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# TECHNOLOGY TRANSFER: THE CANDU APPROACH

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**Abstract**

The many and diverse technologies necessary for the design, construction licensing and operation of a nuclear power plant can be efficiently assimilated by a recipient country through an effective technology transfer program supported by the firm long term commitment of both the recipient country orgnizations and the supplier. AECL's experience with nuclear related technology transfer spans four decades and includes the construction and operation of CANDU plants in five countries and four continents. A sixth country will be added to this list with the start of construction of two CANDU 6 plants in China in early 1997. This background provides the basis for addressing the key factors in the successful transfer of nuclear technology, providing insights into the lessons learned and introducing a framework for success. This paper provides an overview of AECL experience relative to the important factors influencing technology transfer, and reviews specific country experiences.

## 1.0 OVERVIEW

The diverse technologies encompassed by the construction and operation of a nuclear power plant can be assimilated by a country through an effective technology transfer program supported by the firm commitment of both recipient and supplier. AECL's experience with nuclear-related technology transfer spans four decades and includes the construction of CANDU plants in five countries. This background provides the foundation for addressing the key factors in nuclear technology transfer; providing insights into the lessons learned and introducing a framework for success.

### Key Factors in Successful Nuclear Technology Transfer

While the receiving nation, the owner of the power plants and the supplying nation, are all instrumental in creating a successful environment for technology transfer, each has different objectives. The technology that is transferred encompasses a wide range of skills and disciplines. To transfer the applications oriented technology ("know-how") along with the intellectual skills ("know-why") requires motivated people supported by a well-developed educational infrastructure that addresses their specific needs. A nuclear R&D organization is an asset since it provides good experience to staff, preparing them for the nuclear power program and helping them keep abreast of new technology. Acquiring nuclear technology is a long-term process. It is, therefore, advantageous to concentrate on those technologies that offer either significant business opportunity or have application in other sectors of the economy.

### Lessons Learned

A number of factors contribute to successful technology transfer including

- the availability of well-educated and skilled workforce;
- an effective training program that is coupled with an opportunity to put learned skills into practice before they are forgotten;
- the selection of appropriate technology suited to the local manufacturing environment;
- establishing the importance of nuclear safety and quality within the infrastructure of the receiving nation;
- effectively managing conflicting objectives and being able to recognize the costs associated with on-the-job training.

Finally, it is important to precisely define the scope of the technology and the transfer process and establish an organization to coordinate the program.

**A Framework for Success**

A framework comprised of five essential components will facilitate the demanding task of transferring nuclear technology. First, there must be comprehensive planning to address objectives, realistically examine capabilities and most importantly identify any gaps. Second, experience shows that establishing a lead agency to coordinate the technology transfer enhances the chance of success. Third, a firm commitment of human and financial resources must be made within the scope of the technology transfer program. Fourth, due to its large scope and diversity the program requires firm management. Fifth, success largely depends on establishing a relationship between the parties that is based on trust and mutual respect.

## 2.0 Introduction

Not only is the transfer of technology a major feature of contemporary international trade but it is also a fact of life in the sale and acquisition of nuclear power plants. Because of the many facets of nuclear technology, planning and managing its acquisition is of great importance.

From the early beginnings of the development of the peaceful uses of nuclear power by only a few nations in the mid-1940's, there has been a considerable transfer of technology. Today, 34 countries have nuclear programs at various stages of development. Canada, one of the early leaders in the development of nuclear power, has experience with a wide range of technology transfer programs spanning four decades.

Canada, itself a country without a well-established, large-scale industrialized base at the start of its nuclear power program, has developed a autonomous nuclear industry. This has been accomplished through a consistent transfer of appropriate technology to industry and utilities.

In Canada, Atomic Energy of Canada Limited, Ontario Hydro, a provincial utility, and Canadian General Electric, a private sector manufacturing company, shared in the early development of the CANDU nuclear power system. The technology established, enhanced where necessary through cooperative exchanges and programs with other countries working in the field, was disseminated to existing Canadian industry. This "internal" technology transfer was essential to the establishment of a competent and self-sufficient nuclear industry.

