The Critical Issue of Nuclear Power Plant Safety in Developing Countries

by Morris Rosen

A little more than a decade from now, large commercial nuclear power facilities will be in operation in almost 40 countries, of which approximately one-half are presently considered industrially less developed. Ambitious nuclear programmes coupled with minimal and frequently under-staffed regulatory and utility organizations are only one aspect of the difficulties related to the safety of nuclear plants that face these developing countries. Inherent problems of meeting current safety standards and requirements for the significantly non-standard nuclear power plant exports can be compounded by financial considerations that may lead to purchases of reactors of various types, from more than one supplier country and with different safety standards and requirements.

An examination of these issues points to the necessity and opportunity for effective action which could include provision for adequate funding for safety considerations in the purchase contract, and for sufficient regulatory assistance and training from the developed countries. The article will introduce the topic, discuss specific examples, and offer some suggestions.

BACKGROUND

As shown in Figure 1, commercial nuclear power plants are now in operation in 19 countries. Of these only four are considered to be industrially less developed. Recent forecasts indicate that by the year 1990 there will be operating nuclear power facilities in at least 37 countries, 18 of which are presently considered less developed. By the year 2000, the total number of countries could reach 50 without taking into consideration the even greater market potential if economic reactors of less than 400 MWe become available.

Although subject to some uncertainties, estimates of nuclear power capacity project that by 1990 a total of about 100,000 MWe will be generated from 125 to 150 nuclear plants in the less industrially developed countries (including those of the CMEA) out of a world total of 800,000 MWe from 900 plants. Forecasts of the ambitious nuclear programmes for some representative countries are shown in Figure 2.

THE NON-STANDARD NUCLEAR POWER PLANT EXPORTS

Countries embarking on nuclear programmes are presently limited to nuclear systems available from six national suppliers, with three major reactor types, as shown in Figure 3. The gas-cooled reactor as well as the fast-breeder reactor are potential future export reactor types. Three countries, India, Japan, and the United Kingdom, supply their domestic nuclear markets but do not presently export.

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Figure 1: Countries with Operating and Projected Commercial Nuclear Power Plants

1975	Argentina	Japan
	Belgium	Netherlands
	Bulgaria	Pakistan
	Canada	Spain
	Czechoslovakia	Sweden
	France	Switzerland
	Germany, Dem. Rep.	UK
	Germany, Fed. Rep.	USA
	India	USSR
	Italy	
1980	(Additional Countries)	
	Austria	Mexico
	Brazil	Taiwan
	Finland	Yugoslavia
	Korea, Rep.	
1985	(Additional Countries)	
	Hungary	Poland
	Iran	Romania
	Luxembourg	South Africa
	Philippines	
1990	(Additional Countries)	
	Egypt	Thailand
	Israel	Turkey

Figure 2: Representative Nuclear Power Capacity in 1990

Country	MWe	Number of Plants
Brazil	11 000	15
Iran	16 000	15
Korea	7 000	10
Spain	27 000	35
Taiwan	9 000	10
Yugoslavia	4 000	5
Less Developed Total	100 000	125
World Total	800 000	900

Figure 3: Currently Available Export Reactor Types

Exporter	Reactor type
Germany, F.R.	Pressurized-Water Reactor (PWR)
France	Pressurized-Water Reactor
USSR	Pressurized-Water Reactor
USA	Pressurized-Water Reactor Boiling-Water Reactor (BWR)
Sweden	Boiling-Water Reactor
Canada	Heavy-Water Reactor (HWR)

Figure 4: Examples of Reactor Purchases

Purchaser	Supplier	Reactor Type
Argentina	FRG, Canada	HWR
Brazil	USA, FRG	PWR
Finland	USSR, Sweden	PWR, BWR
India	USA, Canada, India	BWR, HWR
Iran	FRG, France	PWR
Korea	USA, Canada	PWR, HWR
Spain	USA, FRG, France	PWR, BWR, GCR

Although uranium supply considerations are of importance in the quest for nuclear power, the availability of financing for these high capital cost projects may be the determining factor in deciding the supplier country. Figure 4 indicates for some countries the various combinations of supplier and reactor type for existing and future facilities. The differences in the facility design that must obviously occur among these combinations is, however, only one aspect of the non-standard nuclear export. More surprising and of more importance are the differences between the domestic plants of the supplier countries and the supposedly similar facility that is constructed in the importing country.

