In perspective: The role of safety assessment and risk management

Unified systematic analysis can help to improve management of industrial risks for prevention of accidents

by Antonio Novegno and Ephraem Asculai

Growing worldwide concern about environmental problems and severe accidents has accompanied the tangible results of using modern technology. Though industrialization has led to a dramatic increase in life expectancy in every country, it also has had detrimental effects on man's environment and contributes to industrial and societal risk.

During the onset of the Industrial Revolution, little thought was given to industrialization's effects on people and the environment, including the health and welfare of workers and the general public. Environmental effects were the last and most recent ones to arouse attention, mainly in the second half of the 20th century.

Throughout history mankind has had to accept natural disasters as being part of life. Besides such disasters, which usually culminate in a great loss of life, other less severe accidents result in economic loss, injury, and death. Taken together, these accidents are by far the leading cause of the accidental loss of lives. The prevention of major accidents, whose consequences are even more far-reaching, may merit still greater attention. *(See accompanying table.)*

The most important public health effects from modern technology are caused by long and chronic

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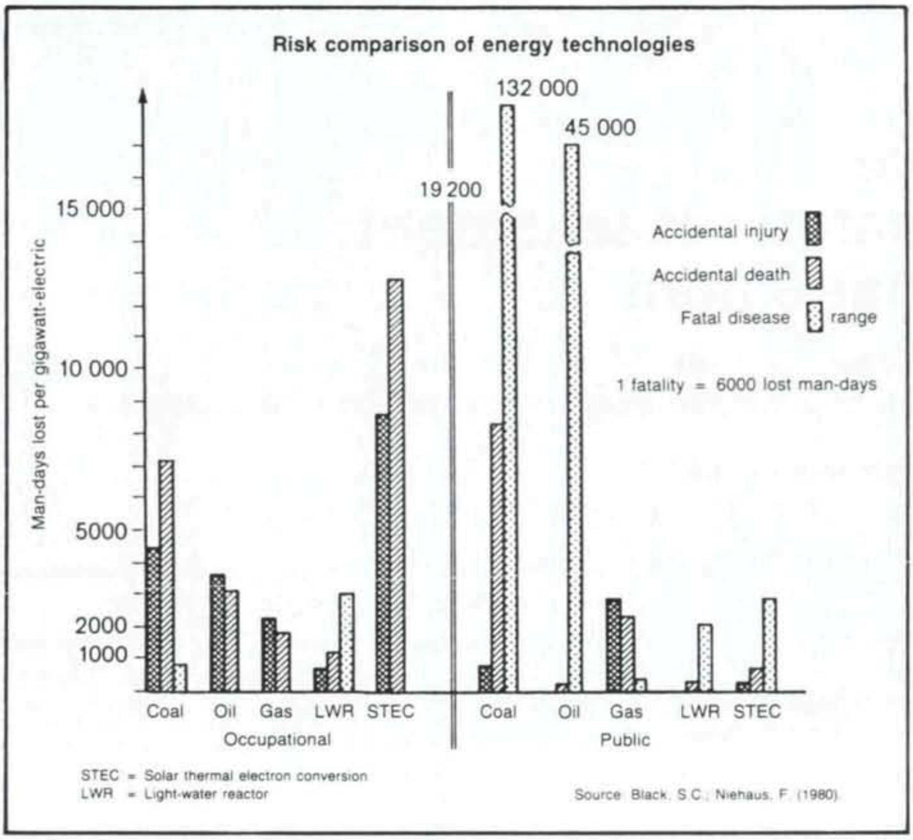
Some industrial accidents with severe consequences, 1976-86