As the nuclear program developed, the CANDU technology was passed to other utilities. Canada has participated or is participating in the construction of nuclear power plants in five countries including India, Pakistan, Korea, Argentina and Romania, and has built high-powered research reactors in India, Taiwan and Korea.

The extent and nature of the technology transferred has varied from country to country. Through agreements with many industrialized countries, for example, the UK, USA, Sweden, France, Italy and Japan, information and technology have been exchanged with mutual benefits. It is from this experience that AECL offers some comments on the factors which are important to the success of such programs.

## 3.0 Major Factors In Technology Transfer

### 3.1 Why Transfer Technology?

Figure 1 illustrates the major factors influencing the transfer of nuclear technology in terms of scope, process, needs and resources. The environment within which the process must operate and succeed is created by the three major participants: the receiving nation, the owner of the power plants which are to be built and the supplying nation.

The national government, particularly in a developing country, looks to technology transfer as a mechanism for industrial and economic development. Eventually, it becomes a means of assuring a high degree of autonomy and security in the provision of a major energy source. The owner of the plant is primarily interested in the supply of electricity from generating plants built to a short schedule and at as low a cost as is consistent with safe, economic and reliable operation. The supplier nation is usually prepared to transfer its technology. This will enhance its market opportunities and the sale of both nuclear power plants and associated technology and provide some return on its investment in research and development.

## 3.2 What Technology Is To Be Transferred?

Technology can be defined as the ability to do something. Technology, therefore, encompasses the technical and managerial "know-how" embodied in both physical and human resources. Nuclear technology encompasses a wide range of skills and disciplines and involves many sectors of the economy.

A broad-based nuclear industry would cover, for example,

- regulatory licensing;
- the complete fuel cycle, from uranium exploration through fuel fabrication to eventual disposal;
- engineering design and development;
- heavy water production, if required;

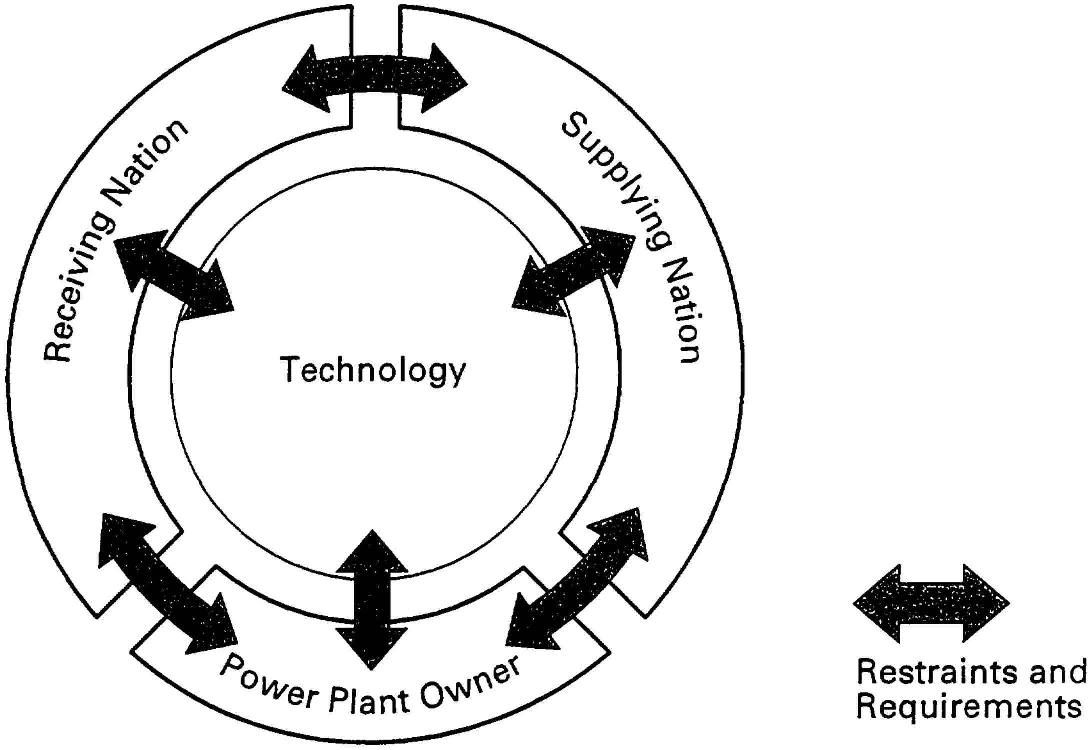


**Figure 1 The Technology Transfer Environment**

- construction technology;
- project and construction management;
- supporting research and development;
- component or equipment manufacture; and
- commissioning and operation of nuclear power plants.