Comparisons of exported nuclear plants with the corresponding domestic model point up at least four major causes for the differences in the fully constructed plants. These differences are due to the usually lower power of the export reactor, dissimilar site characteristics, balance of plant considerations, and the continuous evolution in design and safety requirements within the supplier state.

Reactor Size. The major reactor or nuclear-steam system suppliers are from the highly industrially developed countries whose domestic needs for power are more easily satisfied by reactors of large output. Thus, in the past several years only reactors approximately 1000 MWe or larger have been ordered by domestic United States utilities, and there is little likelihood that significantly smaller output reactors will be ordered in the future. In contrast, the nuclear plant exports of the United States have been in the range of 600 and 900 MWe facilities.

It is common practice to reference an exported reactor facility to a similarly sized plant under construction in the country of origin e.g., an exported 600 MWe, 2-loop, PWR reactor would be referenced to a supposedly similar 2-loop domestic plant. This referencing procedure has and continues to imply that the reference plant meets the safety requirements of the exporting country and therefore can be licensed. However, in the United States, as a result of the demand for larger reactors, there is at present no 2-loop plant of the type being exported under construction, the most recently constructed plant having been operational for 2 years. Thus, the recent 2-loop reactor plant sold to Egypt, Korea, and the Philippines, is referenced to a 2-loop plant under construction in Yugoslavia since 1974. This plant in turn had been referenced to an earlier 2-loop plant under construction in Brazil, which in turn had been referenced to a domestic plant in Puerto Rico for which a construction application was submitted to the U.S. regulatory organization in 1970.

However, the review of the Puerto Rico plant was terminated in late 1972 because of seismology problems at the site, and it was determined not to continue with the project. If the Puerto Rico plant had been constructed, it would have undergone a systematic and detailed review by the U.S. regulatory organization and as a result of this review and the additional requirements that would probably have been imposed during the design and construction stage, a number of modifications would undoubtedly have been made to the facility. Thus, all of the previously mentioned exported 2-loop plants have not undergone a rigorous regulatory review, and modifications that might have been required are not available for consideration.

Site Characteristics. In contrast to the previous example, the two large 4-loop PWRs sold to Iran by the Federal Republic of Germany could be referenced to a recent domestic plant of similar size presently under construction and undergoing the regulatory process in the Federal Republic of Germany. However, although there is a reference plant of similar size currently being reviewed domestically, this is an appropriate example to demonstrate the importance of site characteristics in the facility design. The plant in Iran is located in a relatively high seismic area requiring the use of a design value of 0.5 g for the horizontal ground acceleration in contrast to the relatively low value of 0.2 g or less required in the low seismic areas of Germany. The difference in seismic design requirements can result in significant design changes in the nuclear facility; changes that influence the foundations, interface of structures, pipe requirements, supports, and system components (including reactor internals). Thus, the eventual design of the Iranian facility as constructed may have some significant differences from the domestic reference plant, and these modifications will not have undergone a detailed review by the regulatory bodies of the FRG. The differences in requirements and design necessitated by seismic considerations are of growing importance as reactors are increasingly located in high seismic areas.

Balance of Plant. A third aspect of the non-standard and unreviewed nuclear export relates to the balance of plant (BOP) which comprises the facilities outside the nuclear-steam supply system such as the containment structure, auxiliary buildings (including in some designs the fuel handling and rad-waste systems) and the steam conversion system (turbine generator). Even in a "turn-key" export contract where the reactor supplier assumes overall project responsibility to supply and build the entire facility, the design and construction of the balance of plant including the reactor containment will frequently be performed by a different architect-engineering firm and one which may not have had the responsibility for the domestic facility. Financial arrangements may also require the purchase of major portions of the BOP from a country different from that of the reactor supplier. This general situation of different architect-engineering firms, and differences in BOP suppliers not only introduces obvious interface problems including the use of varying design criteria and safety requirements, but also may result in the use of components and systems that differ materially from those being constructed or in operation and reviewed in the country of origin.

Evolution. The fourth and possibly most important aspect of the non-standard and unreviewed nuclear power plant export is the constant evolution in design and safety requirements brought about by improvements in techniques and by the regulatory review process in the exporting country. This process can result in a myriad of changes including major modifications in, for example, structural supports, automatic actuation systems, rad-waste system requirements,etc. Within the supplier countries, all domestic nuclear facilities have undergone many required modifications and changes as a result of the regulatory review process. However, these changes are not necessarily incorporated into the exported plants.

