observed increase in cancer incidence, as a result of the high doses, risk factors for radiation induced cancer was calculated. Later they were recalculated. Those risk factors are representative for that special exposure situation. However, it has not been shown that they actually are relevant at low doses or low dose rates.

Those risk factors can be used for conservative risk estimates, even for low doses. But, it is necessary to know, that in fact, no late health effects have ever been observed in any population as a result of low doses. Some scientists have even claimed that they have observed beneficial health effects from small doses.

However, let me stress that the basis for all radiation protection activities is the supposition that radiation is harmful and, that the smaller doses we receive, the smaller are the risks.

So, scientists may suggest negative health effects, positive health effects or no health effects at all from small doses—and nobody can show scientific evidence as to which of them is right or wrong.

This confusing situation is evidence enough that possible effects are too close to zero to be detected.

This again gives the opponents to nuclear power the possibility to claim that "even the scientists do not know the risk from small doses". But, let us be happy with that. Because, if it were possible to present a risk factor for small doses, based on observed data, then the risk would need to be much higher than it actually is.

Conclusion

It is not easy to throw light on something that cannot be seen, and science is not always simple. I have made some simplifications and some generalizations, sacrificing little of the scientific exactness for the sake of clarity. I have done this in an honest way, only to make my message clear, not to hide or change the truth. So I hope that my expert colleagues will forgive me for being inexact.

My final point will be that the more one knows about radiation—what it is and especially what it isn't—the better one will be prepared to make the right decisions at any time. It's useful to know when radiation is harmful and when it isn't. Radiation is like fire—a good servant but a bad master.

The more one knows about radiation, the less one needs to guess. Experts know more than laymen.

Maybe that's why experts are less anxious... ❐

Nuclear Techniques for Environmental Conservation

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Nuclear power produces electricity in an environmentally-friendly way, namely without forming carbon dioxide (greenhouse gas), sulfur dioxide and nitrogen oxides which cause acid rain. My presentation here is concerned with the application of various nuclear techniques other than power generation in connection with environmental conservation.

The IAEA is promoting applications of nuclear techniques in the fields of industry, agriculture and medicine in co-operation with member countries. In all fields of their application, nuclear techniques contribute to a reduction of harmful environmental impact.

Industrial Applications

In industry radiation processing for manufacturing is being used to replace thermal and catalytic processes. Radiation processing can also provide new techniques to remove pollutants such as sulfur dioxide and nitrogen oxides. Nuclear analytical techniques, such as the isotope tracer technique, neutron activation analysis, and X-ray fluorescence are very unique techniques to detect trace amounts of pollutants and to study their pathway in the environment and in human beings.

Curing of Surface Coating

As an example of the first item, I would like to mention radiation curing of surface coating which is used in a number of applications, such as coating of wood, steel plates, plastics, paper and even for floppy discs.

In the case of conventional curing technology, coatings are formulated with polymer materials and colour pigments dissolved in organic solvent. This method brings air pollution by evaporated solvent and consumes a larger amount of energy for evaporation of solvent. It is said that several millions of tons of organic solvent are released to the environment per year all over the world.

On the other hand, radiation processing provides environmentally clean curing technology. Namely, coatings which are composed of pre-polymers, crosslinking monomer and pigments are cured instantaneously by radiation.

Radiation induces polymerization reaction which convert liquid coatings to solid film without emission of organic gases. This processing consumes only a small fraction of the energy consumed by conventional ones, and the product is widely accepted on the market because of its superior quality.

Acid Rain

Large amounts of SO_2 and nitrogen oxides are being emitted into the environment from combustion of fossil fuels, such as coal and oil. In the countries in Eastern Europe, such as Poland, Czechoslovakia and the eastern part of Germany, larger amounts of SO_2 is emitted because of the use of coal for heating and generation of electricity without any treatment of flue gases. In France, SO_2 emissions are relatively low because of its large share of nuclear energy.

In the USA significant amounts of SO2 is emitted. Five large lakes near Chicago have been damaged by acid precipitant. In Europe, particularly Eastern Europe, forests and lakes have been damaged.

It was found that both SO_2 and NO_x in flue gases can be simultaneously removed by electron beam irradiation, Almost 90 percent of SO_2 and NO_x can be removed at a dose range of 1.2-1.7 megarad (Mrad).

Mechanism of the reaction has been extensively studied and elucidated. Namely, SO_2 and NO_x are oxidized by hydroxyl radical and oxygen radial which are radiolysis product of water in flue gases, to form sulfuric acid and nitric acid. These acids are then neutralized by added ammonia to form ammonium sulfate and nitrate which can be used as fertilizer. About 20 percent of nitrogen oxide is converted into nitrogen.

Flue gas is first introduced into electrostatic precipitator where fly-ash is removed, then its temperature is reduced to around 80 degrees Celsius by a water spray cooler. After a small amount of ammonia is added, the gas is irradiated by electron beams, where both SO_2 and NO_x are converted to powdery ammonium salt. The powder is then collected from gas by electrostatic precipitator or bag filter. The clean gas is finally released into the environment.

The pilot-scale experiment was first conducted in Japan by a private company in co-operation with JAERI for oil burning flue gas and steel sintering flue gas.

The Polish Government, in co-operation with the IAEA, is carrying out pilot-scale experiments through technical co-operation projects for coal burning flue gas. The demonstration plant is installed at the thermal power plant for local heating in Warsaw.

This demonstration plant has the treatment capacity of flue gas 10 000 Nm^3 per hour by using two electron accelerators of 50 Kilwowatts each. Preliminary data shows the removal of more than 90 percent SO_2 and approximately 80 percent NO_x. Further experiments will be started again this winter to generate data for designing industrial scale plant.

In Japan two pilot plants for treatment of flue gases are under construction, one for coal burning power station and another for incineration of municipal wastes. The former has a capacity of 12 000 Nm^3 flue gas per hour and the latter 2 000 Nm^3 per hour.

Agricultural Use of Sewage Sludge

Sewage sludge from water treatment plants is heavily contaminated by pathogens, including salmonella. Therefore, for the application of the sludge as organic fertilizer, disinfection is necessary.

Radiation is known to be a very efficient way for disinfection, as shown in this slide. In Germany, near Munich a commercial plan for irradiation of sludge containing about three percent solid, has been in operation for more than 15 years using cobalt-60. The sludge has been applied on agricultural land.

In Japan, JAERI has been developing a technology for irradiation of sludge by electron beams at high speed followed by composting. This new radiation processing can produce more hygienic, pathogen-free compost, while conventional compost contains 102-104 counts per gram of total coliform. The cost of production is comparable to that of the conventional process. ❑

Nuclear Applications in Food and Agriculture

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It's now 60 years since George de Hevesy used radioisotopes to examine how calcium and phosphorus are used by animals to form bones, and L.J. Stadler used ionizing radiation to produce mutations in corn and barley. The use of nuclear methods in agriculture, as in medicine, and the biological sciences in general, is therefore nothing new, but what has changed over these 60 years is the tremendous expansion which has taken place—both in the nature of the agricultural problems which nuclear methods have been used to study and solve and in the number of countries in the world which are applying these methods as part of their efforts to increase agricultural production.

Indeed, it would be virtually impossible nowadays to find a national agricultural research institute in the industrialized world which is not using nuclear methods for one purpose or another. Also, in the industrially less advanced countries, the last 25 years have seen a steady expansion in the incorporation of these methods into agricultural research and development programmes, often with the assistance of the IAEA and FAO through their joint division in Vienna whose specific function is to assist with the transfer of agriculturally-related nuclear know-how.

With radioisotope-based methods forming the backbone to many of the new approaches in molecular biology and biotechnology which are now so much in vogue, it is very likely that the role of nuclear methods in agriculture, and the benefits which will flow to countries at large through the use of these methods, will increase substantially in the years to come.

I would like, however, to make a couple of points of a general nature concerning this technology and its transfer. The first is that over the years, with the developments which have taken place in nuclear instrumentation, in isotope production and labelling methods, and in associated equipment and materials, radioisotopic methods are now not only more widely applicable, cheaper and easier to use than ever before, but they also invariably involve the handling of up to 100 times fewer isotopes than was the case before. So, the old adage that nuclear methods are "high tech," requiring expensive and complicated instruments and a sophisticated laboratory set up is much less the case today than it was 20 years ago. In fact, for some purposes, a laboratory to count and use radioisotopes can be set up for under US $5 000, and is therefore really within the reach of most institutes.

On the other hand, we must reject the use of nuclear techniques as an end in itself. These methods can only be recommended when they are the most effective way to obtain results, and in many situations other more conventional options will be entirely satisfactory to meet requirements. Furthermore, the use of nuclear techniques can be only justified when a good foundation already exists to use and interpret the results obtained from conventional methods and they should certainly not be considered a panacea, offering solutions to every problem that happens to come along.

The key point to be stressed at the outset therefore, is that in agriculture, nuclear methods can be used effectively only when they are combined with other methods, and they are at their most effective when used by groups of people with the necessary basic knowledge in the relevant agricultural specialties.

Against this background, I would like to describe some applications and achievements, focusing where possible on what has been going on in Australia and Asia through national activities, as well as through international programmes supported by the IAEA and FAO. Many of these programmes have been guided technically by experts from Australian Universities and the Commonwealth Scientific and Industrial Research Organization. In fact, it's no exaggeration when I say that in the fields of animal and soil science at any rate, the programmes which the IAEA and FAO have supported in the tropics and subtropics have relied heavily on people from this country, and let's hope this continues.

Two broad categories of nuclear methods can be applied to agriculture. The first makes use of the ability of radiation to penetrate and cause chemical changes to biological materials. This property is used to alter plants in ways that make them more useful and to change insects and parasites so that they are less of a pest to the farmer. The basic piece of equipment used for this work is usually a source containing high energy gamma ray emitting isotopes like cobalt-60 or caesium-137.

There is one other application of ionizing radiation in agriculture—namely irradiation of food to increase its shelf-life or reduce the level of contamination by potentially dangerous organisms like *Salmonella*.

Taking Asia as a whole, the agricultural sector which has probably benefitted most from radiation-based techniques is plant breeding. In this region, over 600 plant varieties derived from parent seed or other material which had been exposed to ionizing radiation, are now growing over literally millions of hectares of land after undergoing extensive field trials and government approval procedures. China, India and Japan have been particularly successful in this field.

All these varieties have come from what is termed induced mutation breeding programmes, many of them carried out over periods ranging from 10-20 years. During this time, the nuclear technique may well have only accounted for as little as 30 minutes of the work because that is roughly the time required to irradiate the seed forming the original parent material.However, without irradiation it would have been impossible to develop the end product! Irradiation works by bringing about changes in the genetic material of the initial cells of the plant, so that when these cells divide and form tissues, the altered genetic information is passed on.

As a result the plant's metabolism is changed and it may then look different or perform its various tasks in a more efficient way. Radiation in effect has caused the plant to mutate, and by rigorously selecting and breeding from the mutant lines for the character which was deficient in the parent material, we eventually end up with something with a higher agronomic value, such as, better yield, architecture, grain quality or resistance to disease or other stresses.

This methodology has been used for all kinds of food and industrial crops, and even for ornamental flowers; but in the Asian region, it's biggest impact has been on rice, cotton and wheat breeding. For example, the Chinese rice mutant variety Yuangfenzao was released in 1975 and it is presently growing on 1.1 million hectares of land in the lower Yangtze river region of South China. It matures about three weeks earlier than the parent variety and can yield up to ten tons grain per hectare.

The cotton mutant NIAB 78 from Pakistan was developed at the Nuclear Institute for Agriculture and Biology in Mymensing. It was released in 1983, and now covers over 60 percent of the total cotton growing area in Pakistan. Last year, Pakistan produced a record nine billion bales of cotton—largely due to the high yield, wide adaptability and short-stature nature of NIAB 78.

India also has been very successful in developing plant mutant varieties with valuable agronomic characteristics such as higher yields and resistance to various diseases. For example, Sharbati Sonora is a semi-dwarf plant compared to the original variety Sonora 64 and is also high yielding. However, its particular value lies in the fact that the seeds it produces have an amber color instead of the red color of the parent, and this makes it very popular for making chapatis, a small flat thin cake of unleavened bread.

More recently, Indian scientists have gone on to produce many other useful mutants such as the high yielding Basmati rice, and early maturing varieties of mungbean and large seeded varieties of pigeon pea and peanuts. These then are just a few examples of the benefits which mutation breeding have brought to this part of the world, but of course outstandingly successful varieties also have been produced by this method in other areas. For example, most of the peppermint oil used for making toothpaste and chewing gum in the USA; much of the barley produced throughout Europe—including that used to make Scotch whiskey and Czechoslovakian beer; 80 percent of the rice produced in Califor- nia; and 60 percent of the durum wheat harvested in Italy for producing pasta, all come from mutants produced directly, or indirectly through crossing, from radiation-treated parent materials. These facts leave little doubt that this technology has produced pay-offs which can be counted in the billions of US dollars and has helped to feed and improve the quality of life of millions of people worldwide.