Accident	Consequences
● *Seveso, Italy, 10 July 1976* In a chemical plant, a chemical reaction occurred causing an explosion of 0,5 to 10 kg of highly poisonous Dioxin to be scattered over an area of 18 square kilometres.	More than 1000 people had to be evacuated. There were no deaths. Dioxin deformed many children by causing skin eruptions (chlorine acne). Miscarriages and soil contamination were further effects.
● *San Carlos de la Rapita, Spain, 11 July 1978* A 38-tonne lorry, overloaded with some 45 cubic metres of inflammable propylene gas crashed into a wall of a camping place and exploded, producing 30-metre high flames.	215 deaths
● *Cubatão, Brazil, 25 February 1984* A pipeline was damaged and gasoline leaked and exploded causing a giant fireball.	At least 500 deaths
● *Mexico-City, Mexico, 19 November 1984* Containers with liquid gas exploded in the San Juan Ixhuatepec storage facility (gigantic gas explosion).	452 people died, 4248 were injured. Some 1000 people are still missing, believed dead.
● *Bhopal, India, 17 December 1984* A poisonous gas (Methylisocyanide) escaped from a petrochemical factory manufacturing a substance for controlling insect pests. This poisonous gas spread over an area of 40 square kilometers.	2500 deaths from poisoning, the same order of magnitude in critical health condition. Some 150 000 people had to be treated in hospitals. Long-term effects such as blindness, permanent mental disorders, liver and kidney damage, and embryonic disfiguration.
● *Chernobyl, USSR, 26 April 1986* A power excursion occurred at the fourth unit of Chernobyl nuclear power station, causing a steam explosion, destruction of the reactor, and severe contamination of the environment by radionuclides released from the reactor fuel.	31 persons killed, 203 persons hospitalized for acute radiation sickness, 135 000 persons evacuated. Maximum collective committed effective dose-equivalent estimated at 2.9×10^7 man-rem for the European part of the USSR.

Note: Table based in part on Chakraborty, S. "How quantifiable are catastrophic risks", *Risikountersuchungen als Entscheidungsinstrument* (1985.)



exposure to pollutant emissions in the vicinity of industrial complexes, including energy production systems.

In addition to these easily discernible environmental problems, a new set of problems having, perhaps, the most far-reaching and global effects is emerging. This set includes, among others, problems of "acid rain" affecting forestry and agriculture; nitrogen oxide (NO_x), which has severe economic effects on various materials; fluorohydrocarbons and carbon dioxide concentrations in the atmosphere, which may have a lasting and serious effect on global climate and influence life and its quality for generations to come.

Environmental problems emanating from technology are really safety-related problems, since it is rare to have economic and social environmental impacts without safety issues being involved. This is even more obvious for accidental emissions and impacts on the environment, which usually result from either improper design of safety-related features or from failure of safety and safety-related systems.

These two types of impacts on the environment — from routine industrial operations and from accidental emissions — are interrelated. Managing one type of risk will have an effect on the other. As an example, better environmental safety may mean more occupational risk to workers who have to manufacture, install, and maintain additional safety-related equipment.

Managing these risks therefore needs an integrated approach, in which all causes and possible results can be taken into account. This should be carried out not only for the single industrial plant or operation, but for industrial complexes and regional operations as well when they are closely situated or can possibly influence each other and the same environment as a whole.

Comparative studies of risks in energy systems

The health and environmental effects of different energy technologies have in the last decade become an important aspect in the public debate about energy systems. Comparative studies on risks and impacts from nuclear, coal, oil, and hydroelectric power serve to put energy-related hazards into proper perspective.

The main objective of such studies is to provide energy planners with scientific information about one of the various factors influencing decision-making regarding energy systems, both on the national and international level.

Early studies concentrated first on specific aspects of the risks involved in energy production and then on the conceptual framework, methodological issues, and data availability. More recently, specific problems, such as nuclear risks, sulphur dioxide releases, acid rain, radioactivity in coal, and low-level radiation, were singled out. Finally, quantification and comparison of the various health detriments, of continuous impacts, and of consequences of rare accidents were explored.

Great effort was devoted to developing models that simulate long-range dispersion of airborne pollutants and enrichment through terrestrial food chains. The lack of extensive epidemiological studies restricted the establishment of dose-effect relationships needed to assess the full range of health hazards. Some of the aspects of risk comparison are still not solved, mainly because of lack of data, complexity of the comparative health and environmental studies, data uncertainty, and lack of knowledge about methods and data manipulation.