Figure 2 illustrates the essential range of technology involved. The more application-oriented technology often termed "know-how" is associated with physical training in terms of manipulative skills. Where analytical capability related to decision-making and innovative thinking is involved and understanding of the reasoning behind the technology is necessary, the "know-why" is as essential as the "know-how". Here, the training is more intellectual in nature and is in effect an educational process.

The type of training necessary to assimilate the technology also determines the educational background required. The more physical training programs require less prior formal education whereas those individuals who will acquire the "know-why" will most likely have received university or technical college training.

### 3.3 What Are The Priorities?

Each nuclear power plant requires an investment of over a billion dollars and the human resources employed in the design, manufacture, construction and operation of the plant may well exceed 5000 at the peak.

The introduction of nuclear technology in any country requires the development of a sufficient number of trained personnel covering a wide range of disciplines at various levels. In addition, depending on the extent of the technology transfer envisaged, sufficient funds will also be necessary for investment in the required facilities.

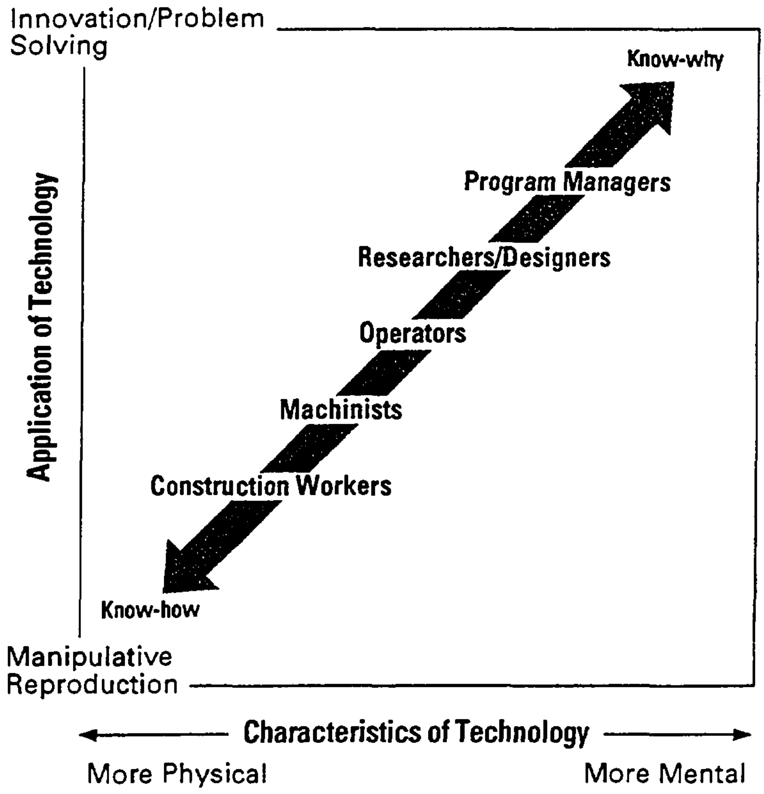


**Figure 2 The Scope of Technology Transfer**

The acquisition of the diverse nuclear technologies is a long term process spanning, in most cases, the construction of several nuclear plants. Clearly, it is advantageous to concentrate on those technologies for which there is significant business, even if only one or two plants are being built, or on those which also have application in other sectors of the economy.

There is some argument about the amount of technology which is essential to a nation for the introduction of its first nuclear plant. Clearly, some ability to license and regulate the industry is essential as is the ability to successfully operate and maintain the completed plant. Other areas of technology can then be introduced and developed at a pace and timing consistent with the nation's economic and industrial goals.