The second major use of ionizing radiation in agriculture is to produce sterile insects for large-scale pest control and eradication programmes.

This technology has been used with outstanding success in the USA and Mexico since the late 1950's against the New World Screwworm *Cochliomyia hominivorax* whose larvae cause very severe damage to both livestock and man as they feed on the living flesh of wounds.

Sterile flies produced by irradiation also have been used with great success to eradicate the Mediterranean fruit fly from the USA, Mexico and parts of Guatemala. Another particularly successful operation was the elimination of the melon fly from the Japanese islands of Kume, Miyako and Okinawa.

The principle of the sterile insect technique (SIT) is that millions of insects are reared under controlled conditions and allowed to mate so that they produce eggs in the millions. These eggs are collected and allowed to develop into larvae—again under controlled conditions. The larvae are allowed to develop into pupae and these are exposed to 60-cobalt or caesium-137 rays for a few minutes. Finally, they are packed, put into an airplane or onto trucks and released into the wild to mate with native females in the field population.

Because the sperm produced by irradiated males contains defective genetic material, the eggs which develop in the female flies after mating don't hatch. As a result, the wild insect population is reduced and after successive releases of sterile insects, it eventually dies out altogether.

There is no doubt that when planned carefully and conducted properly, the biological control or eradication of insects using SIT is not only cost-effective but also—and this is very important nowadays—environmentally sound.

According to the United States Department of Agriculture for example, in terms of increased animal production and savings on the use of insecticide, eradication of the screwworm from the Southern United States saved $ 380 million a year or US $11.5 billion since the programme was started over 30 years ago. In the same vein, the Mexican Mediterranean fruit fly eradication programme has prevented losses of around US $500 million a year, and the Japanese estimate that their melon fly eradication programmes save over ten billion yen or US $60-70 million per annum as a result of reduced usage of insecticides and disinfectants, and higher yields and quality of fruit and vegetables. Added to this are the opening up of export markets because of the lifting of quarantine restrictions, the new job opportunities created and the high level of public acceptance.

On the other side of the coin, and this is particularly relevant for the less well-off countries, when we talk about SIT, we have to think *big money*. The screwworm production and irradiation facility in Mexico cost US $25 million to build and still costs US $10 million a year to operate. The construction facilities alone at Okinawa also cost US $20 million to build. In other words, before SIT should be considered, one thing that must be done is a proper cost-benefit analysis. In all the examples I've given, the benefit/cost ratio has been calculated at more than ten.

So far, all the applications I've discussed involve the use of ionizing radiation to produce, in a rather direct way, agriculturally useful end-products. I'd now like to turn to the other major group of nuclear applications—namely the use of isotopes.

Isotopes are powerful tools in agriculture. Their value lies in the fact that when we measure with isotopes, our measurements are based on the properties of single atoms—it is impossible to find anything more basic, more specific or more sensitive than that!

In addition, because it's now possible to obtain either radioactive or heavy isotopic forms of elements such as carbon, nitrogen, oxygen, phosphorus, which are the basic building blocks of all forms of life including the genes that control them—isotopes give us the potential, not only to measure individual biologically important elements or compounds, but also to follow them around. In other words, through isotopes, we have tools which allow us to look right into life's processes. We can find out how these processes come about, discover the factors which control them, and eventually through this understanding, we can develop, test and refine ways of altering these processes to maximize agricultural output. All this may sound very grand and academic, but let me give a few examples.

A lot is written nowadays about fertilizers—mostly about groundwater contamination by phosphates and nitrates caused by the excessive use of fertilizers in industrialized countries. It seems to have been forgotten that for many farmers in this world, the use of industrially-produced fertilizers to increase levels of crop production, maintain levels of soil fertility and reduce soil erosion is simply financially out of the question.

Whatever our personal views on these matters, and irrespective of the situation, the key consideration must always be to optimize fertilizer use efficiency. To do this requires careful study of the options available—the type of fertilizer; where and when to place it; and with which crop or combination of crops to use it. These are relevant questions for all countries and they are questions that can be answered accurately with the help of isotopic methods.

The principles of all these isotopic methods are essentially the same. Basically, a labelled form of the element or compound to be studied—in this case fertilizer labelled with radioactive phosphorus-32 to examine phosphorus requirements, is put into the soil where it mixes with normal unlabelled soil phosphorus and then is incorporated into the plant. By knowing the amount of phosphorus-32 placed in the soil (and it can be placed at different depths from the soil surface), and then taking soil and plant samples at various times after the labelled fertilizer has been added, it is possible to determine how much fertilizer phosphorus goes into the plant, and how much stays in the soil. Of course, if this is repeated for different combinations of available phosphate sources, plants and soil types, the most appropriate fertilizing regime for a particular agronomic system can be developed.

This kind of approach has been used in a number of Asian countries with considerable success, both to identify locally available sources of phosphate fertilizers as well as the best way of using them.

For example, in Indonesia and Sri Lanka, as well as other countries, local rock phosphates now are being used extensively to supply the phosphorus requirements of rice and tea. In fact, in Sri Lanka, local rock phosphates have now completely replaced imported phosphate fertilizers for use in tea plantations with substantial savings in imported fertilizers, and in Indonesia they now even make special applicators for tea plantations so that the rock phosphate is placed at the correct depth in the soil.

Another element which is vital for plant growth and soil fertility is nitrogen. Indeed, in most tropical and subtropical countries, nitrogen is the most universal soil deficiency, and since many farmers simply can't afford to apply nitrogen, little or no plant growth would occur if it were not for the existence of plants which can make their own nitrogen fertilizer from the atmosphere—a process called "biological nitrogen fixation."

The most important group of nitrogen-fixing crop plants in Asia are the legumes (cowpea, soybean, and winged bean). There are also important nitrogen-fixing trees grown in the region, such as Leaucaena and Acacias which are used both as fuelwood and for feeding animals.

These crops and trees are able to fix considerable amounts of atmospheric nitrogen (as much as 250 kg per hectare), and they can grow on soils of low fertility. This makes them very popular in Asia—not only in their own right, but also, as part of multi- and inter-cropping systems because they can then supply nitrogen at no additional cost to other crops such as cereals which also need nitrogen but can't produce it themselves.

Legumes are able to fix nitrogen because of nodules on their roots which contain literally billions of bacteria called Rhizobia which are able to break the bond that holds together the two nitrogen atoms which make up nitrogen gas in the atmosphere, thereby freeing them to combine with oxygen and hydrogen in the soil to produce nitrate and ammonium compounds which then can be used by the plant.

By using fertilizers labelled with the stable isotope nitrogen-15, the process of biological nitrogen fixation can be quantified. This then allows scientists to determine how much nitrogen different crop plants obtain from soil reserves and fertilizers.

The ability of the nitrogen-15 technique to allow soil and crop specialists to discriminate between these three potential sources of nitrogen for plant growth has revolutionized the whole business of nitrogen fertilization; not only by enabling the development of more efficient fertilizing strategies, but also in helping in the selection of efficient nitrogen-fixing plant varieties within species.

In fact, it has been estimated by FAO that every US dollar invested in nitrogen-fixing bacteria or other organisms is equivalent to adding 100 kg nitrogen fertilizer per hectare worth at today's prices, between US $50-$75. It's difficult to think of a better investment than that, or of a better reason for using nitrogen-15 to investigate ways of maximizing the benefits of biological nitrogen fixation to soils and plants alike.

Perhaps, however, with all the thought being given nowadays to the environment, desertification and deforestation, more consideration should be given in the future to nitrogen-fixing trees. These could have a considerable impact here in Australia to stabilize coastal soils, but in Asia, and certainly in Africa, their additional potential to provide fuelwood and animal feed makes them an even more attractive proposition.

The success of the efforts of Australia and other countries to stop desert encroachment and even to rehabilitate desert soils will not however simply depend on selecting potentially good nitrogen-fixing tree species. It will also depend on selecting the right bacteria to allow them to grow optimally. There are, in fact, enormous differences between lines of Casuarina trees for example, and the amount of nitrogen they can fix. So here again we can see that for obtaining solutions to some of today's pressing environmental problems, isotope technology is certainly going to play an important part.

Isotope technology also has played an important part in helping to improve the performance of one of Asia's greatest natural resources—the water buffalo. I hardly have to remind anyone about the importance of this animal to Asia—not just for meat production over the continent as a whole, or for milk production in Pakistan and India, but as the major source of draught power for growing food crops and transport.

My final example on the use of nuclear methods in agriculture is about how isotopic methods have been used to help to bring about a transformation in the way these animals are being fed and managed.

Back in the 1970's, the buffaloes of India and Indonesia were being fed with rice straw and native grasses. However, these materials are very indigestible and have only limited amounts of the protein and minerals which are needed to provide a balanced diet. So animals which have to rely entirely on such roughage don't grow or reproduce particularly well. In fact, they often lose weight, and if they manage to produce a calf every two or three years, then they are doing well. Since draught power requires a good body condition, and milk cannot be produced by an animal unless it first produces a calf, poor nutrition seriously compromises their ability to produce meat and milk, and to provide draught power.

The approach which was taken to try and get around these problems was to find ways to improve the efficiency of the feed digesting processes which take place in the forestomach or rumen of the buffaloes, and at the same time ensuring that as much as possible of the protein and energy that the animal was provided with was able to escape getting used up by the microorganisms in the stomach and get through to the intestines where it could be absorbed and then used for growth or making milk. In the terminology of ruminant nutritionists sources of feeds with good "rumen by-pass" characteristics had to be found.

To find supplements with these characteristics, scientists at the Indian Veterinary Research Institute, and then later at the Indonesian Atomic Energy Commission, used materials labelled with carbon-14, phosphorus-32 and nitrogen-15 to measure how efficiently the rumen of buffaloes digested different kinds of locally available feedstuffs, as well as how much protein in the diet was able to avoid rumen breakdown and reach the intestines.

They tried all sorts of materials to optimize these processes—including rice bran, soybean waste and even the leaves of Lacuna, the nitrogen-fixing tree mentioned earlier.

The information obtained from this work was then used in feeding trials to determine the best combination of local materials for supplementing the grass or straw being fed to the buffaloes, and eventually, these supplements were made into multi-nutrient blocks—again using local materials which could be licked by the animal. These blocks were then tested—initially to look at their effects on bodyweight, and later to examine whether they could help to solve some of the reproductive problems of buffaloes such as the long time it takes for them normally to reach puberty and the fact that after they calve, it takes many months before they get pregnant again. For this particular work, radioimmunoassay procedures which allow us to measure concentrations of hormones and other substances down to levels of less than one millionth of a gram per liter was used to monitor the levels of the reproductive hormone progesterone, and this provided an invaluable and early insight into how the animals' ovaries were reacting to different diets.

Although the results of this work only started to be put into practice about five years ago in the case of India, and about two years ago in Indonesia, the dramatic effects on growth and milk production are already becoming clear. In Indonesia, for example, where buffaloes mainly are used for meat and draught power, weight gains of three to four kilograms a week above normal now are being obtained by feeding animals a multi-nutrient block consisting of molasses, urea and local sources of by-pass proteins and energy.

This means that before such supplementation programmes were put into operation by the Indonesian Directorate General for Livestock Services, a buffalo had to eat 55 kilograms of grass to put on one kilogram of weight. Now, it puts on one kilogram of weight by eating only ten kilograms grass if it's given 150 grams of the supplement. In effect, the efficiency of feed conversion into meat has been increased enormously.

In India, which has been using this technology for somewhat longer than Indonesia, and where buffaloes are a major source of milk, the impact of the supplementation technology has been enormous. At the largest milk co-operative, run by the National Dairy Development Board at Anand in Gujurat, about 170 million liters of milk are produced every year. In 1989, the amount of milk collected by this cooperative increased by 30 percent or around 50 million liters.

This increase came about as a direct result of the farmers starting to feed the urea/molasses block as well as a source of by-pass protein to their buffaloes and cows. At a market value of five Rupees per liter, this means that approximately 250 million Rupees or US $12 million worth of additional milk are now being produced at this co-operative and the price incidentally is actually 25 percent lower than the price of producing milk by the older haphazard methods of feed supplementation.

By any yardstick, these are spectacular gains in output and efficiency, and of course 15 years after the research first started, the feeding of buffaloes and cattle at Anand has nothing directly to do with any nuclear technique. And yet, without isotopes to test and refine the concepts which lie behind the present system of livestock feeding at Anand, the benefits being reaped by thousands of peasant farmers and probably millions of city dwellers in India probably would not have been possible.