Thus the above discussion of the causes for the non-standard nuclear power plant export indicates that developing countries purchase facilities that, as constructed, have significant differences from the domestically built facilities of the supplier country, and that have not undergone the required and detailed regulatory review process associated with the licensing and construction of the reference facility.

NON-UNIFORM SAFETY STANDARDS AND REQUIREMENTS

Safety standards and requirements are basic for the design, construction, and operation of nuclear facilities and are the codification of sound engineering practice and experience. When establishing nuclear safety standards and requirement in an importing country, the choice will essentially consist of using the available standards of the importing country, international standards, or those of the exporting country. Since standards are associated with industrial undertakings, the developing countries usually do not have a base of engineering related standards, and certainly no specific nuclear standards. International standards are being developed, including a large safety standards programme at the IAEA, but their general application and use in the nuclear field may still be many years in the future. Although somewhat of an over-simplification, the importing country, especially the developing countries, must almost of necessity adopt the standards and requirements of the exporting country.

This situation, however, is complicated by four significant factors. These are the different number and extent of written and codified standards of the various exporting countries, the continuous development and evolution of standards and requirements, the differences in content and of application, and the non-applicability of some standards.

Number and Extent of Standards. The various supplier countries have significantly different numbers of written and codified standards. This is somewhat related to the structure of the electric utility industry. The multiple utility countries such as the USA and the FRG have significantly more written requirements than the essentially single but also technically strong utility countries such as the United Kingdom and France. In the case of reactors purchased from the less codified exporting countries, the developing countries have the obvious problem of determining what the requirements are, whether they are being met, and thus whether the design and construction is similar to that of the domestic facility. The problem is further complicated when significant portions of the balance of plant are supplied by different countries with differing numbers of codified standards.

Development and Evolution of Standards. The development and evolution of codified safety standards and requirements creates an additional and more difficult problem for developing countries. In the USA, the Nuclear Regulatory Commission has over the past 4 years issued approximately 300 regulatory guides which describe acceptable methods of meeting NRC regulations. The FRG has a large programme to clarify its requirements, and a large number of standards are being prepared. Several problems exist for the developing countries as a result of this situation, most importantly the determination of whether the plant meets the newly codified standards and whether the plant requires updating to these standards by "backfitting" to meet special requirements.

Differences in Content and Application. There are also differences in application of specific standards among the exporters, as well as differences in content. Differences in application arise from differing judgements as to how to satisfy specific criteria. For example, to protect a safety system from damage by a missile arising from a given piece of equipment, one could prevent the generation of the missile by designing and constructing the equipment to very high standards, prevent the missile from hitting the safety system by shielding or locating the safety system so that it is not in direct line of the missile, or prevent damage to the safety system by adequately strong construction, safe location, or by providing well separated redundant systems. The variations in judgement have led to differences in requirements such as redundancy and separation of emergency core cooling systems, the use of containment spray systems, and missile shield requirements.

Specific standards also differ in content as demonstrated by differences in the USA and FRG standards for the required structural accident load combinations, fission product release quantities during accidents, and allowable stress values used in the containment design. This leads to significant design differences e.g., the use of containment spray additives for iodine removal and most notably the containment design as seen in the FRG double containment which would not meet USA requirements as constructed. The result of the above is to leave the developing countries with an insufficient understanding of the reasons for many safety decisions, as well as difficulties in making updating or backfitting decisions. The difficulties are exacerbated when purchases are made from more than one supplier country.

Non-Applicability. A final aspect of standards and safety requirements in the non-applicability of some standards, for example, if there is a requirement for fire or construction inspectors who may not exist in a developing country, or if there is a requirement for information such as historical seismic or flood data which are not available.

WEAKNESS OF REGULATORY ORGANIZATIONS

In view of both the non-standard nuclear power plant exports and the non-uniform safety standards and safety requirements, an appropriate safety concern is the adequacy of the regulatory organization in the developing countries. In performing its review and inspection function, this organization must make decisions on numerous modifications and interfaces that have not been reviewed by the regulatory authority of the exporting country. Additionally, it must also be concerned with safety issues somewhat unique to developing countries, which will subsequently be discussed.