### 3.4 What Processes Are Involved?

It is essential that an appropriate infrastructure be in place to assimilate the technology. As a minimum an educational infrastructure will be required since the acquisition of even one plant requires high calibre professionals, technicians and skilled tradesmen to regulate, operate and maintain the plant. Even more trained people will be required as technology transfer programs are put in place because skilled people are the prime ingredient to their success.

In addition, it is Canada's expe
rience that the prior existence of a nuclear research and development organization is an asset to the technology transfer process. Such an organization is most useful in providing preliminary experience to professional and technical staff for future participation in the nuclear power program. This was, in fact, one of the key factors in Canada's own nuclear power development.

Furthermore, nuclear technology, as with any high technology, is continually evolving. One of the most important means of keeping pace with future advances in the supplier's country and throughout the world is an effective and competent research and development staff.

The actual process of transferring the technology will involve a number of activities such as the:

- provision of documents, drawings and computer codes;

These represent the physical embodiment of any technology.

- provision of training, in class-rooms and on-the-job; and

Acquisition of documentation alone is analogous to buying engineering textbooks and expecting to be an engineer without attending college or completing the course work. It is more likely that only key individuals will be fully trained and those will then be expected to pass on the knowledge acquired to their compatriots.

- undertaking of cooperative programs in areas of mutual interest.

It is an effective way of providing the basic understanding behind the technology ("know-why") and keeping abreast of technological developments.

### 3.5 How Are The Needs Of The Individuals Met?

The effective transfer of technology is highly dependent on people and their needs, shaped by different backgrounds, different cultures and various career objectives, have to be considered.

Most of those involved, however, will have already acquired skills and capabilities which will influence their attitude towards training. Hence, technology transfer is basically an adult education process.

Adults generally look for the fastest and easiest way of learning new skills and quickly tire of processes that are not well matched to their individual needs.

### 3.6 How Are The Resource Needs Met?

The technology transfer program should be realistic. However, it is likely that the parties engaged in technology transfer have never gone through the process before. Therefore, it will be difficult to precisely identify the resources at the start of the program. Proper monitoring and assessment checkpoints must be built-in to allow for the reallocation of resources to meet changing program needs.

AECL has found that receiving nations assign high quality staff at the start of the technology transfer program who, on return to their country, are key figures in their nation's nuclear program. Inevitably, they are then promoted and have progressively less time to directly apply the technology they have acquired. This "turnover" of staff creates a need for an ongoing program with new human resources entering each year. The process, once started, becomes ongoing.

## 4.0 Some Specifics About AECL's Experience

### 4.1 CANDU Technologies

Figure 3 summarizes the basic technologies involved in the design, construction and operation of a CANDU nuclear power plant. It also serves to illustrate the different interests of the national government, the utility and local industry.

The government has overall interest in all facets of the technology and, in most cases, will determine the expected degree and timing of the technology transfer. In particular, the government will be responsible for regulation and safety licensing. The utility, on the other hand, needs no other technology than that required to successfully maintain and operate the plant, that is, the upper half of Figure 3. Local industry, whether engineering design companies, constructors or component manufacturers, is likely to be only concerned with the technology needed to do the job. For the most part they are interested only in the results of R&D and not in the basic R&D itself.

### 4.2 Country Specific Examples

**CANDU In Korea**

The development of Korea's nuclear power program provides a clear example of the time taken to develop a nuclear industry with a high degree of national participation or self-sufficiency. The Korean program, Figure 4, is extensive. Already 14 nuclear power plants, with a combined capacity of 13 GWe, are in operation or under construction.

The first plants, KORI-1 and Wolsong-1, were purchased on an essentially turn-key basis. In the case of Wolsong, the Korean regulatory authority began to develop its skills in licensing and regulation with the assistance of Canada's Atomic Energy Control Board. In addition, the Korea Electric Power Company (KEPCO) operations and maintenance staff were trained at AECL and Ontario Hydro facilities and received further training and a deeper understanding of the system through active participation in the commissioning of the plant.