Many people ask what nuclear techniques have to do with agriculture. I hope I have gone some way towards answering this question. I hope also, however, that in intentionally choosing examples where nuclear methods have contributed to major increases in agricultural production, the point has not been lost that underpinning each of the approaches discussed were strong elements of sustainability and care for the environment. Sustainability, environmental protection and ensuring the wholesomeness and safety of the food we eat will be the key agricultural issues in the years to come. Nuclear methods have already shown their value in addressing these issues and I have every confidence that this will continue in the future. ❒

Nuclear Non-proliferation
The Promotion of Peaceful Uses of Nuclear Energy

Ambassador Tetsuya Endo
Japanese Permanent Representative
to the IAEA till March 1992

Cairo, Egypt
3-4 March 1992

The issue of nuclear non-proliferation is currently attracting far more attention worldwide than it ever has before. Of course, this issue has been brought to the attention of the general public in the past; for example, when we received the news that India had conducted an underground nuclear test in the Rajestan Desert in May 1974. However, such events have attracted only rather short-lived attention and they cannot be compared to the current situation.

The following three reasons may explain the increasing worldwide interest in the issue of non-proliferation: Firstly, along with general advances in the field of technology, the development of nuclear weapons has become much easier. I am not familiar with the techniques used to produce nuclear weapons as Japan does not possess any. However, techniques used for extracting plutonium by reprocessing or for making highly-enriched uranium, both of which are used in the construction of nuclear weapons, are widely spread, which means that today nuclear technology is within easy reach of many more countries and people.

Secondly, Iraq's nuclear weapons development plan was disclosed by a joint UN/IAEA inspection. Iraq was developing nuclear weapons clandestinely, despite its being a party to the Treaty on Non-proliferation of Nuclear Weapons (NPT) and receiving routine IAEA inspections. Iraq's nuclear weapons development was found to be far more advanced than had been rumored.

Thirdly, following the dissolution of the USSR, the nuclear weapons in its former republics are supposed to have been brought under the exclusive control of the Russian Federation. However, this raises a number of serious problems from the viewpoint of non-proliferation. We do not know whether Russian control of the nuclear weapons can be relied upon or how plutonium or highly-enriched uranium, recovered as a result of nuclear disarmament, will be treated. It is also not clear whether their systems of physical protection or nuclear storage will be satisfactory and there is also the possibility that there will be a "brain drain" of nuclear experts and scientists to other countries.

I would first of all like to touch upon the issue of nuclear non-proliferation in general and secondly to speak about some of the problems concerning the current non-proliferation regime. I should then like to go on to present my personal views on how the regime might be strengthened.

The Issue of Non-proliferation

Modern science and technology can be said to have both a bright side and a dark side; in other words, a dual personality of the type made famous in Robert Louis Stevenson's book *The Strange Case of Dr. Jekyll and Mr. Hyde.* This concept with relation to nuclear energy needs little in the way of explanation.

Nuclear energy makes a significant contribution to modern human society through the generation of electricity and the use of radiation and radioisotopes in the fields of agriculture, industry and medicine. Nuclear energy generation, which of all energy forms creates the lowest level of CO_2 emissions, accounts for about 17 percent of total world electricity consumption. Japan, which is poor in natural energy resources, relies on nuclear energy for nearly 30 percent of its electricity and in France the figure is as high as 75 percent.

However, nuclear energy also has a second, darker side; its development, originally intended for the production of atomic bombs during World War II, led to the bombing of Hiroshima and Nagasaki in August 1945. Although the bombs used then were of a relatively small destructive power compared with those currently available, both cities were completely destroyed. Tens of thousands of people were killed or seriously injured and many are still suffering from the after-effects today.

The very existence of humankind has come to be threatened by the presence of nuclear weapons, the most powerful weapons of mass-destruction known, together with the development of means of their delivery, such as missiles.

The dual characteristics of nuclear energy were recognized at an early stage and the view was expressed shortly after World War II that nuclear energy should be under international control and the number of nuclear weapons states be strictly limited.

Following the United States, the USSR succeeded in carrying out a nuclear test in 1949, the UK in 1952, France in 1960 and China in October 1964, thus forming the so-called "nuclear club". This meant that all permanent Member States of the UN Security Council had become nuclear weapons states. The then-US President J.F. Kennedy predicted that the number of nuclear weapons states might soon reach between 15 and 20.

The NPT, which was drafted in 1968 and came into effect in 1970, aims to prevent an increase in the number of nuclear-weapons states beyond five. Therefore, the current five nuclear-weapons states, namely the USA, the former

USSR the UK, France and China occupy a privileged position and the Treaty cannot help being unequal. However, for the sake of assuring international peace and security, the aim of the Treaty is widely recognized as being of greater importance than its inherent inequalities.

Problems Faced by the Non-proliferation Regime

The non-proliferation regime based on the NPT has been well managed so far. Although several countries have at times been suspected of developing nuclear weapons, at least there is no country which has openly admitted their possession. Apart from India, which conducted an underground test in 1974, no country other than the five recognized nuclear-weapons states has conducted a test.

However, the current non-proliferation regime, of which the NPT is the core, does have a drawback in that it does not cover all of the so-called "threshold countries." In addition, in the post cold war period, the international situation has become unstable from the viewpoint of nuclear non-proliferation. After the Gulf War, Iraq's covert nuclear weapons development plan was disclosed by a UN/IAEA joint inspection. As Iraq is a party to the NPT, this brought the purpose of the existing IAEA safeguards system into question.

The non-proliferation regime faces severe trials which I will now analyze.

Threshold Countries

The number of NPT member states is now 145, which amounts to an overwhelming majority worldwide; it is the most universal arms control treaty. However, some threshold countries which are technically close to having nuclear weapons, have not joined the Treaty. Israel, India and Pakistan fall into this category, as may some other countries such as Cuba and Algeria. The DPRK, or North Korea, can also be considered to be de facto in the same category, as it has so far failed to ratify its safeguards agreement (as of March 1992) with the IAEA, despite being a party to the NPT and having signed a safeguards agreement.

The reasons why some countries fail to join or comply with the NPT vary, but this is a crucial factor. To make matters worse, the threshold countries are located in the Middle East, Southwest Asia and Northeast Asia, all of which are politically unstable regions and this highlights the weakness of the NPT.

On the other hand, there has been some good news recently. South Africa joined the NPT in July 1991, signing a safeguards agreement with the IAEA and inspection activities based on the agreement will begin soon. Also, China and France, the two nuclear-weapons states which until now have been outside the NPT, are currently making moves towards joining it.

Two threshold countries in Latin America, Argentina and Brazil, have moderated their confrontation as a result of the emergence of civil governments. These two countries jointly concluded a safeguards agreement with the IAEA in December 1991, when presidents of both countries came to Vienna to attend the signing ceremony, and nuclear facilities and materials of both countries will soon come under the safeguards system. Neither Argentina nor Brazil have joined the NPT, saying that it is not an impartial treaty. However, the conclusion of a safeguards agreement with the IAEA to accept full-scope safeguards shows their clear commitment to non-proliferation.

The Post Cold War Period and Nuclear Control

Secondly, I would like to touch upon the international situation in the post Cold War period and nuclear control following the dissolution of the USSR.

The two superpowers, the USA and the USSR, led the world during the Cold War period, and the international situation was basically stable, even though problems might have been said to exist during this period from a democratic or moral viewpoint. A balance was maintained between the two countries' nuclear weapons, and they were frequently involved in major regional conflicts in the form of a deterrent.

Since the collapse of the Cold War structure, the risk of nuclear war between the USA and the USSR has lessened. However, the crisis-control ability of the two countries is also diminishing and with it the danger of regional conflicts has increased. Iraq's invasion of Kuwait was an example of such a conflict.

Along with a general raising of scientific and technological standards, the development of nuclear weapons has also become easier in a technical sense through the use of plutonium and of enriched uranium. In other words, the risk of proliferation of nuclear weapons has grown. Once referred to as "final weapons which would never be used," nuclear weapons may now indeed be used in regional conflicts, and the risk continues to grow. Had Iraq already been in possession of a nuclear bomb at the time of the Gulf War, the outcome certainly would have been very different.

Following the dissolution of the USSR, all nuclear weapons, both tactical and strategic are to come under the exclusive control of the Government of the Russian Federation. However, for the time being, there remain some nuclear weapons in the Ukraine, Belarus and Kasachstan and it may take a considerable time to transport them to Russia. Russian exclusive control may not be assured during such a transition period, as relationships between Russia and the independent states do not appear to be firmly established at this stage.

After all nuclear weapons are transferred to Russia, they will be dismantled gradually, in line with the progress of nuclear disarmament generally. Concern has been expressed, however, that recovered plutonium or highly-enriched uranium may be smuggled out, or stolen, and that the Russian export control regime may not be entirely reliable.

There is also the fear of a so-called "brain drain." I am not sure how many researchers and technicians were engaged in the development of nuclear weapons in the USSR—it is estimated that some 2000 were directly involved. There seem to exist some countries which are prepared to acquire "brains" regardless of expense. Russia and the Western countries fully recognize that this is a serious problem and that appropriate measures should be taken immediately. There exists no international forum at present for this purpose, although some countries, such as Russia, the USA, Germany and Japan have begun to investigate ways of tackling this problem, for example, through the creation of an international science and technology institute to employ nuclear scientists from the former USSR.

Weaknesses of the IAEA Safeguards System

I now turn to the problems of the existing IAEA safeguards system. As mentioned before, the NPT is the core of the non-proliferation regime.

Non-nuclear-weapons states which join the NPT conclude safeguards agreements with and declare all their nuclear facilities to the IAEA. They then receive regular on-site inspections carried out by IAEA inspectors in order to verify formally that nuclear materials in their facilities are not being diverted for military purposes. This is known as "full-scope safeguards."

However, as this system is in principle applied only to declared nuclear materials and facilities, it is difficult to detect the development of nuclear weapons if it is engaged in clandestinely.

As is generally known, Iraq is a party to the NPT and has two research reactors in Tuwaitha near Baghdad. These were built with the assistance of France and the former USSR and fuelled with enriched uranium provided by these two countries. In November 1990, shortly before the Gulf War began, both of these reactors received IAEA inspections and were not found to present any problems. Nevertheless, a joint on-site inspection by the UN Special Committee and the IAEA, based on UN Security Council Resolution 687 which was adopted on 3 April 1991, disclosed that Iraq had built uranium enrichment facilities in secret and had begun partial operation of them. In addition, their attempts to produce plutonium at the safeguarded reactors in the intervals between the IAEA inspections were also disclosed.

It came as a shock to the IAEA safeguards system that Iraq was engaged in a large-scale development of nuclear weapons whilst receiving full-scope safeguards. There is little point in maintaining a safeguards system if, despite spending large amounts of money and having so many inspectors, it is unable to detect clandestine nuclear weapons development. It would seem that the current system is a sort of paper tiger, in reality only capable of exerting pressure on faithful Member States. In fact, the credibility of the whole IAEA safeguards system is now being questioned by the general public.

Improvement and Strengthening of the Non-proliferation Regime.

As I have described above, the non-proliferation regime and the global political situation have now reached a crossroad. In order to fully utilize the potential of nuclear energy, we should minimize its dark side as much as possible. We should tackle the problems which the non-proliferation regime is facing and work to improve and strengthen it. To this end, I would propose the following four approaches.

Promotion of Detente and Disarmament

The most important way of strengthening the regime is by the establishment of a political climate in which nuclear weapons are no longer considered necessary for security. Of course, there are several technical means by which the non-proliferation regime might be strengthened, but the rationale for possessing nuclear weapons is the perceived necessity of having them to assure security, and if this is removed, then countries will no longer require nuclear weapons. This idea may seem rather impractical, but one must never lose sight of the fact that the most fundamental disincentive to nuclear proliferation is the removal of the necessity of nuclear weapons for security. We should therefore pay attention once again to the more classical methods of promoting detente and removing the threat of regional conflicts.

Further Universalization of the NPT

The NPT, the core of the non-proliferation regime, is not an impartial treaty and there clearly exists a gap between the five nuclear-weapons states and the non-nuclear-weapons states. The NPT should be made more attractive, in order to make it more universal and to overcome its inherent inequalities. This is very important as the NPT Extension Conference will be held in 1995.

The first thing is to define more clearly the advantages available to NPT Member States. This means giving preferential treatment to NPT members. In other words, developing countries which become members of the NPT should receive preferential treatment in the field of nuclear power generation, the supply of nuclear materials and equipment, and also in technical assistance in the field of nuclear energy.

We should also study the application of this type of preferential treatment not only in the nuclear field, but also in the field of economics and technical cooperation in general, by limiting provision of official development aid to countries which do not cooperate with the non-proliferation regime, i.e. which do not join the NPT or accept full-scope safeguards. The USA has adopted such a policy in that it has ceased to provide economic assistance to Pakistan.

Although there are many difficulties in linking the non-proliferation regime with official development aid, such a policy should be investigated as it is very important that we try to strengthen the regime and make the NPT more universal. At the same time, it goes without saying that the nuclear-weapons-states should redouble their efforts towards nuclear disarmament and, in particular, towards a comprehensive test ban taking advantage of the termination of the Cold War.