Regulatory organizations of the exporting countries have highly trained and experienced staffs drawn from the numerous technical disciplines required to review and inspect nuclear facilities during siting, design, construction, and operation. This is in addition to the expertise of independent consultants and other organizations which are used wherever appropriate. For example, the U.S. Nuclear Regulatory Commission with approximately 1000 professional staff members nearly all of whom hold a college degree and more than half hold advanced degrees, comprises one of the broadest spectra of technical and scientific disciplines in the U.S. government.

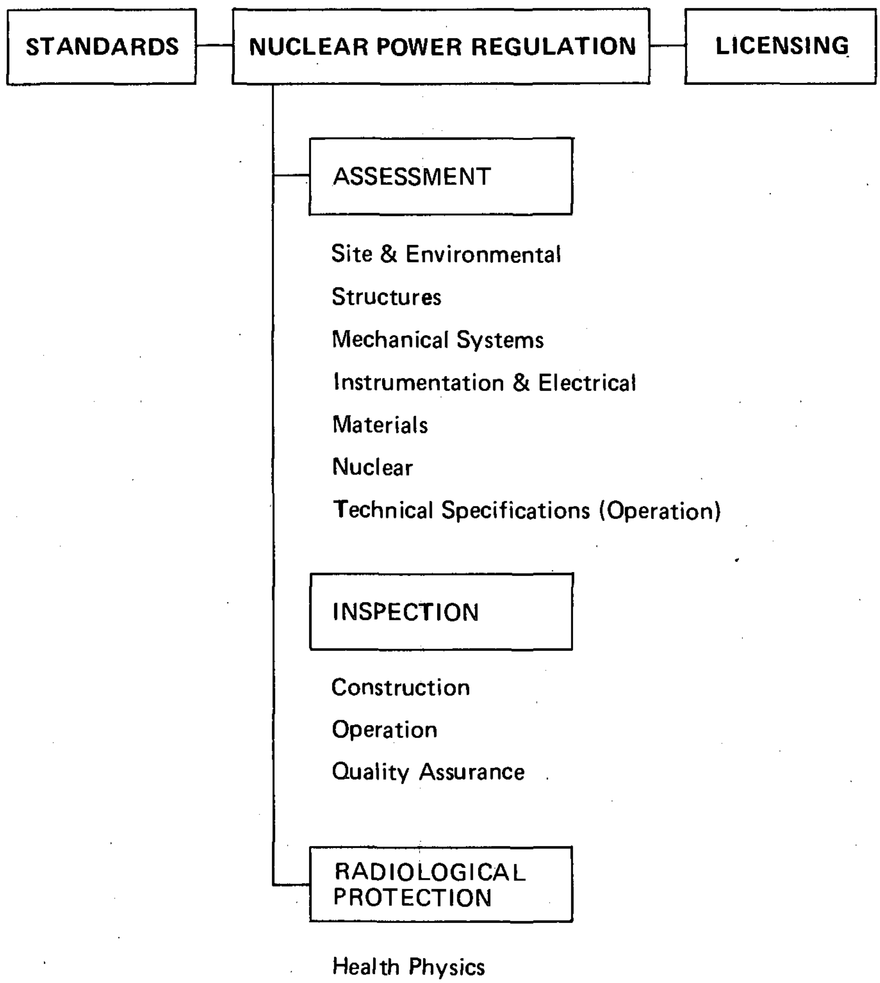
Obviously a developing country does not need a staff of the size or with the range of disciplines required in the exporting country. However, experience in countries with ongoing programmes suggests that even when extensive use of consultants is planned, a full-time regulatory staff of about 50 professionals may be the minimum for a country planning to licence and operate 5 to 7 nuclear power plants. The essential requirement is that the regulatory body possess sufficient competence to independently evaluate the work performed by the suppliers as well as by its own consultants. Figure 5 shows a minimum regulatory organization with the minimum number of experts that must be available. This indicates that with only one individual for each functional requirement, an experienced staff of approximately 15 is required. At the present time, with little exception, the regulatory organizations of developing countries with active nuclear programmes can be classified as sub-minimal. In many cases they consist of less than 15 full-time staff members associated with nuclear power activities. This minimal staff may not be familiar with the disciplines of nuclear safety and may be in need of extensive training.