Since the conclusions that can be drawn from such general comparisons are very limited, later studies tried to compare energy supply technologies only. *(See accompanying figure.)*

However, in spite of the large uncertainties incorporated in such assessments, the general conclusions that have been drawn are valid and show a definite rank ordering of energy systems according to various risk dimensions. Nevertheless, it is important to recognize that the most important value of risk comparisons for various energy sources rests not with the overall results, but with the identification of major risk contributors in each of the fuel cycles investigated.

It is also important to recognize that a quantitative comparison of the risk/impact dimension related to different energy systems cannot strongly influence decision-makers in defining national energy plans. In fact, many other aspects contribute, in a complex way, in determining a national "mix of energy" in a country. These aspects include: energy demand; international trade; industrial development; economic situation; balance of payments; security of supply; capital costs; and others. Therefore, it was suggested that risk/impact analysis with emphasis on risk-management could play an important role at the level of national utility planning, where, for example, specific technology features and siting must be decided on a national or regional basis.

From risk comparisons to "risk management"

As follow-up to studies on comparisons of risks of energy systems and because of the overall consideration discussed above, the last few years have seen a shift in emphasis from comparisons to the management of risks.

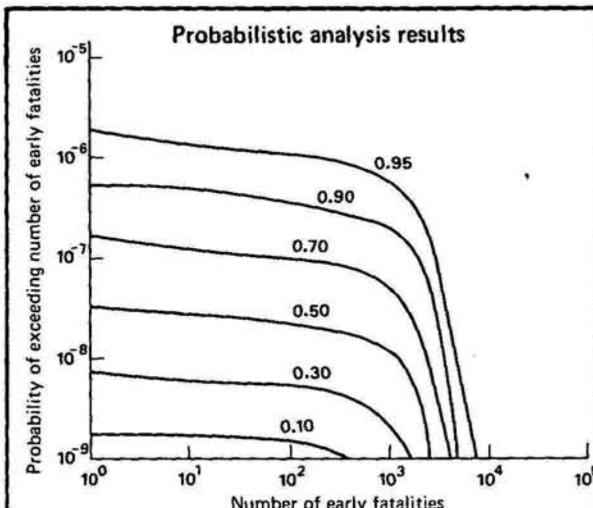
Comparing risks of reference plants puts risks into perspective; however, such information is not yet sufficient to decide if a plant is safe enough. It cannot be the objective of a rational safety policy to reduce (or increase) all risks to the same level for the individual or society in general. Rather, it seems reasonable to reduce a low risk even further if this is easily achieved, or to leave a quite high risk (if not out of proportion with other risks) on such a level if it were too difficult (expensive) to reduce further. A method that approaches this question systematically is cost-effectiveness analysis. *(See figures on page 36 for examples of results.)*

The IAEA actively promotes the use of such methods and in 1983 started a co-ordinated research programme ("Comparisons of cost-effectiveness of risk reduction among different energy systems"). Its main purpose is to co-ordinate within Member States a certain number of national risk assessment research projects, as case studies, utilizing the cost-effectiveness approach.

Fifteen Member States are co-operating with the Agency in this effort.* To date, 18 case studies have been completed using the methodological framework defined during the first co-ordinated research programme (CRP) meeting. These studies are mainly dealing with the different facilities and operations related to the nuclear fuel cycle (uranium mines, power stations, transportation of radioactive material, waste disposal). Ten further case studies are being done and will be completed before the end of the CRP.