I sincerely hope that the threshold countries and others which have not yet done so will join the NPT. At the same time, to supplement the NPT, the establishment of regional or sub-regional non-proliferation regimes, if and when deemed appropriate, is worth considering.

Each region has its own characteristics and, based on this, there have been some such movements to establish nuclear-weapons-free zones. An example is the Treaty of Tlatelolco concluded in 1967 which covers the area of Latin America. This treaty was actually concluded before the NPT and had its 25th anniversary in February of this year. Another example is the treaty of Rarotonga, concluded in 1986 to cover the South Pacific region.

These two treaties are similar to the NPT in general and from the viewpoint of non-proliferation, they place stricter obligations on their Member States than does the NPT.

Recently, the Republic of Korea (or South Korea) and the DPRK reached a basic agreement to make the Korean Peninsula a nuclear-weapons-free zone. The idea of establishing a nuclear-weapons-free zone in the Middle East also has been proposed and I welcome such movements. I hope that the region of South Asia will follow suit in the near future.

The IAEA Safeguards System

Now we turn to the NPT-IAEA safeguards system itself. This was discussed at the 4th NPT Review Conference held in Geneva in the Summer of 1990. The IAEA, having in mind lessons learned from the Gulf War, also has actively studied ways to improve and strengthen it. At the February Board Meeting, a conclusion was reached with regard to the special inspection system and the early submission of design information of nuclear facilities.

As I mentioned before, in principle, the IAEA safeguards system covers declared nuclear materials and facilities, but such routine inspections turned out to be insufficient in detecting nuclear weapons development conducted in secret by Iraq.

It was therefore reaffirmed that the IAEA could conduct special inspections on undeclared facilities if it is judged necessary. It was also reaffirmed that in case Member States do not accept such special inspections, the Board of the IAEA will report the matter to the UN Security Council.

Not only information provided by the countries concerned, but also all other credible information available can be used when requesting special inspections. At first, special inspections were regarded as impractical, or "pie in the sky;" but now they have been activated and I consider this to be a significant step forwards in the strengthening of the safeguards system.

Export Control of Nuclear-related Materials and Equipment

I should like to repeat that the NPT/IAEA safeguards system is the core of the non-proliferation regime and that this should be strengthened. However, this alone is not enough. To support IAEA safeguards, we should control, through an international framework, the export of nuclear-related materials and equipment, in addition to nuclear material such as plutonium and uranium-235 which may be directly used for the development of nuclear weapons.

At the risk of appearing rather technical, I should point out the existence of the Zangger Committee which was established in 1974 to clarify the scope of Article 3.2 of the NPT, as well as the London Guidelines which were established among major exporting countries in 1978, following India's nuclear test in 1974.

Both the Zangger Committee and the London Guidelines list fissionable materials such as plutonium-239, uranium-233 and -235, as well as reactors, auxiliary devices and some sensitive technologies. Member States agree with each other that when these items are exported, they should be safeguarded and they request assurance that such items shall never be used for the purpose of creating nuclear explosions.

Nowadays it is widely recognized that such existing controls are not sufficient to secure non-proliferation and that some export control on dual-use items in addition to direct-use items used in the development of nuclear weapons is necessary.

There are also new suppliers in addition to the 26 London Guidelines Member States, including Argentina, Brazil, China, Yugoslavia and the Republic of Korea. Negotiations to establish an export control regime of dual-use items started in the Spring of 1991 and after several meetings, it appears that an agreement will soon be reached, hopefully in Warsaw at the end of March this year.

Conclusion

In order to promote peaceful uses of nuclear energy, we should minimize the dark side, i.e. proliferation. Of course, the NPT is the core of the non-proliferation regime. The NPT/IAEA regime is not all-powerful, however, so we should aim to support it with some other approaches.

The world today has both bright aspects and unstable, unreliable aspects in terms of non-proliferation, and therefore strengthening of the non-proliferation regime is required.

I come from the country that was the first and hopefully the last victim of a nuclear bomb and I therefore strongly hope that the non-proliferation regime will be strengthened. However, I am also from a country that is poor in natural resources, and so I recognize the need for nuclear energy. I hope that all of you here will now have a greater understanding towards the non-proliferation regime and that you will cooperate to enhance the bright, positive aspects of nuclear energy. ❐

Nuclear Proliferation and IAEA Safeguards
The Situation

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Forty-five years ago this month, two cities were destroyed and the super power confrontation dominated by nuclear weapons began. Less than a year ago, the walls dividing East and West crumbled and the destruction of missiles started. In the euphoria which has followed, it is easy to believe that all danger of nuclear weapons has passed and that the whole issue is now dead. Nothing could be further from the truth. It is my job today to explain why this is so and what the role of the IAEA is in helping to deal with this threat.

Let me begin by recalling how we came to the present position. For the first four years of the Cold War, one power alone had nuclear weapons and the issue was on what basis the existing stocks could be destroyed before others developed weapons. The general belief was that this would be anything from ten years upwards. This belief was shattered by the explosion of the first Soviet bomb in 1949. The general belief then became that the "secret of the atomic bomb" could be contained between the two major powers. This was shattered by the explosion of the British bomb in 1952 followed by the French and Chinese bombs. The belief that only the most advanced nations would have the resources to produce nuclear explosives was shattered by the Indian explosion.

By this stage, it was clear; there was no "secret." If anything was going to contain the spread of nuclear weapons, it certainly was not hanging on to a vain belief in the supremacy of Western technology. Where there was a will there was a way. Neither was there going to be containment by the sacrifice of self interest in the common good. The justification for the development of nuclear weapons as the "need to have a seat at the conference table" was a direct incitement to the "have nots" to make sure they joined the "haves."

The number of weapons available was not a major factor. The fact that between them the superpowers disposed of some 50 000 warheads blinds us with numbers. This is sufficient to destroy each inhabitant of the planet three times over. More bombs just "make the rubble bounce higher." To put this in perspective, remember that in the first few years of the Cold War, the total American stockpile was less than half a dozen weapons, not easily delivered; and yet, this was considered to threaten humanity. There was nothing wrong with this belief—the change is in the way we have become blinded into complacency by sheer numbers.

A few weapons were sufficient to ensure the Cold War never became hot. One bomb ensured a seat at the conference table. I do not want to get drawn any more into the politics of the past, but I do want to point out that the arguments used by the major powers in the past can be used also by the developing powers of the present.

Where does this get us presently? To the situation where, excluding other considerations, there could be an incentive for several nations to develop a nuclear weapon. Not necessarily an extensive programme, but enough to threaten to change the balance of power in a region. The danger is that the cold threat becomes a hot reality and the rest of the world gets drawn in. There is no hiding place; and no declaration of impartiality or "nuclear free zones" has any relevance.

Which at last brings me to the role of the IAEA. Originally set up in a period of thaw in the Cold War to further the peaceful development of nuclear energy, its role has expanded greatly as the perception of nuclear power has changed. The realization that the threat of nuclear weapons came not only from the superpowers, but increasingly from the proliferation of nuclear capability among the rest of the world, concentrated minds wonderfully. Increasingly, it came to be accepted that the development of nuclear power must be accompanied by "safeguards" to restrict the use of peaceful purposes. The development of these safeguards internationally centered on the IAEA.

The Non-proliferation Treaty

The most important milestone in this development came in 1968 with the creation of the Treaty on the Non-proliferation of Nuclear Weapons (NPT). Non-nuclear weapon states assenting to the Treaty agreed not to develop nuclear weapons. Those already possessing them agreed not to pass on nuclear weapons or assist any nations to produce them. Most importantly, non-nuclear weapons powers agreed to independent verification by the IAEA as an agent of the United Nations of compliance with their obligations under the Treaty.

The NPT was a landmark in international affairs. For the first time in history, independent states agreed to give up part of their sovereignty to accept outside inspection on their territory. It is far from being an idealistic treaty, which the cynic would say accounts for its success.

It is a blatantly unfair treaty. Those without weapons forgo the option, while those with weapons agree only to seek ways to reduce the number. It is, however, a realistic treaty. Verification replaces pious hopes—idealism is replaced by reality. States which sign do so because they realize that it is in their long-term interests to do so. To achieve assurance about their neighbor, they have to give assurance themselves. Most importantly, they realize that if they are to receive supplies of raw material (i.e.uranium) or nuclear technologies for their electrical power needs, they must demonstrate their intentions to the suppliers.

This point should not be passed over lightly and it can be held that supplier/ buyer relationships should not be the basis for a non-proliferation regime in any case. Several of the most important industrial nations to the NPT initially objected to the potential interference in the development of their industry and to the potential for industrial espionage, giving their competitors unfair advantage. Japan and the Federal Republic of Germany hesitated for eight years before committing themselves for this reason.

The suppliers of uranium or technology, such as Australia, must accept that the NPT is a two-way commitment. They are committed to assure the supply of technology and material in return for the supplied country forgoing a measure of sovereignty. Attempts to make this a one-way treaty can rebound. When some countries felt their industry threatened by attempts in the late 1970's to go beyond the terms of the Treaty, the effect was to increase their determination to "go it alone."

Japan, for example, insisted on building reprocessing and enrichment plants since it felt it could not rely on assurances of supply from outside. Similar steps were taken by other countries even to the extent of developing uneconomic sources of supply so that the final result of the external pressure was completely counter-productive.

Since in general the supplier nations are those which are energy rich with many alternative energy sources other than nuclear, they often do not appreciate the extent to which other countries are completely dependent on outside energy sources. In practice, this means they have no option but to go for nuclear electrical production. For them, it is preferably "nuclear with safeguards" but we must never deceive outselves—if the choice is exclusively between nuclear energy and safeguards, nuclear energy will win.

Some countries, in fact, have never been convinced by the arguments in favor of signing and have remained outside the non-proliferation regime. These include India, Pakistan, and Israel. Significantly, these are countries which have been involved in recent times in fierce confrontations. (It should be made clear that they do have limited safeguards on some facilities that were supplied under special bilateral agreements and that there has never been evidence of violation of the terms of these special agreements. Any controversial steps have been outside the scope of the special agreements.)

The Goals

The NPT placed heavy tasks on the IAEA. It was called on to develop a verification system that would be accepted by nations suspicious of each other, as fair, reliable and transparent. That last word is important. Not only must the system work, it must be seen to be working.

The IAEA is required to demonstrate by independent verification that the requirements of the NPT are being met. This is more onerous than the verification called for in the recent superpower agreement to destroy missiles since the requirement there is for two parties to satisfy each other.

The IAEA is required to satisfy all parties, numbering over a hundred, each with differing interpretations of what constitutes adequate safeguards. Some nations would emphasize the necessity for safeguards to be non-intrusive. Others, the USA in particular, look for a degree of reassurance that others find politically and economically unacceptable. The debate to establish universally acceptable objectives has been continuous.

Related to the need to precisely define political objectives has been the need to establish technical criteria for meeting the safeguards goals. Again, these technical criteria are directly related to political attitudes. Is the objective to detect the loss or misuse of any amount of material however small? Is it to detect a failure to account for sufficient material to make a single nuclear weapon, or is only a continuing weapons programme of significance?

As well as what is to be done is the question of how it is to be done. Is the role of the safeguards inspector who carries out the verification to be that of an international policeman with unlimited powers or is it more related to that of the tax auditor calling for random checks on declared accounts?

Much undeserved criticism of the safeguards system has come about because of a failure to appreciate the necessity to operate within a consensus of what is desirable on the one hand and what is politically and economically acceptable on the other.

Balancing these factors, the approach that has been adopted is to concentrate on nuclear materials accountancy as the primary safeguards measure with periodic inspections to verify the operator's records and the reports he is required to submit to the IAEA. To limit interference with plant operation attention is concentrated on agreed "key measurement points." These are the stages in the operating process of nuclear plants where measurements can be taken to establish an accounting balance of nuclear materials entering and leaving the plant. To complete the accountancy, an inventory or stocktaking is taken periodically of material held within the plant. Cameras and seals are employed as a complementary measure to ensure no material escapes the accountancy measurements.

To take into account the fears of undue interference, an agreement is reached for each plant of the number of days of inspection that will be applied. For a small research lab with limited material, this may be quite small; but for a major plant, the inspectors may be continually present throughout the 24 hour shifts. Agreement on the effort, as well as on the devices to be installed, has to be formally reached and recorded for each plant in a legal document called the "facility attachment."

The technical goal for these measures is to be able to detect whether or not a quantity of material amounting to eight kilograms of plutonium or 25 kilograms of uranium of weapons grade is missing. (These numbers derive from the amount of each required to produce a simple weapon. Sophisticated weapons require considerably less.)

Linked with these quantities is the idea of a goal time-scale for being able to detect missing material. This is set at one month for weapons grade material and up to one year for material such as refined ore which requires considerable further processing before it can be used for power production.