The difficulties of staffing these regulatory organizations are partly the result of the responsible government officials not recognizing the importance of the regulatory organizations' role in coping with the unreviewed aspects of the imported nuclear facility. This is exacerbated by the general shortage of experienced manpower and also the low pay scale of government employees, a situation which attracts young and inexperienced staff who after training leave for higher paid jobs in industry.

UNIQUE SAFETY ISSUES

In considering the essentially unreviewed nuclear power plant export one must also note the safety issues that are somewhat unique to developing countries. An awareness of these

Figure 5: A Minimal Regulatory Organization



unique siting, design, construction, and operation considerations adds emphasis to the need for an adequate regulatory review.

In the initial siting evaluation, developing countries may be faced with political and military considerations which limit the number of available sites. Although this should increase the need for careful site studies, financial and time limitations may not allow for adequate investigations. The use of domestic and occasionally of foreign consultants inexperienced in nuclear applications may be complicated by the existence of only limited historical data in the seismology and hydrology areas. In addition, calculational models that have been developed for temperate climates (e.g., atmosphere dispersions and rainfall models) may not apply to particular site locations in developing countries.

The achievement of a safe design for a nuclear power plant imported into a developing country is frequently complicated by a contract specifying that the plant will be built to the licensing requirements existing in the exporting country as of some cut-off date. This date typically pre-dates the actual start of construction by several years and as in the case of some recent reactor sales, may pre-date expected commercial operation by as much as 10 years. In the exporting country with its strong regulatory body, the design of such a facility would normally be modified and updated through the review process. In the importing country, however, these modifications would usually not be required by the local regulatory staff which would not, in general, be aware of the changing standards in the exporting country, nor would it be technically competent to decide upon the updating and backfitting needed. In addition, part of the plant may be designed after construction has begun using new safety standards, and so the plant design is then based on a mixture of standards which are difficult to clearly differentiate.

The design area is also complicated by the difficult balance of plant interfaces, a situation which can be exacerbated by the use of several supplier countries. In addition, different design safety considerations may also be necessary if unique seismic, temperature, humidity, and electric load instability conditions exist.

Although construction in a developing country has the normal difficulties associated with large projects such as problems with contractor interfaces, it may also be affected by poor domestic subcontractor performance, and the greater potential for shipping damage to equipment. Unexpected problems may also require rapid decisions that are difficult when some of the decision-makers in the exporting country may be thousands of miles away. Futhermore, the quality assurance programme required for nuclear projects is greatly complicated by the mixture of domestic and foreign contractors, all with differing or non-existing quality control and assurance procedures.

Operation of the facility may raise safety issues due to the minimal training of staff in areas such as maintenance. For example, in some circumstances supplemental staff may be required and not be readily available in countries without a large infrastructure of trained personnel. A more important consideration is the pressing need for power in the developing countries which could lead to operation under conditions during which operation should be limited or not permitted. This consideration is magnified in importance by the lack of technical experts in the regulatory body competent to make expeditious decisions, especially those related to a return to power or limitation of power when operational safety conditions are exceeded.

SUGGESTIONS

The issues presented in this article indicate a need for effective action. First, and of prime importance, is the necessity to bring about an awareness on the part of the exporter as well as the importer of the unique demands of nuclear power plants and the unique problems of developing countries, so that the readiness of a developing country to embark on a nuclear power programme can be assessed in terms of the known prerequisites. Secondly, adequate consideration must be given during contract negotiations to plant safety, most importantly the selection of an appropriate cut-off date for standards and safety requirements. This date should as a minimum correspond to the anticipated date for start of construction. Funds must also be provided in the contract for potential updating and backfitting as well as for training of regulatory personnel.

Thirdly, the exporter must continuously advise the purchasing utility and the regulatory body of changes in the design and safety requirements during construction so that they can receive proper attention. At the same time, the export government, in addition to providing training opportunities at its own regulatory body and with reactor suppliers and architect-engineering firms, should supply direct regulatory assistance including full-time resident experts, perhaps by making them available through the technical assistance programme of the IAEA.

Finally, the IAEA should continue its programme of safety missions by qualified experts to review the safety of nuclear power facilities in developing countries. This will complement the already existing technical assistance programmes and training courses, and the Agency's development of international nuclear safety standards.