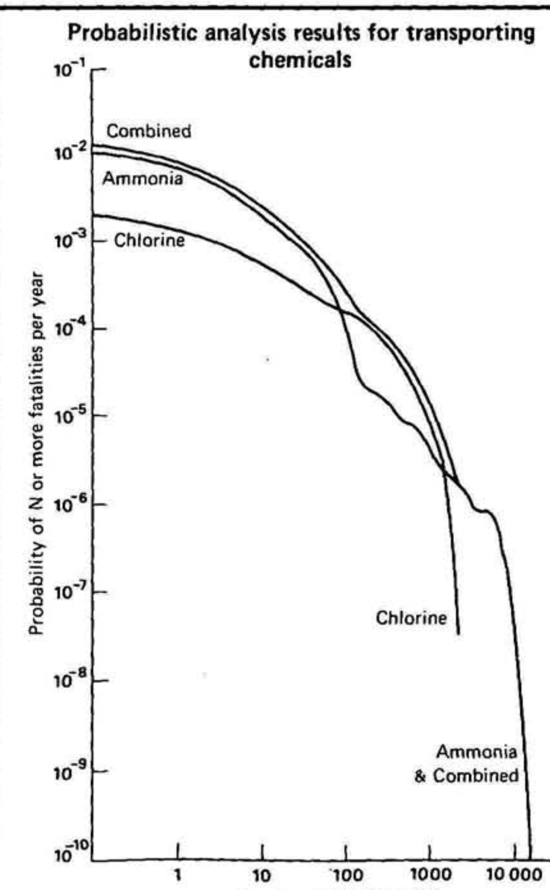
In conducting such case studies, it has been demonstrated that within the field of risk management tech-

* The report of the second research co-ordination meeting is available from the authors; the final report is expected in 1988.



Source: Fitzpatrick, R., Arrieta, T., Teichmann, T., Davis, P., *Probabilistic Risk Assessment (PRA) Insights*, NUREG/CR-4405 (1985).

Results are shown as the probability of exceeding a certain effect (number of early fatalities in this case) as a function of the effect for a year of reactor operation. The figure includes also the estimates of uncertainties: For example, the curve of 0.95 indicates that one has a 95% confidence that the "real" results are contained within this curve.



Source: Based on Seman, M.A., "International experience in assessment of risks due to oil and gas production and chemicals manufacture" at IAEA/UNEP/WHO workshop, 13–17 October 1986, Paris, France.

The use of PSA is not limited to the nuclear industry. Shown are the results of a PSA calculated for the transportation of chlorine and ammonia, utilizing its own set of assumptions about release rates, atmospheric dispersions, and the effects of these compounds on man.

niques, cost-effectiveness analysis of risk reduction is an adequate method for evaluating and defining the optimal allocation of protection and safety resources within large industrial systems.

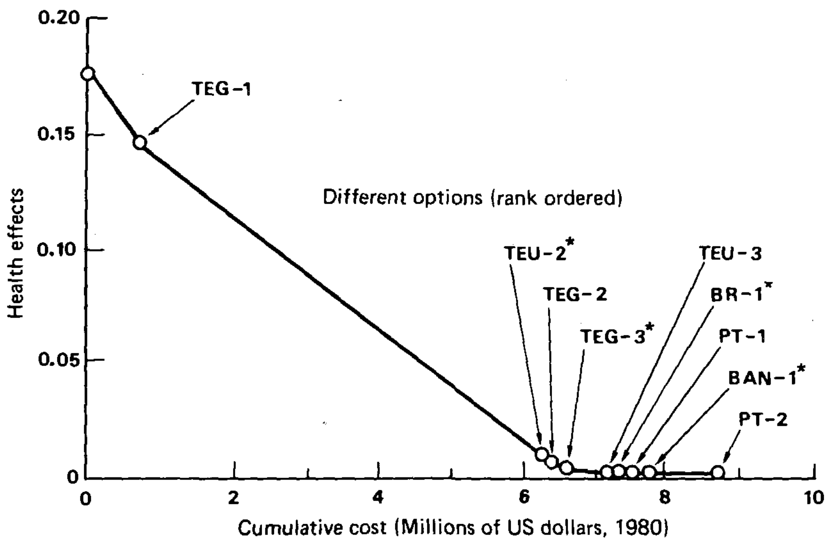
Safety and risk management of severe accidents

Perhaps the best example of a complete system of risk assessment and risk management is in the field of nuclear energy.