There is an essential difference between financial and material accounting in that money always comes in items. It is either there or not. Material accountancy is not so simple. It is based upon measurement and all measurements have a measurement uncertainty. When an inspector reports that a certain amount of material is present, this inevitably means "within certain limits." This leads to frequent misunderstandings between experts and laymen since sometimes what is stated to be "material unaccounted for" is only a reflection of measurement uncertainty. On the other hand, what a plant operator claims as a poor measurement system may be an attempt to conceal a diversion of material. This illustrates just one of the many problems an inspector is faced with in dealing with practical realities.

The Tools of the Trade

To carry out the necessary measurements, it has been necessary to develop a wide range of very sophisticated instruments. To illustrate how sophisticated, look at the effort that has been going on recently to introduce devices at airports to detect explosives in baggage. These use a technique known as "neutron activation." Such techniques have in fact been in routine use by IAEA inspectors for more then 12 years. It would have been way beyond the resources of the IAEA to develop this alone and assistance came from support programmes from many nations. Australia played a most important part in the growth of these support programmes.

As an illustration of how international co-operation works in safeguards, I can cite the case of an instrument that was developed to measure the degree of enrichment of uranium in a very complex plant. The original idea and first prototype came from Australia. Further development took place in the UK. Testing of the first version took place in a Japanese plant at the invitation of the Japanese Government. Final installation took place in plants in the European Community. Such co-operation is typical in this field.

Development of a network of analytical laboratories to analyse chemical samples taken by IAEA inspectors also has had to take place. A single laboratory, no matter how large, would have been unacceptable since the results of analysis have to be indisputable. This requires several laboratories cross checking each other and distributed throughout the world to ease the problems of transportation since samples may arise anywhere.

Since the operators are required to report all production and transfer of nuclear material, it is possible at IAEA headquarters in Vienna to keep track of such material throughout the world. (Provided of course that it comes from countries accepting safeguards.) To do this efficiently requires massive computer power and this results in the information system at Vienna being one of the world leaders in data processing.

Safeguards Staff

The tasks I have just described could not have been carried out without a major recruitment and training effort that is unique by any standards. The number of safeguards inspectors is now approaching the 300 mark. They are drawn from nearly every nationality in the world, and of necessity in a UN organization, must come from any race, religion or political creed. Naturally, there is also equal opportunity for women as for men. The average age of an inspector is in the range from mid-30's to mid-40's.

Typically, they have a degree in science or engineering and have worked in the nuclear field for several years before joining the IAEA. Several months training at post-gradute level is given since the inspectors have to become masters of many technical disciplines outside their original speciality. A knowledge of chemistry, physics, statistics and electronics is essential.

The inspectors are required to spend up to a third of their time away from home. Since they may be travelling to the far side of the world, physical fitness and a liking for travel is an absolute necessity.

That describes the profile of the staff, but can you imagine for a moment what it is like to work as an inspector?

Can you imagine for example what it must have felt like to be the first woman to enter a reprocessing plant in a traditionally male-dominated country such as Japan?

Or to take part in inspections in Iraq at the height of a major war?

Or to visit an African republic where civil war has led to the breakdown of virtually all transport and communications?

The inspection staff have a wealth of human experience that could put most TV soap operas in the shade.

The strains placed on inspectors are immense. Inspections are usually conducted in English, but this may not be the mother tongue of either the inspector or the plant staff to whom he or she is talking. The inspector is usually surrounded by government representatives. Every action is under close scrutiny and could be the subject of complaint at the international level that agreements are being infringed upon, or by the inspectors' supervisors that they are not stringent enough. There are many opportunities for misunderstandings, yet at all times the inspector must be alert to sort out innocent errors from serious anomalies. Management aims to ensure that inspectors can respond to these pressures and that inspection results are removed from personal influence.

The Effectiveness of Safeguards

With these difficulties in mind, it is a fair question to ask how effective safeguards really are. To which the only real answer is, it depends upon what you expect from them. The problem is that everyone has different expectations. The present system is based on a consensus that the objective is not to make misuse of material absolutely impossible, but to give timely warning if such misuse were to take place. It is verification, not prevention.

Probably the best indication of the effectiveness of safeguards is to recall that 20 years ago it was considered almost inevitable that by 1990 there would be at least 15 nuclear armed States with the number continually growing. That situation has not taken place. At present, only six key States arouse speculation about their nuclear activities and they stand outside the safeguards system.

It could well be asked, why do they stand aside? Apart from the obvious answer with regard to intentions, it is a tribute to the perceived effectiveness of safeguards that they do so. If you consider the system ineffective, why not accept it? On the other hand, if you consider it efficient and wish to retain your options, you have every incentive to stay outside.

The Continuing Need for Safeguards

I began on a cautionary note. Was this overdone? In view of the recent changes in the politics of the world, are safeguards now unnecessary? Emphatically not. Pandora's box has been opened and can never be closed. Today there are more than 400 nuclear power plants in operation in 26 countries. They produce more electricity than the entire world produced from all sources 30 years ago. Even if they could all be shut down tomorrow, the nuclear material already produced would continue in existence. The amount of plutonium stockpiled is now measured in hundreds of tons. We can debate for hours what should have been done in the past. There is no alternative for the future. ❒

Nuclear Safety
What is it, What does it Involve?

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The purpose of a nuclear power plant is to produce energy competitively in the economic context of the present. Like all large industrial installations, a nuclear power plant may have an impact on the natural environment owing to its architecture and its generation of industrial waste and liquid and gaseous effluent.

Nuclear safety is the result of a set of measures taken in order to:

- to sustain normal operation without significantly (in comparison with natural radioactivity) polluting the environment with radioactive products;
- prevent functional incidents or accidents; and
- mitigate the consequences of potential incidents or accidents.

The technical and human measures necessary throughout the lifetime of the plant to achieve these three objectives are:

- before plant construction—design studies and fabrication control;
- during plant construction and startup—quality of construction and controls/tests for startup;
- during operation—strict implementation of operation and maintenance rules and operating experience feedback; and
- after final shutdown—confinement and monitoring actions associated with the decommissioning.

The Basic Principles

In order to confine radioactive products and to prevent their dispersion in the event of an incident or accident, nuclear safety relies on:

- a series of barriers, including:

the fuel cladding;

the primary circuit;

the containment; and

- the defence in depth principle.

The objective is to protect them and to maintain their integrity.

The defence in depth is a global approach applied in the design and the operation of the plant by taking into account the possibility that things can go wrong owing to technical or human failures.

In order to ensure the integrity of the three barriers, it is necessary to maintain under all circumstances (normal operation, shutdown or outage, and incident/accident situations) the three main safety functions, namely reactivity control, energy dissipation, and confinement of radioactive products.

- **Reactivity control.** In a pressurized water reactor (PWR), this is effected through the control rods and the boron concentration in the primary circuit water. In the event of an incident, it is necessary to stop the fission reaction to facilitate fuel cooling. This is done by means of the automatic scram system.
- **Energy dissipation.** In normal operation, the fuel is cooled by the steam generators; in a plant shutdown, the decay heat from the fuel is removed through the steam generator by the decay heat removal system, which is a redundant system. In accident or incident situations, both these means can be used. In addition, in some difficult cases, energy dissipation can be effected by special procedures such as feed and bleed.
- **Confinement of radioactive products.** The three barriers are intended to confine radioactive products. Therefore, they must be monitored permanently during operation: for cladding, by the control of activity in the primary circuit; by periodic measurement of the leak rate in the prim- ary circuit, by periodic testing of the leak tightness of the parts of the circuit that should be isolated during accidents; by the periodic testing of all containment penetrations; and by containment leak rate surveillance.

Safety in the Design Phase

Defence in Depth

In the design phase, successive lines of defence should be integrated:

Line 1: Prevention of incidents by means of high quality in design and construction in order to reduce failure probabilities. This requires the following preventive measures:

- installation dimensioning;
- rules for studies, design and construction;

- taking into account possible failures of equipment and human operators, and various external and internal events;
- designing safeguard systems to compensate for equipment failures;
- achieving high quality and controls at all stages; and
- incorporating sufficient safety margins.

These preventive measures need to be accompanied by operational measures:

- continuous surveillance via operating procedures, surveillance of the barriers, periodic testing and maintenance of all materials and equipment; and
- performance of operational activities to minimize the risks of errors, through clear organization, good preparation of activities, good coordination of teams and control of interventions.

Line 2: Protection of the reactor.

In case of perturbations, protective systems are designed in order to restore automatically the plant to its normal functioning.

Line 3: Reactor safeguard.

In case the two previous lines of defence fail, which would mean that an accident had been initiated, other means are provided for mitigating the consequences for the environment. These means are the safeguard systems (the auxiliary feedwater system, the safety injection system, the containment spray system); the dimensioning of safety margins of materials, systems and buildings; and the implementation of incident and accident procedures.

Line 4: Accident management.

If the first three lines of defence fail, accident management procedures and the emergency plan, which constitute the ultimate lines of defence, are implemented.

Risk Assessment

In relation to risk, the design must observe two principles:

- the greater the probability of occurrence of an event, the more effort is made to mitigate its consequences; and
- the total probability of undesirable consequences must be below a certain given limit.

No particular protective measures are specified for events of very low probability. This then constitutes the domain of residual risk.

The events taken into account in the design are two-fold:

- events of plant internal origin, such as fire or flooding; and
- events originating outside the plant, such as aircraft crashes, explosions or rare events for which it is difficult to estimate the probability.

To protect against rare external events, plants need to be designed and sized with wide safety margins.

Events to be taken into account in design are categorized according to the frequencies of their occurrence. The equipment and components that are needed in order to limit to the acceptable zone the consequences of these events are then categorized as safety related or as important to safety; they also need to be qualified in order to ensure that they would fulfil their function in normal and accident conditions.

In order to investigate the domain of residual risk, probabilistic methods are used as a complementary tool to deterministic studies. To conduct a probabilistic safety assessment, it is necessary to proceed in the following way:

- identify all potential accident initiators (from previous studies and from operating experience);
- determine by an event tree method the sequences that can be induced—the sequences are constructed by accumulating human or equipment failures that could have consequences for the reactor (core melt, for instance);
- study the reliability of systems in the activities taken into account in the event tree;
- study the human reliability associated—human errors can be included as potential initiating events, as aggravating or recovery factors in accident sequences, and as potential unavailability factors for systems due to maintenance; and
- calculate the frequency of occurrence of the consequences to the reactor (such as core melt) from the frequency of initiation through all identified accident sequences and the system/human reliability.

The discussion of the results, not as absolute but as relative values, allows one to find ways to specify improvements in order either to reduce the probability of occurrence of the sequence or to mitigate its consequences.

Risk assessment has shown the importance of protecting against common cause failures. This is why, in the design phase, we use the single failure criterion.The single failure criterion means that no random and isolated event should prevent an item of equipment from functioning.

It is applied in such a way as to provide when necessary redundancy, physical separation and diversity. In order to apply this criterion during operation also, operational constraints need to be observed. The limited authorized time for operation when common cause failures occur and the conditions required for intervention for maintenance on one item of redundant failed items of equipment are examples.

Prevention against External and Internal Events

The internal and external events considered are very diverse and are studied as part of the design basis of the installations and for the design of equipment important to safety. They might represent a common cause failure which requires special prevention.

The events usually considered are:

- *external*—earthquakes, aircraft crashes, the industrial environment, (such as explosions), flooding, and ice; or
- *internal*—fire, high energy pipe whipping, internal flooding; and internal missiles.

The external events are treated on a case by case basis since they are site and environment specific. The principle is to increase the number of protective measures and to set wide margins for the design basis. The internal disruptions are considered such that, if they occur, the initial event should not propagate or lead to a more severe accident. Qualification of equipment as well as vulnerability studies are part of the defence in depth process.

Safety in Construction and Plant Startup

Safety in this stage requires checking that the quality of the materials/components/equipment is adequate as defined in the design.

Fabrication Stage

In accordance with quality assurance manuals, fabrication rules are defined that set the detailed operation modes, the qualification of the procedures used, the surveillance of these activities, the way to recover from any anomaly, and the reporting of end of fabrication. Prior to fixing these rules, qualification to accident conditions of the equipment is also performed.

In the fabrication process, complementary tests are performed in order to check quality—either systematic tests on all items of the series or more complete functional tests on a limited random sample.

On-site Construction Stage

In this stage, the main safety work consists of surveillance and checking of the work and its quality by the subcontractors. Controllers need to verify the use and adequacy of construction manuals, to check the work procedures used, to ensure the required cleanness when necessary, or to make sure that storage conditions of equipment are adequate to prevent deterioration.

Startup Tests

Before normal operation of the plant, a series of tests need to be performed:

- testing of equipment to check that their performance is adequate;
- testing of systems as a whole or of functions in various predetermined plant conditions; and
- regulatory tests aimed at verifying the behavior of the barriers and their tightness (e.g. hydraulic pressure test of the primary circuit, contain- ment pressure test).