The initial plants acquired under turnkey contracts, provided little opportunity for local participation beyond construction and the areas of regulation and operation mentioned earlier. However, through technology transfer programs, each succeeding group of nuclear power plants has provided and will continue to provide opportunities for increasing levels of participation. Even so, it is expected that some three decades will have passed before the target of near self-sufficiency can be achieved. The learning curve for each activity sector will be similar to those illustrated in Figure 4.

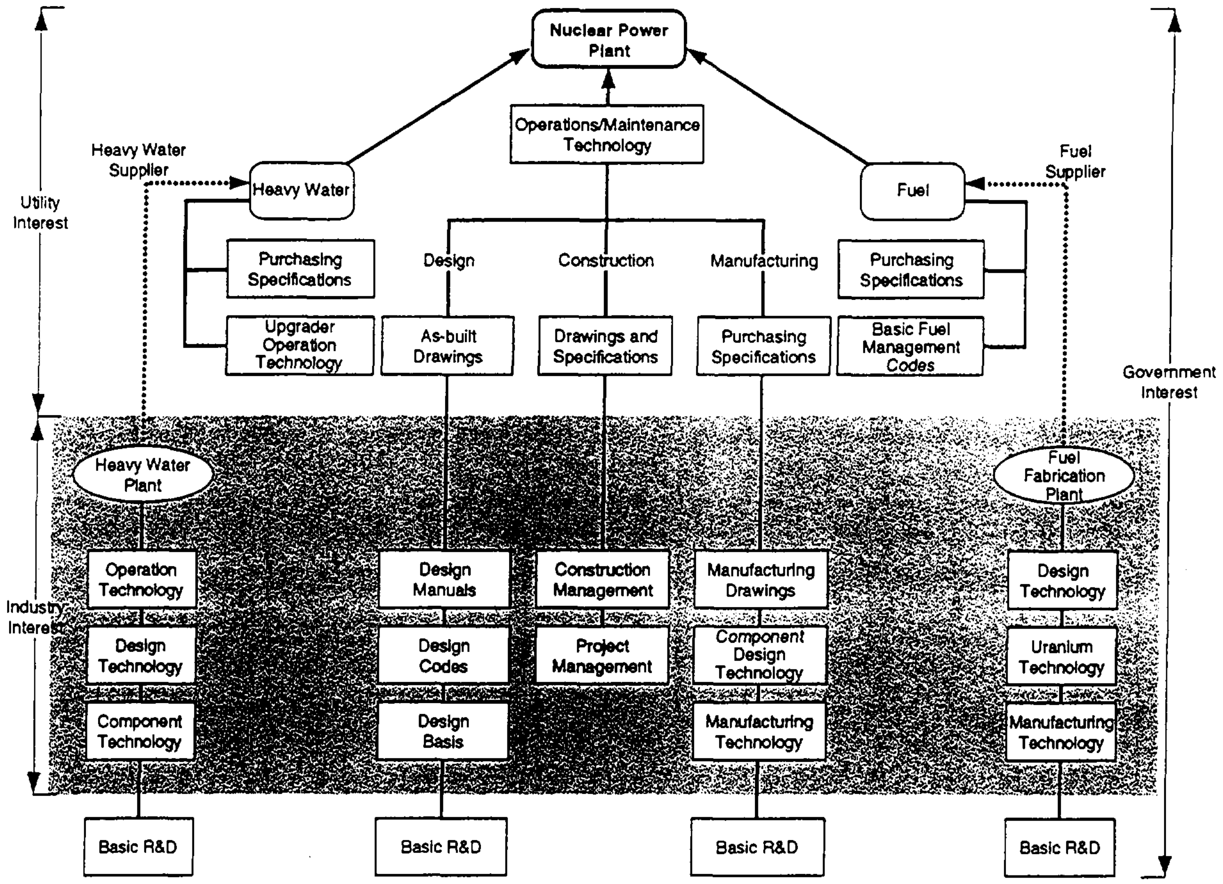


**Figure 3 Summary of CANDU Nuclear Power Plant Technology**

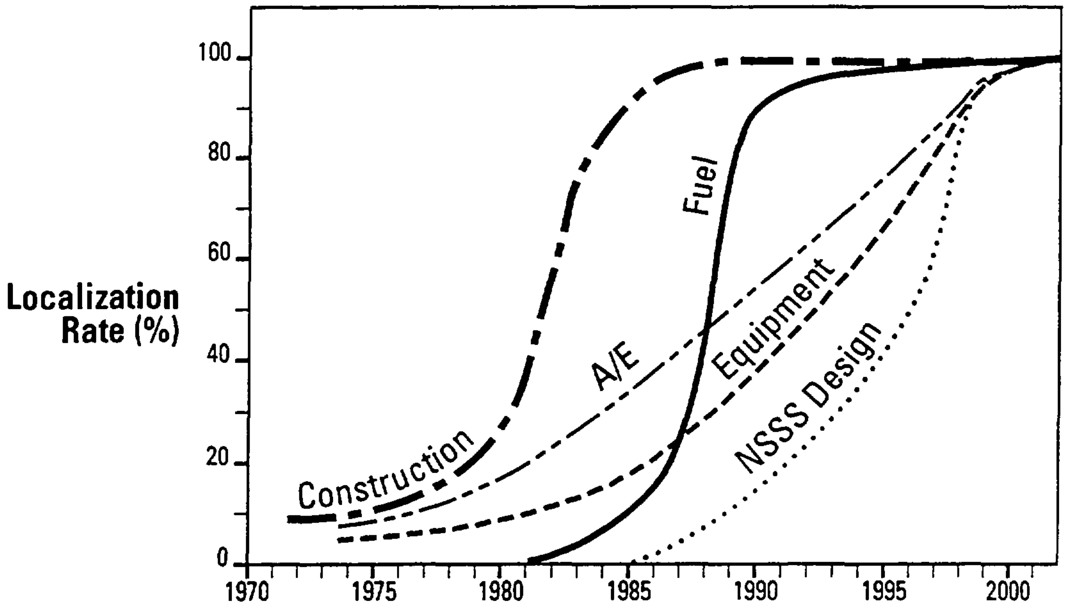


**Figure 4 Korean Nuclear Program: Increasing Local Participation Over Time**

Again using the Korean nuclear program as an example, the Korea Atomic Energy Research Institute (KAERI) has played a significant role in the Korean nuclear program with the acquisition of technology through cooperative agreements and its further development.

The following table identifies the increasing manufacturing localization for the Wolsong Units 3 and 4 project over what was achieved for the Wolsong Unit 2 project.

**Major Nuclear Equipment Localization In Korea**

| Wolsong Unit 2 | Wolsong Units 3 &4 |
|---|---|
| • Major Heat Exchangers | • Major Heat Exchangers |
| • Major Tanks | • Major Tanks |
| • Pressurizer | • Pressurizer |
| • Degasser Condenser | • Degasser Condenser |
| • Reactivity Mechanism Deck | • Reactivity Mechanism Deck |
| • Steam Generator (partial) | • Steam Generator (more) |
| | • Calandria (W4) |
| | • Feeder Header Frame |

**CANDU In Romania**

The Cernavoda site in Romania was developed for a five-unit CANDU station. Unit 1 is now in the final stages of commissioning. Figure 5 summarizes the progress in nuclear technology transfer in accordance with Romania/Canada contractual arrangements.

Many CANDU components were designed and manufactured in Romania by suppliers with no previous nuclear experience. Thus all Romanian components had to be certified for nuclear plant service in a stringent process of testing and verification.