For every nuclear power plant, an entire environmental impact study is carried out. This consists of a safety study of the plant operation and the evaluation of the occupational risk to the workers. It also includes the calculation of routine emissions of radioactivity to the environment, the expected levels of exposure of the public, and the evaluation of the consequences of accidental high releases of radioactivity to the environment.

There are two approaches to the calculation of environmental consequences of an accident occurring at a nuclear power plant. The traditional way is called the "deterministic" approach. It utilizes a preset assumption of a "Design Basis Accident" (DBA) and calculates its consequences for conservative atmospheric conditions compared with standards for permissible exposure levels during an emergency.

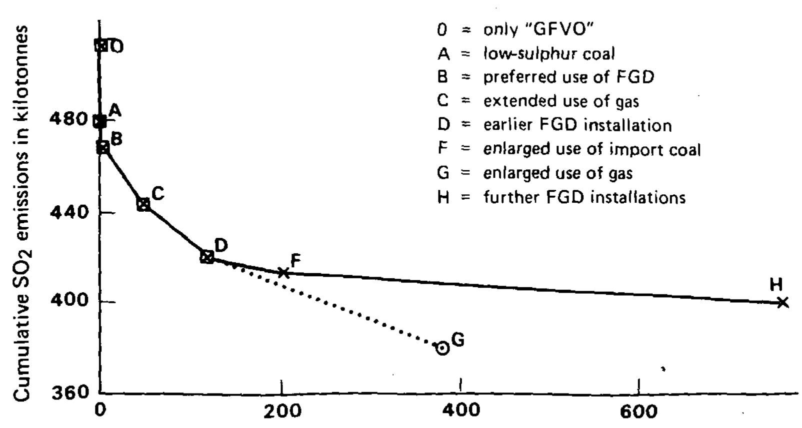
A newer approach is probabilistic safety assessment (PSA). No single accident scenario is defined, but rather a set of scenarios, alongside their estimated probabilities of occurrence, are prescribed. Given this set, the



Cost-effectiveness analysis of risk reduction at nuclear power plants

Note: Health effects and analysis based on 1.3 gigawatts-electric PWR over 20 years.
Source: IAEA-SM-273 (1984).