All the tests performed and their results are verified by the safety authorities and the results are archived at the plant for use as references in performing the equivalent tests later in the plant lifetime.

Safety in Normal Operation

Safety in normal operation means:

- operating and maintaining equipment quality and rigorousness;
- preventing incidents by keeping the safety level as defined in the design (this means respecting the operational technical specifications and performing the required periodic testing, maintenance and requalification); and
- constantly improving safety through operating experience feedback, good operating practices, training and modifications when necessary.

Rigorousness and Vigilance

All plant personnel require an attitude of rigorousness and vigilance to engender what may be termed safety culture. Safety depends on professionalism, which may be summarized by the following: be rigorous in all activities, even straightforward ones; use your knowledge and apply good practices; think before acting; co-ordinate with other personnel; watch for and report any deviation or anomaly; respect quality assurance rules; and report on your own or others' errors. Such behavior is required at the individual level; but also at the collective level.

Another aspect of the need for rigorousness and vigilance is the quality of documentation: this concerns the operating procedures, drawings, maintenance procedures. The updating of documentation according to plant modifications is essential to prevent failures.

Maintaining the Level of Safety

The level of safety can be maintained by:

- **Observing technical specification.** They define the limit of the normal functioning of the plant.They indicate precisely the limits and the operation rules, the protection thresholds, the required availabilities of components/systems, the operational modes in the event of unavailability of this equipment and the necessary conditions for intervention for this equipment.
- **Periodic testing of safety related equipment.** These tests are performed with a set frequency and with given controls and modes of realization. While the results obtained are archived, any anomaly detected is remedied immediately and the plant status is adapted according to the resulting unavailability.
- **Requalification.** After a modification or after a maintenance intervention, it is necessary to qualify the component or the system or the function in order to check its good operation in its functioning with regard to plant safety.
- **Plant outage.** This plant outage is complex and leads to the deliberate opening of one or more barriers, the primary circuit or the containment; cold shutdown technical specifications are the rules to observe to maintain the level of safety; good co-ordination between the control room crew and the maintenance personnel is essential, as is good planning of the work to be performed.

Enhancing Safety

Safety can be enhanced by taking into account operating experience feedback: learning from experience is essential. The analysis in depth of plant events may lead to modifications to training, to dissemination of good practices, to improvements in documentation, to organizational modifications or to plant modifications which require prior approval by safety authorities.

Training

Training is essential to attain and maintain safety levels and to engender safety culture. Competent and qualified personnel for plant operation and maintenance require appropriate training and continuous retraining.

Some basic requirements for achieving the necessary quality of training are:

- direct involvement of the management in the training of plant personnel;
- continuous use of training tools;
- the inclusion of operating experience feedback in the training;
- the competence of instructors; and
- the use of the best means of teaching.

In addition to classroom courses, simulators are essential to training: functional simulators for familiarization with some functions of the plant as well as full scope simulators which constitute the real tool on which the operators can perform, learn the procedures and act as a team.

Safety in Incidents or Accidents

It is possible to define the lines for defence in depth so as to be able to cope with unusual and unforeseen situations:

- 1st line—automatic actions,
- 2nd line—actions of the control room operators, and
- 3rd line—actions of the emergency team.

The automatic actions are part of the design. The control room operators need to check the appropriate automatic actions and use the control panel to make the right diagnosis of the situation and to check the availability of the means required to deal with it. This allows the operators to determine the appropriate accident procedure to use to restore the plant to a safe state. In most countries with nuclear power plants, the operators are now assisted by a safety engineer who can help in decision making and in checking the adequacy of the actions taken (procedures) and the plant reaction.

The accident procedures are event oriented, symptom based or plant cooling state based, and they relate to beyond design basis accidents as well as design basis accidents. Ultimate procedures also provide a way for mitigatory measures to be taken in the event of a severe accident. Operators and safety engineers are well trained and retrain- ed in all these procedures.

In order to provide a last line of defence and to master complex accident situations, local and national crisis teams may be called upon. These would provide assistance to the plant in further actions to be taken for the protection of the public and the environment, as mobilizers of all national means that might be necessary and as a liaison with local and national authorities and the public for decisions on taking further protective measures such as evacuation.

Conclusions

Safety considerations are intrinsic in all the stages of the lifetime of a nuclear power plant, including all aspects of design, operation, organization and management; and they concern both plant equipment and human resources.

Safety of nuclear power plants as a permanent feature is an essential prerequisite for continued excellent performance. ❐

The Radiological Consequences of the Chernobyl Accident

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The accident at the Chernobyl nuclear power plant on 26 April 1986, had an impact on society like no other previous industrial accident. In the early post-accident phase, more than 130 000 people were evacuated from the immediate "prohibited" 30 kilometer zone around the reactor and about 600 000 workers dealt with rescue and clean-up operations in this most affected area.

However, by March 1989 it became clear from the first summarized contamination maps published by former USSR scientists, that outside this zone as well as additional areas in Byelorussia (now Belarus), Northern Ukraine and the Central economic region of the then-Russian Soviet Federal Socialist Republic were contaminated with more than half the total amount of iodine and caesium radioisotopes deposited on Soviet territory.

In September 1988, the Council of Ministers of the former USSR adopted the so-called 350 mSv concept. This lifetime dose limit was established as an intervention level for relocation. This criterion subsequently was complemented by the additional limit concerning the soil surface contamination of 1480 kBq/m^2 (40 Ci/km2). Both criteria were to be implemented as of January 1990. Some four months later, in April 1989, the (former) Byelorussian Academy of Sciences registered disagreement with the 350 mSv-lifetime dose concept.

In 1990, upon request by the former USSR Government, a multinational team was formed to assess the radiological situation in the three affected Republics within the framework of the International Chernobyl Project (ICP). Organizations participating in the ICP included: the Commission of the European Communities, the U.N. Food and Agriculture Organization, the International Labor Office, the U.N. Scientific Committee on the Effects of Atomic Radiation, the World Health Organization, and the World Meteorological Organization.

In March 1990, a group of international scientists undertook a preparatory fact finding mission to the affected areas. They met with officials, scientists, doctors and, most of all, with the residents. It was evident that there was a pronounced distrust by many of these people of the former USSR authorities, as well as of the scientific and medical communities.

In April 1990, a 21-member international advisory committee (IAC) from ten countries and seven international organizations was formed to direct the ICP and prepare its final report. In view of time and financial constraints, the IAC recommended a two-part approach:

- verification of the existing official results; and
- focus on the key issues of concern of the local population and policy makers, such as the true extent of the environmental contamination; the past, current and future radiation exposure of the population; the actual and potential health effects; and the adequacy of measures being taken to protect the public.

From May 1990 to January 1991, the IAC-adopted work plan was implemented by five appointed task leaders, responsible for the categories historical portrayal, environmental contamination, radiation exposure, health impact and protective measures.

In May 1991, the findings of the project were presented in the form of a 1 000-page technical report to the international scientific community on the occasion of an international conference in Vienna. In the following, the main results of this report are discussed.

Implementation of the International Chernobyl Project

Some 200 experts from universities, research institutes and other organizations in 25 countries and seven multinational organizations participated on a vol- untary basis. Almost 50 missions to the former USSR were carried out by the experts, using their own equipment and their own field and analytical methods. Several Governmental authorities and commercial companies in five countries donated equipment supplies and computing time. The IAEA Physics and Chem- istry Instrumentation Laboratory at Seibersdorf, Austria, organized an intercom- parison exercise with major laboratories in the former USSR. Nevertheless, the ICP had constraints and limitations:

- The radiological situation immediately after the accident could no longer be independently assessed because of the decay of short-lived radioisotopes;
- Due to limited time and resources the experts could neither examine and verify independently all available information, nor could they carry out an extensive independent analyses; and
- The project did not address the health effects of evacuees not resident in the affected Republics, nor was the emergency personnel dealing temporarily with recovery work and accident management included

It was decided to assess data, techniques and methodologies used by the authorities. In addition, sufficient data would have to be obtained by ICP members in order to formulate independent judgements.

The Findings

Environmental Contamination

The results of the intercomparison exercise and the visits to the main laboratories showed that the analytical capabilities appeared to be adequate. The few problems identified did not significantly affect the use of data for subsequent conservative dose assessment purposes.

The assessment of the field studies revealed that the methods can be considered appropriate to give adequate average results for the surface deposition in a region. According to this method, "hot spots" are identified but neither listed, nor used for the estimation of the average surface deposition for a given region, since they reportedly did not contribute significantly to the total dose of the inhabitants.

Using a combination of different survey methods in four settlements in the three affected Republics, including soil sample profiles, *in situ* gamma spectrometry and external gamma dose rate surveys, the official fallout maps could be corroborated.

Local water sampling programmes were found to be adequate. Independent water samples showed mostly radionuclide levels significantly lower than the intervention levels established by the authorities. However, some sediments were found to contain increased levels of radionuclides, possibly leading to a long-term contamination of the aquatic food chain.

Air sampling programmes could not be evaluated due to the lack of information. It is noted though that, based on independently taken air samples, the occurrence of airborne resuspension cannot be excluded, particularly during agricultural activities and dry periods.

Food monitoring programmes cover adequately the complete cycle from commercial production to consumption. In most cases, the radioactive contamination of food samples was found to be below the intervention levels established by the authorities.

The private food production sector is not monitored as thoroughly. Milk from some individual farms and food collected in natural areas (such as mushrooms, berries) in contravention to official recommendations can be contaminated above intervention levels.

Radiation Exposure of the Population

Due to variation in soil conditions and eating habits, the evaluation of past and future radiation exposure is difficult. The official exposures were assessed through a three-part approach:

- review of official information on radiation doses to people living in seven settlements selected for the study;
- assessment of the radiation exposure of the selected populations using internationally recognized methods and their own independently compiled database obtained through extensive fieldwork in mid-1990; and
- comparison of the independent Project estimates with the official dose values.

The results showed that in most areas the most significant contributor to dose is external exposure. Based on the analysis of 8 000 film badge dosimeters, 90 percent of the results were below the detection limit of 0.2 mSv for a two month exposure period.

Whole body counting of caesium was carried out in an independent survey of 9 000 people in nine settlements. The results indicated lower body contents than predicted by modelling of dietary intake.

Absorbed thyroid doses could not be verified independently because of the complete decay of iodine by the time of the ICP. Officially reported average thyroid doses ranged from 0.2 Gy to 3.2 Gy for children from birth to seven years old (maximum: 30-40 Gy).

In order to have a general basis of comparison, independent dose estimates were made for the surveyed settlements, using average surface deposition data. The results show that the range of the 70 year doses (from the year 1986 to 2056) is 80 to 160 mSv (including strontium), as compared to 150 to 400 mSv for the corresponding official values.

Health Impact

Reports continued of a higher incidence of illness among residents of the affected areas, reflected in an increased registration of complaints and a greater number of diagnosis of illnesses of various kinds. This part of the ICP used a two-part approach:

- review of official data key medical centers and institutes; and
- examination of people in both surveyed contaminated and surveyed control settlements and comparison of results. These results were reviewed by project members and external epidemiologist.

In addition, nutritional aspects were assessed by review of official data and conduct of total diet studies in 13 settlements.

This study had several methodological limitations:

- only the people remaining in the surveyed contaminated areas were studied;
- only small to rural size settlements were selected since they usually had higher environmental contamination levels; and
- review of official data was extremely difficult due to deficiencies in equipment and methodology that had been used.

Major results, in general, were that the reported adverse health effects attributed to radiation have not been substantiated either by those local studies which were adequately performed or by the studies under the ICP. There were many important psychological problems such as anxiety and stress related to the Chernobyl accident, wholly disproportionate to the biological significance of the environmental radioactive contamination. However, people are not acting in an irrational way. There is no radiophobia, but they have serious concerns, resulting in 72 percent of the adults wanting to relocate.

The children were found to be generally healthy, but about 10 to 15 percent of the adults had substantial medical problems (excluding hypertensive adults).

Cardiovascular disorders were similar for contaminated and control settlements and comparable with published values for Moscow and [illegible]ingrad.

No detrimental effects on growth as a result of the accident were found.

Intake and excretion of iodine were found to be at the low end of the acceptable range.

Dietary intakes of toxic elements were low by international standards and were well below the maximum tolerable intake levels.

No abnormalities in either thyroid stimulating hormone or thyroid hormone were found in children examined. No statistically significant difference was found between surveyed contaminated and surveyed control settlements for any age group. Thyroid nodules were extremely rare in children and occurred in up to 15 percent of adults in both contaminated and control settlements. Project results are similar to those reported for populations in other countries.

No statistically significant differences in haemoglobin levels, leucocyte and platelet were found for any age group in control and contaminated settlements.

Judged on the basis of lymphocyte level and the prevalence of other diseases the immune systems do not appear to have been significantly affected by the accident.