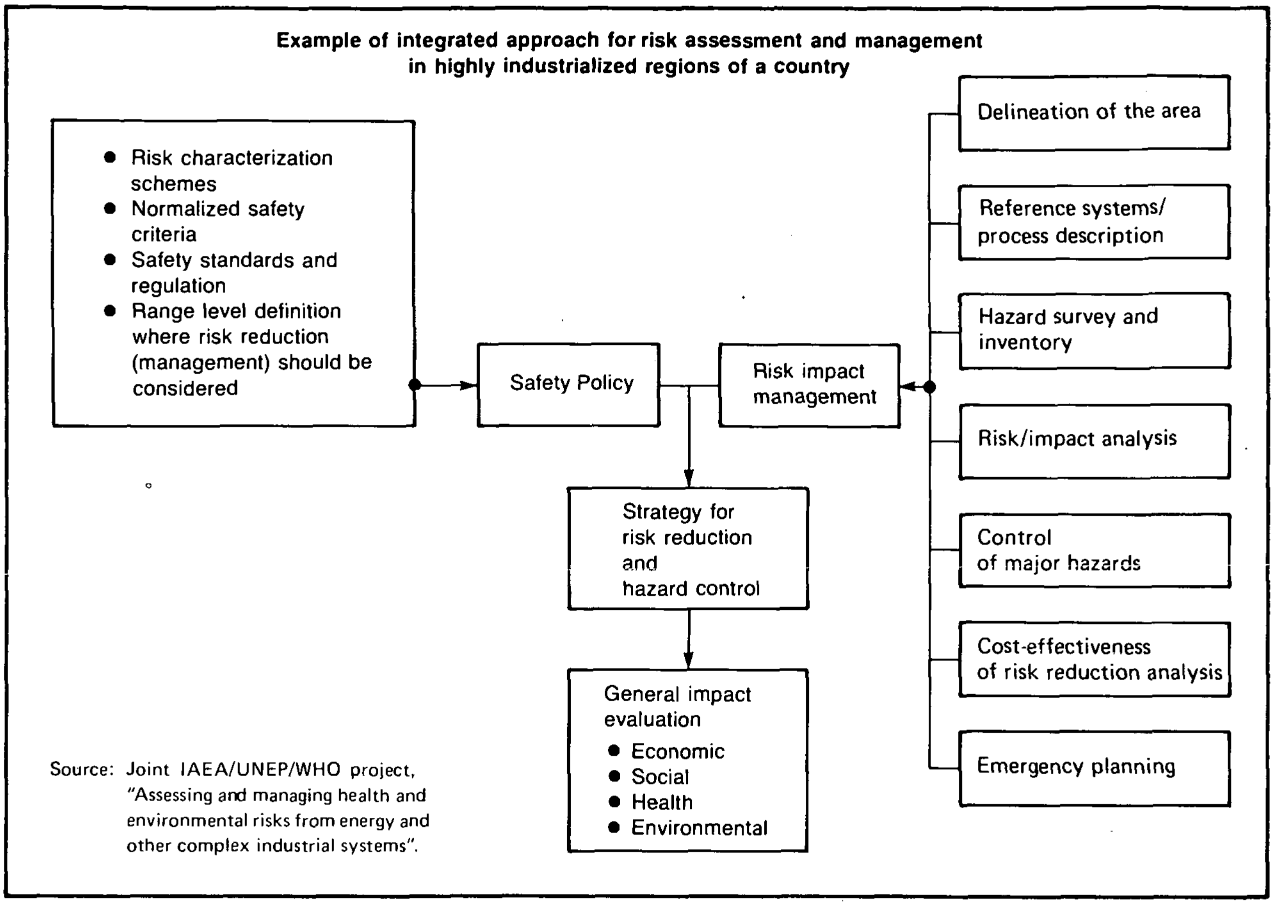
Costs and effectiveness of measures to reduce SO_2 emissions



FGD = Flue-gas desulfurization GFVO = Existing regulations enforced

Note: Analysis shows trade-off between SO_2 emissions and costs in Baden-Württemberg, Federal Republic of Germany. Source: IAEA-SM-273 (1984).

Shown are two examples of risk reduction curves related to the practical application of the cost-effectiveness approach in nuclear and coal energy systems.



Example of integrated approach for risk assessment and management in highly industrialized regions of a country

Source: Joint IAEA/UNEP/WHO project, "Assessing and managing health and environmental risks from energy and other complex industrial systems".

environmental consequences are calculated, in terms of early and latent fatalities, early and latent illness, and economic costs, among others, taking into account possible weather conditions, population distribution, and land use. Results obtained are presented in terms of probabilities of occurrence and associated consequences. In addition, the probabilistic approach allows uncertainties of the analysis to be estimated and represented. The use of PSA is not limited to the nuclear industry. *(See the graphs on page 35.)*

It is very clear that such an analysis has merits on its own even without formal use. It improves the understanding of plant behaviour under abnormal conditions, of man-machine interaction, and of the relative importance of safety functions, systems, and components. It is an additional training tool and can be used for many purposes. They include designing operator computer aids or developing accident scenarios for simulator training. However, in addition to all these *qualitative* insights gained, PSA also provides *quantitative* estimates.

PSA cannot, of course, substitute for lack of knowledge, but it can help to identify information gaps. It is necessary and desirable that the best use is also made of these quantitative results. Toward this end, a set of probabilistic safety criteria (PSC) should be set, against which results of the PSA should be evaluated and the risk managed.

Movement toward integrated, regional approach

The recent history of catastrophic industrial accidents, such as Bhopal, Chernobyl, and, more recently, the chemical accident in Basel, Switzerland, has dramatically underlined the need to identify, assess, and manage risks from complex industrial activities to maximize safety and minimize detrimental effects to workers, the general public, and the environment. It is, therefore, necessary to develop an integrated approach for risk assessment and management in highly industrial regions of a country.