Cancer incidence in the former USSR has been rising reportedly for the last decade, starting before the accident and has continued to rise at the same rate since the accident. The team could not assess whether the rise is due to increased incidence, methodological differences, better detection and diagnosis or other causes. The official data did not reveal a marked increase in leukemia or thyroid tumors since the accident. However, the possibility of an increase in the incidence of these tumors cannot be excluded owing to the classification scheme used and other factors. Available data do not provide an adequate basis for determining whether there had been a small increase of leukemia or thyroid cancers as a consequence of the accident.

There is no evidence of radiation induced cataracts in the general population.

No statistically significant evidence was found of an increase in incidence offoetal anomalies as a result of radiation exposure.

On the basis of the dose estimates by the ICP and current internationally accepted radiation risk estimates, future increases over the natural incidence of all cancers or hereditary effects would be so small that they would be difficult to detect. However, based on reported absorbed thyroid doses in children, a statistical increase in the incidence of thyroid tumors may be detectable in the future.

Protective Measures

The authorities instituted early countermeasures (sheltering, administration of stable iodine, evacuation), as well as intermediate and long-term coutermeasures (relocation, restrictions of food, agricultural measures, decontamination).

A central issue in the former USSR request was to examine those protective measures taken or proposed from 1990 onwards by the authorities. In addition, a more limited evaluation also was made of protective measures taken prior to 1990. These measures were compared with international recommendations and evaluated for their appropriateness.

Due to the unprecedented nature and scale of the accident, many early protective measures had to be improvised. Owing to the complexity of the events, the ICP was not able to investigate in detail many actions taken. However, the general response had been reasonable and consistent with internationally established guidelines prevailing at the time of the accident. Some measures doubtless could have been better or taken in a more timely manner.

The protective measures taken or planned for the longer term, although well intentioned, generally exceed what would have been strictly necessary from a radiological viewpoint—relocation and foodstuff restrictions should have been less extensive—however, any relaxation of the current policy is likely to be counterproductive, since the present levels of stress and anxiety among the residents are high. The final decision can be only taken by the authorities, taking into account—besides radiation protection aspects—many socio-political factors.

The following points were noted as a result of the assessment by the ICP:

- intervention levels of dose for evacuation were consistent with international guidance;
- the numerical value of the intervention levels for administration of stable iodine were not in full agreement with international recommendations;
- the wide range of measures taken for surface decontamination were reported moderately effective;
- the intervention levels for food restrictions established by the authorities are at the lower bound of the range recommended internationally; and
- the social consequences, including costs, of banning the consumption of foodstuffs were in many cases disproportionate to the doses averted.

The major topic of "relocation" was analyzed in detail. Results show that various conceptual misunderstandings, terminological problems among the central and local authorities, together with the considerable delays in developing a policy and communicating it, has been largely responsible for the failure to reach a broad consensus. The cautious approach adopted in overestimating on purpose the doses to people living in contaminated areas of concern was inappropriate, in principle. This led to overstating the radiological consequences of continuing to live in contaminated areas and caused the unnecessary relocation of some people.

There is the pronounced need to restore public confidence, which has been seriously eroded over the past five years. More realistic and comprehensive information should be provided to the public on the levels of dose and risk, if they should decide to remain in the contaminated areas of concern. These risks should be compared with other risks of everyday life, such as inhalation of the natural carcinogen radon or industrial emissions. ❐

The Fuel Cycle and Nuclear Waste Management

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During the early days of its development, nuclear power appeared to be an ideal energy source. Rather small lumps of uranium can generate vast amounts of electricity in a compact utility. Of course, there is no such thing as a free lunch, and the process of nuclear power generation required some clever engineering. Additionally, because of the military significance of the materials involved, there were some socio-political constraints on the widespread distribution of this technology. Nevertheless, nuclear power has expanded to become one of the major methods of electricity generation (producing about 17 percent of the total worldwide).

Like all industries, the production of nuclear power generates a range of wastes. Until the last couple of decades, wastes of all sorts were tacitly accepted as an inevitable consequence of industrialization and, in most cases, they did not receive a great deal of attention. The environmental consciousness which arose in the 1960's, although to a large extent attributable to the affluence derived from industrial development, has led to a much more careful evaluation of the detrimental aspects of such development. Radioactive wastes have been popularly identified as particularly intransigent and hence are considered a critical problem associated with nuclear power generation. Where do such wastes come from, what are their properties and are they really such a problem?

The Nuclear Fuel Cycle

The nuclear fuel cycle is those processes associated with the production of fuel for nuclear reactors and its subsequent re-use after reprocessing or direct disposal.

Basically the processes involved include:

- mining of the uranium ore,
- extraction and purification of the uranium,
- (optional) enrichment of the Uranium-235 (U-235) concentration,
- fuel element fabrication,
- reactor operation, and

- spent fuel removal and storage, either
    - direct disposal of spent fuel, or
    - reprocessing of spent fuel to extract usable fissile materials (uranium, plutonium) which can then be used to produce further fuel elements.

Every process listed above produces waste, and a proportion of such wastes will have enhanced radioactivity.

Mining and uranium extraction from the ore produces the highest volumes of waste. Although the total radioactivity of the waste is less than that of the original rock (as the uranium has been removed), some radioactive "daughters" of uranium, such as radium, may be rendered more mobile by the processing involved.

The operation of the enrichment and fuel element fabrication facilities will produce small quantities of radioactively contaminated waste. Even though most of the radioactive products of fission will be sealed within the fuel elements, reactor operation will also produce a range of contaminated and activated wastes.

The spent fuel is both very hot and very radioactive when removed from the reactor and hence must be stored for a period of time before further handling. The spent fuel either can be considered as waste and disposed of directly or reprocessed by separating all of the waste products from fissile material which can be re-used. The waste radionuclides are then immobilized in some manner before disposal.

All of the facilities involved will become contaminated to some extent and further wastes will be produced during their eventual dismantling (decommissioning, in the jargon).

Wastes can be categorized by their origin, as above, or by their radioactive content. By far, the largest volume are low-level wastes (LLW) which contain very small concentrations of radionuclides and, in particular, contain nuclide which decay in relatively short periods of time (half-lives in the order of tens of years or less).

A smaller volume of wastes contain higher radionuclide concentrations and are classified as intermediate-level wastes (ILW). Low- and intermediate-level wastes may be further subdivided depending on the amount of particular radionuclides which they contain—especially if these are long-lived or are particularly toxic (e.g. 04-emitters, transuranics).

A very small volume of waste is so radioactive that the heat produced by radioactive decay is significant. Such high-level waste (HLW), although of small volume, contains the major part of the radioactivity produced in the nuclear fuel cycle.

In the following sections, I will examine the properties of high-level waste and the option for its disposal in more detail, as this is commonly considered to be the most problematic waste type. Most of the other wastes are really just conventional junk—steel, concrete, plastics, etc.—which has slight traces of radioactivity. Although it is necessary that such waste is properly treated, in principle, it is little different from other hazardous waste, such as that resulting from the chemical industry.

High-Level Waste Characteristics

As previously mentioned, HLW is so radioactive that it produces significant heat and this situation persists for hundreds of years. The waste either comprises the spent fuel element itself or radioactive residues from reprocessing immobilized in stable solid matrix. Many options are available for such matrices including various types of glass, ceramics and synthetic rock (such as SYNROC, which was developed in Australia). All these materials are characterized by their insolubility, stability with respect to high temperatures and irradiation and mechanical strength. The waste is further encapsulated in a shielding container (steel or concrete) for transport and storage.

The heat and radiation output is predominantly due to relatively short-lived radionuclides and hence drops off markedly with time. The concentration of important radionuclides in high-level waste changes with time and this affects the total toxicity of the waste.

Disposal Options For HLW

Many different strategies for the management of HLW have been studied. Perhaps the most attractive, in principle, is the destruction of the problematic long-lived nuclide by nuclear activation (transmutation or "nuclear incineration") converting them into shorter-lived species. In practice, however, such a process involves extensive handling of very radioactive materials which poses considerable hazards to the workers involved. Although the concentration of long-lived components is decreased, the total activity for the short-term (hundreds of years) is increased.

Alternatively, the waste could just be stored indefinitely. This is generally not considered acceptable because, apart from the risks associated with accidents at the storage site, it places a burden on future generations.

All other strategies involve some kind of disposal. Some of the more exotic options considered include space disposal and disposal in the Antarctic ice sheet. Both these options are problematic because of the technical difficulties involved and the hazards associated with getting the waste to its final resting place. They also would involve considerable problems due to the statutes of international law. Legal problems also limit various main disposal options (on or under the sea bed) which, from a technical point of view, appear very attractive.

All countries with HLW management programmes have thus focussed on some form of geological disposal. Even here, some exotic variants have been considered—rock-melting waste packages, disposal in subduction zones, and extremely deep bore-holes. Plans which consider only established technology have, however, converged on some kind of mined repository.

Basically, the aim of a repository is to ensure that releases of radioactivity from the waste never cause any hazard to mankind. This is achieved by a system of massive engineered barriers and by selection of an appropriate rock environment. This ensures that the waste is completely isolated until radioactive decay has reduced the activity present and, thereafter, the rate of release of any activity is insignificant. Because of the toxicity of the waste, redundant barriers are often incorporate—for example, putting an insoluble waste inside a chemically inert canister which is further sealed in a thick layer of plastic clay and buried at depths of hundreds of meters below the surface.

Many different types of rock have been considered as potential hosts for HLW repositories, but these can be classified as either dry or wet. Dry rocks (such as salt or anhydride) do not contain a groundwater flow system and have no direct mechanism for degradation of the engineered barriers or transport of radionuclides. Wet rocks do contain mobile groundwater but also may be suitable if groundwater flow is low and is either localized in well-defined zones (crystal-line rocks) or occurs only by very slow diffusion throughout the entire rock (clays).

In general, the topography and structural geology of the chosen sites ensures the favorable low-flow conditions. Deep sites are also usually characterized by chemically reducing conditions-meaning the absence of oxidants like dissolved oxygen which could encourage barrier corrosion or radionuclide dissolution.

The host rock provides a suitable environment for the engineered barriers (physical protection, low water flow, etc.) but also has important barrier roles of its own. In particular, the transport of any radionuclides released from the repository can be greatly diminished by sorption onto the rock, while concentrations may be reduced by dilution and dispersion along groundwater flow paths.

Assessing the Performance of a HLW Repository

The previous discussion has considered general aspects of HLW disposal; now I will try to show how the future behavior of the repository is evaluated (performance assessment). Possibly more important then the mathematical evaluation of performance, however, is convincing external critics that the conclusions reached are reasonable. To demonstrate both these aspects, I will use the example of the current Swiss design for a HLW repository.

As shown earlier, radioactive waste remains hazardous for very long periods of time, and hence this sets the time scale over which repository performance must be assessed. The approach used is based on mathematical models which predict the behavior of various components of the repository system based on theoretical treatment or empirical experimental data.

In the Swiss case, vitrified HLW will be sealed in massive steel canisters which are emplaced horizontally in tunnels backfilled with a compacted clay. For a granite host rock in Northern Switzerland, the repository would be built at a depth of circa 1 200 meters, where maximum expected water flow rates would correspond to less than one liter per year past each waste canister. It has been calculated that the canister would remain intact for a least one thousand years—much longer than the period of enhanced heat and radiation. After the canister finally fails, the glass will begin to dissolve—but at an extremely slow rate. Total destruction of the glass block would take more than 100 000 years.

Radionuclides which are leached from the glass may slowly diffuse through the clay and into the rock. The time taken is so long, however, that most of the radionuclides originally contained in the waste will decay away completely within the engineered barriers—even some long-lived radionuclides such as the isotopes of plutonium.

A very small concentration of radionuclides may, nevertheless, eventually escape into the flowing groundwater. They will, however, be transported even more slowly than the groundwater itself due to uptake onto the rock (absorption). In consequence, the eventual releases to accessible water (boreholes or surface water) are so low that they are negligible in comparison with either legal limits or natural concentrations of radionuclides.

Proof of Repository Safety

Relatively, the HLW repository is a very simple, passive system. Corrosion and degradation processes tend to be limited by the low availability of water and the ambient geochemistry. Nevertheless, extending predictions to geological timescales goes far beyond normal applications; although, in the future, this may be required for a much wider range of wastes.

The long timescales involved and the "novel" nature of radioactive waste tend to be considered the biggest problems involved with proving the validity of any repository assessment. In fact, nuclear waste is not as novel as it appears to be and there are examples, often termed "natural analogues," that we can use to justify our model predictions.

At a uranium mine in Oklo in Gabon, there is well-established evidence of the existence of natural nuclear reactors which were active 2 000 million years ago. The chain reaction in this very rich ore body produced all the important radionuclides present in HLW. The very fact that such reactors are observable today clearly demonstrates that the concept of containment over geological periods is feasible.

On a more detailed level, the models used to predict corrosion of the glass and the canister can be checked by comparison with archaeological materials (on timescales of up to a couple of thousand years) or geological samples of natural glasses or native metals (timescales of many millions of years). Such studies clearly indicate that the processes predicted by the models occur in real life and, quantitatively, model predictions are in the right ball-park.

Even the more complex models which evaluate the geochemical barriers provided by the chemical conditions in the repository (ensuring low solubility of the radionuclides) and sorption processes can be checked by field observation. Here it is seen that the steel canister adopted for the Swiss design may play a more important role than assumed in current models. Areas with reducing conditions together with the presence of iron oxides can be found on a wide range of physical scales and these are commonly observed to be geochemical traps—they increase the concentration of trace elements to levels far above those in the surrounding rocks. This implies that, rather than releasing radionuclides, an iron-based waste package may act as a trap and reduce the concentration of natural radionuclides in surrounding waters!

All Very Nice—But What If?

If you visit one of the sites considered for waste disposal and see the dry rock and the massive engineered barriers, it is quite easy to be convinced that everything will be OK as long as conditions stay as they are today. Inevitably, however, when you consider the long timescales involved, a series of possible horror events (scenarios) spring to mind; what if...volcanoes, earthquakes, meteorite impact ...? Naturally, the people involved in building repositories must take all these possibilities seriously and they have created long lists of possible disturbing events and processes.

For hazardous installations on the surface, there are a range of events which, even if very unlikely, could cause serious damage such as crashing jumbo jets, nuclear attack, major earthquakes, meteorite impact. The deeper the waste is emplaced, however, the more difficult it is to postulate any external influences which will seriously affect it. By the time that depths in the range of kilometers are considered, most of the surface catastrophes have a completely negligible influence—even such long-term events as glacier or sea-level/climate changes. Selecting an appropriate site would allow vulcanism to be fairly well excluded and use of plastic clay backfills ensures that deep-rock movements cause minimal effects.

There will always remain some theoretical "mega-catastrophes" which would cause significant disruption of the repository. Apart from being extremely unlikely, however, events like massive meteorite impacts would cause such global devastation that the consequences of some radionuclides released from a repository would be completely trivial by comparison.

Conclusions

All industries produce waste and nuclear power is responsible for some types of waste which are particularly unattractive. Such wastes are, however, produced only in very low volumes, in particular when related to the value of the product (electricity). Hence, expensive repositories involving multiple barriers can be designed to provide a very high degree of safety. Although the repositories must contain the waste for long periods of time, the models used to demonstrate such safety can be checked by comparison with observations of natural systems. The basic feasibility of the overall concept of long-term isolation of HLW can be clearly shown by the existence of the Oklo natural reactors.

In discussing the problems involved in building repositories which must last for "periods well beyond any engineering experience," people tend to take a rather myopic view of history. Although the time since the Western industrial revolution is rather short, the ancient Chinese were happily building tombs to last millennia. By careful site selection coupled with very clever use of engineered barriers such as clay, charcoal and wood, tombs have preserved even fragile lacquer and paper objects (and also bodies) for two millennia. With current engineering materials and technology, it seems reasonable to feel confident that we can do as good a job with nuclear waste. ❐

The Fuel Cycle and Plutonium as a Reactor Fuel

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I want to tell you about the problem of providing fuel for nuclear power stations. I will describe to you how, by reprocessing irradiated uranium fuel, we can obtain a supply of a new fuel called plutonium, and how, by incorporating this into fresh fuel, we can significantly reduce the amount of new uranium needed to fuel a nuclear reactor. And, to take it further, I shall describe how, by using the plutonium in a fast reactor, we can insulate our nuclear power stations from any future uranium supply problem.

The naturally-occurring fuel for nuclear power stations is uranium. The atoms of natural uranium are basically of two forms, known as Uranium-235 (U-235) and Uranium-238 (U-238). In its naturally-occurring form, uranium has about 0.7percent of U-235 and 99.3 percent of U-238. These forms are chemically identical, but the atoms of U-238 are slightly heavier and this gives them different physical properties.

One of the different physical properties is the ability of the atomic nucleus to split—the phenomenon known as nuclear fission. This can occur spontaneously; the nuclei of very heavy atoms like uranium are large and unstable.

However, fission is much more likely to occur if the nucleus is hit by the small sub-atomic particle called a neutron. When it is struck by a neutron, and undergoes fission, the atom is split into two roughly equal fragments, called fission fragments, releasing a very considerable amount of energy and two or three free neutrons. The energy gives the fission fragments and the free neutrons high speed, and as they collide with atoms in the surrounding material, they are slowed down and the energy of motion is turned into heat.

If the neutrons produced by fission collide with other uranium atoms, further fissions can occur. This chain reaction can release energy continuously and the heat so produced can be removed by a coolant (water, carbon dioxide or helium gas, or in fast reactors, liquid sodium) to boil water and so generate electricity.

Because, as I mentioned, the different weights of the two sorts of uranium atoms give them different physical properties, only the U-235 atoms undergo fission easily, and the fission process in U-235 occurs more easily if the neutrons which cause it are slowed down.

Most current nuclear reactors, therefore, have what is called a moderator, usually water or graphite, to slow down the chain reaction neutrons. Such reactors are called thermal reactors. The word thermal refers to the energy of the neutrons causing the chain reaction.

A nuclear reactor of course does not consist only of the fuel, the coolant and, for thermal reactors, the moderator. It has to have a structure, usually of steel, and the structural materials reduce the efficiency of the chain reaction process by capturing neutrons parasitically. To overcome this and to increase the amount of heat generated in a reactor of given size, the fuel is enriched—the ration of U-235 to U-238 is increased (these days, usually by centrifuges making use of the fact that U-235 and U-238 atoms have different weights), so that fuel for most of the world's thermal reactors contains about two to three percent U-235.

To fuel a 1 000 MW(e) thermal reactor, we need to be able to obtain about 110 tons of natural uranium per year. After enrichment, this produces the 25 tonnes of enriched uranium needed to re-fuel the reactor each year. The balance, 85 tonnes of U-238, or depleted uranium, cannot be used as fuel for thermal reactors and must be stored.

Now what will happen to the fuel after it has been in the reactor?

We could decide to store the irradiated fuel in an irradiated fuel repository. This is the general practice in, for example, the United States and Canada—both of which have large indigenous uranium deposits and hence foresee no problems in obtaining new fuel in future years.

The result of adopting this practice is that 25 tons of highly radioactive irradiated fuel is transferred into the irradiated fuel repository every year for each 1 000 MW(e) of nuclear generating capacity on our system. It is only a practicable option for a country with considerable indigenous uranium reserves so that there is a secure supply of new fuel and for organizations with large storage facilities for the irradiated fuel.

The 1 000 MW(e) reactor we are considering in a 40-year lifetime would need to be supplied with about 4 500 tonnes of new uranium. For countries such as the UK and Japan, this would need to be imported; and as we have seen in recent times with world oil supplies producers' cartels or political instabilities can threaten security of supply.

However, there is another way and that is to reprocess the fuel. This method enables us to separate the fission products from the unburned uranium in the irradiated fuel and, in addition, we obtain plutonium as a by-product. The U-238, which makes up about 97 or 98 percent of the enriched fuel put into the reactor is not easily fissioned; but it undergoes another sort of change when its nuclei are hit by neutrons. It transmutes changes into plutonium and plutonium-239 (Pu-239). Pu-239, which is the end product of the transmutation of U-238, is, like U-235, easily fissioned.

For the example we are considering, the reprocessing of the 25 tons of irradiated fuel discharged each year from the 1 000 MW(e) thermal reactor results in a further 24 tonnes of depleted uranium being sent to the depleted uranium store and gives about 0.2 tonnes of plutonium. There is also a very small quantity of highly radioactive fission-product waste. By reprocessing the fuel, the amount of highly radioactive waste is reduced by several orders of magnitude and the storage problem is much reduced from the situation we would have had if the irradiated fuel had simply been transferred to a repository.

Most of the stages in a reprocessing plant are standard chemical engineering processes. Because of the radioactive materials involved, the processes need to be carried out by remote control behind shielding barriers. This is normal practice in the chemical industry where toxic materials are involved.

In the reprocessing plant, the fuel elements are first broken down to remove structural components. The spent fuel rods are then dissolved in boiling nitric acid. The resultant liquid undergoes a series of chemical processes using an organic solvent dissolved in kerosene to first separate uranium/plutonium solution from the liquid waste and then to separate uranium and plutonium.

Kerosene does not mix with water and, being lighter, floats on top. If the two liquids are shaken together and then left, they settle into two layers. Using this principle, the organic solvent is first mixed with the dissolved irradiated fuel solution. Uranium and plutonium transfer to the solvent, leaving waste products in the acid solution.

During this stage of chemical separation, more than 99.9 percent of highly-active waste is removed. Repetition of this stage further purifies the uranium/plutonium stream.

During the following stage, chemicals are added to the solution to separate uranium and plutonium. The uranium and plutonium-bearing solutions then undergo further treatment to turn them into their respective oxide powders.The plutonium recovered in a reprocessing plant can be used to replace U-235 in the fuel being supplied to the thermal reactor.

This can be an attractive economic proposition. If the option chosen for dealing with the irradiated fuel is to reprocess it, so as to reduce the quantity of highly radioactive material to be stored, the plutonium which is obtained as a by-product is effectively free. As it is usual in modern thermal reactors to use the uranium in the form of its oxide, a fuel supply which is using plutonium returned from the reprocessing plant would be producing mixed uranium-plutonium oxide fuel, or mixed oxide fuel, MOX. The first MOX fuel irradiations in a pressurized water reactor, were in the Belgium BR3 reactor in 1963. Several countries are now recycling fuel in this way and MOX fuel is now being irradiated in reactors in Japan, Belgium, Germany, France and Switzerland.

The effect of recycling plutonium in this way is to reduce the need for new supplies of uranium to fuel the thermal reactor. For the 1 000MW(e) reactor example we have been considering, the incorporation of the 0.2 tons of plutonium obtained each year from the reprocessing plant into the fuel supply system, allows the demand for enriched uranium to be reduced, and this feedback to a reduction in the amount of natural uranium required. In my example, the amount required becomes about 77 tons.

If we look at the two options we have been considering—irradiated fuel storage, and reprocessing of irradiated fuel with plutonium recycling as thermal MOX—we can see this reduction in demand.

The amount of natural uranium needed each year to fuel the 1 000 MW(e) thermal reactor is reduced by about one-third if we adopted recycling of plutonium. As I observed earlier, there are economic advantages in doing this, and it uses up the plutonium coming from the fuel reprocessing plant, but new natural uranium continues to be required, though the amounts needed are significantly reduced.

An alternative way of using the plutonium is to introduce fast reactors into the system. The major advantage of a fast reactor—so called because the neutrons inducing the chain reaction are not slowed down by a moderator—is that it can generate its own fuel supply, and can allow the energy supply problem to be isolated from the uranium resource situation.

A 1 000 MW(e) fast reactor requires about four tons of plutonium (as a mixed plutonium-uranium oxide) as its fuel charge.

If we introduce such a reactor into the system we have been considering, the fuel from the 1 000 MW(e) thermal reactor, will, at a production rate of about 0.2 tons per year, produce the fuel charge for a fast reactor in about 20 years.

The fuel from the fast reactor also can be reprocessed. In the fast reactor fuel cycle, we need to add about two tons per year of the depleted uranium from the depleted uranium store, to the plutonium produced by the fast reactor, and the fast reactor fuel cycle can be closed. What is more, the fast reactor can be designed and operated to produce a slight excess of plutonium over and above its own refuelling needs, and in about 30 years, a fast reactor will produce enough plutonium to form the fuel charge of another fast reactor.

This final illustration demonstrates an important point about fast reactors, or as they are frequently called, fast breeder reactors. Fast breeder reactors do not breed plutonium quickly. For a given size of reactor, the plutonium charge for a new fast reactor is made in 20 years by a thermal reactor and in 30 years by a fast reactor. Fast reactors burn plutonium.

And, as fast reactors enable us to convert virtually all the otherwise useless U-238 which, with a thermal reactor system would go into a depleted uranium store, into the new fuel plutonium, we can significantly increase the amount of energy which can be obtained from a given amount of uranium.

To put a figure on it, a thermal reactor system can, at best, fission only 1.5 to two percent of the uranium atoms in natural uranium. Around 98 percent or more of the uranium supply ends up in a depleted uranium store. A fast reactor can convert this depleted uranium into plutonium and can use it very efficiently as a fuel, allowing all the atoms of uranium in natural uranium to be fissioned. The ratio of 100 percent usage for fast reactors to 1.5 or two percent usage for thermal reactors, means that fast reactors extract about 60 times more energy from a given amount of uranium than thermal reactors.

The world's uranium reserves, like the reserves of oil and coal, are limited. But, efficient use of available uranium in a mixed system of thermal and fast reactors, each type supported by its appropriate fuel cycle services, provides the world with the prospect of an abundant source of energy. ❐

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