In the last few years, the attention of safety decision-makers in various countries and in several international organizations has been drawn to the need to identify and implement unified "safety policies" regarding the risks from technological activities.

The Commission of the European Communities (CEC) has adopted several "directives" related to major hazard installations, air pollution from industrial plants, and other risks. The main purpose is to develop in European countries a common policy for managing high risk/impacts for industrial installations, which for technical and economic reasons are generally concentrated in defined regions of a country.

Several industrialized countries — the USA, France, Federal Republic of Germany, Netherlands, Sweden — have in recent years implemented specific risk assessment research case studies in large industrialized areas.

Therefore, quantitative risk analysis, with emphasis on risk management, has become an important aspect in high-level decision-making for regulation and protection of public health and environmental impacts.

At the plant level, risk management cannot resolve the complex and multiple objectives of the decision-making process related to environmental impacts, health, and socio-economic effects. This assessment and management should be broadened to include regions where different industrial facilities are located and different targets of risk reduction are considered. The Chernobyl and Basel accidents have demonstrated that such regions may cover areas belonging to different sovereign States. For instance, the definition of emergency plans (an important part of a risk management process) in industrialized areas has to be structured so that the plans are flexible and able to cope with all severe accidents that might occur in that region.

Joint IAEA/UNEP/WHO project

A policy of risk management implies the definition of quantitative safety criteria and standards, development of guidelines and procedures, and development of a rational tool for optimizing policy decisions on the allocation of safety funds. The regional approach, therefore, seems to be the most appropriate for managing complex problems of technological risk management. In this regard, the IAEA has joined the United Nations Environment Programme (UNEP) and the World Health Organization (WHO) in initiating a joint project on the assessment and management of health and environmental risks from energy and other complex industrial systems. *(See chart on page 37.)* The approach is integrated and based on the principle of optimal allocation of resources for risk reduction, taking into account the complex and multiple objectives of the decision-making process involved. This new research effort will be conducted through the implementation of case studies in developed and developing countries. It seeks to establish a unified systematic procedure for risk decision-making in highly industrialized areas of countries.

The project has four main activities:

- Development of a guide to procedures for risk management and hazard control, drawing on results from a number of case studies that will be carried out in Member States
- Establishment and operation of a system for the collection, evaluation, and distribution of information concerning methods and, as required, health and environmental effects
- Training of personnel in risk management and hazard control
- Promotion of an approach to risk management and hazard control, and procedures for the planning of energy production and use, and of other complex technologies at the national level.

Atucha-I in Argentina, a 692-MWe nuclear plant.

Nuclear power in developing countries (as of 31 December 1986)

	Reactors in operation		Reactors under construction		Reactors planned	
	No. of units	Total net capacity (MWe)	No. of units	Total net capacity (MWe)	No. of units	Total net capacity (MWe)
Argentina	2	935	1	692	2	NA
Brazil	1	626	1	1245	1	1245
Bulgaria	4	1632	2	1906	2	1906
China	—	—	1	288	2	1800
Cuba	—	—	2	816	—	—
Czechoslovakia	7	2799	9	5508	—	—
Egypt	—	—	—	—	2	1000*
Hungary	3	1235	1	410	2	1900
India	6	1154	4	880	4	880
Iraq	—	—	—	—	1	400
Iran, Isl.Rep.of	—	—	2	2400	—	—
Korea, Rep. of	7	5380	2	1800	2	1800
Libyan, Arab Jamahiriya	—	—	—	—	2	816
Mexico	—	—	2	1308	—	—
Pakistan	1	125	—	—	1	900
Poland	—	—	2	880	10	8430
Romania	—	—	3	1980	1	660
Taiwan, China	6	4918	—	—	4	4120
Thailand	—	—	—	—	1	900
Turkey	—	—	—	—	1	NA
Yugoslavia	1	632	—	—	1	1000

NA = Not available.

* Capacity of one unit only.

Source: IAEA PRIS