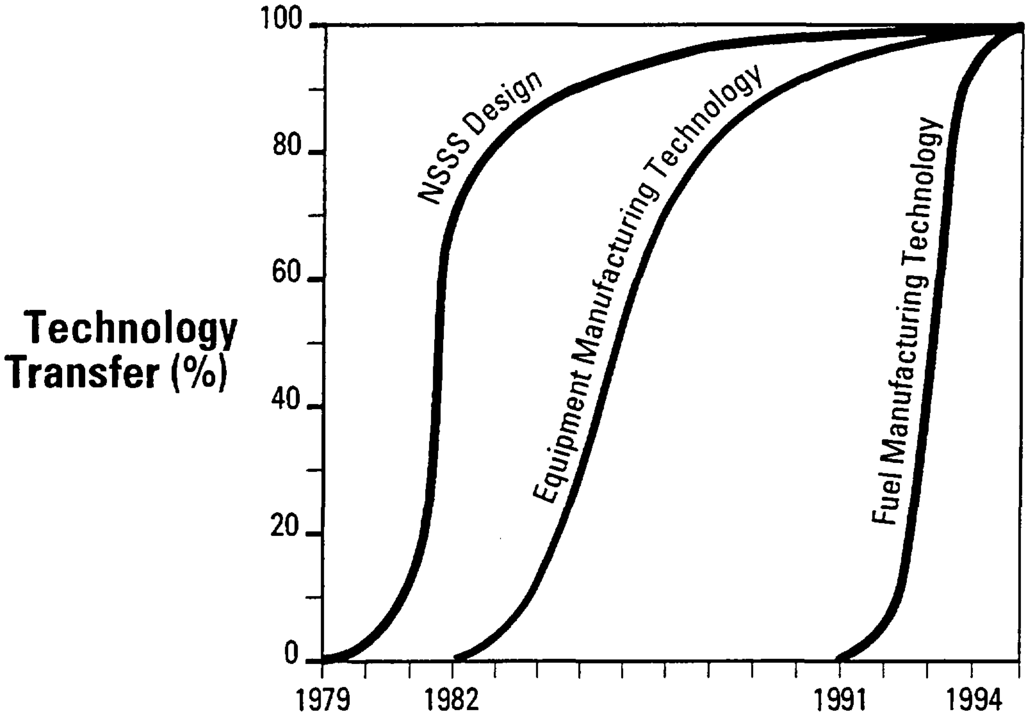


**Figure 5 AECL Transfer of Technology to Romania**

Small process equipment such as pumps, heat exchangers and valves went through certification in supplier facilities or in national laboratories. Other components such as 200 electric motors received final certification at the plant site.

The qualification of major equipment such as the Main Circulating Water Cooling Pumps and the Class III Stand-By Diesel Generators offered special challenges. Components with their characteristics and size had never been tested in Romania.

### 4.3 Lessons Learned

To date, AECL's experience in nuclear technology transfer has provided some insight into the factors that contribute to the success of technology transfer. Some of the lessons learned are:

- people are important;

Without the availability of trained personnel to interpret the documentation and implement the technology, the technology is of little practical value.

- training is essential;

Training is a necessary ingredient in technology transfer for not all the technology resides in documented form. Much of it can only be transferred through personal communication.

- practice is essential;

It is well recognized that on-the-job experience is one of the most effective ways of transferring technology. This, therefore, has been a cornerstone of all our technology transfer programs. However, if the technology once transferred is not put into practice but is put to one side to be addressed at a later date, the expertise that has been created will quickly dissipate and the technology will have to be relearned. This reinforces the argument that only those technologies of immediate interest should be considered.

- technology must be appropriate;

Experience indicates that adjustments in manufacturing techniques and equipment or in the skills demanded of labour will often be essential.

- there will be environmental differences;

The broader socio-economic-technological differences which influence the ways in which people behave and how work is achieved must be recognized. In nuclear technology transfer, the concepts of nuclear safety and quality have to be properly communicated and their importance clearly established within the nation's infrastructure.

- potential conflicts must be recognized;

It is likely that more than one objective will exist. For example, the use of local suppliers of equipment and services may appear to conflict with maintaining project schedules and overall costs. It is essential that both parties recognize the various objectives and reach an understanding regarding their relative priority.

- there may be cost impacts;

On-the-job training is an effective way to learn. However, this often extends the time taken to complete the job.

- misconceptions and misinterpretations will occur; and

Despite the best intentions of both parties, there will be misconceptions and misinterpretations about what is involved in or expected of the technology transfer. A very precise definition of the scope of technology to be supplied and the processes to be followed could minimize these problems.

- there is a need for a coordinating organization.

The reactor supplier does not control all the potential technology involved although it has access to it. Several companies, therefore, will be involved in the transfer of technology. In the receiving nation, many companies will be engaged each with its own interests and goals. The coordinating organization in the receiving nation will:

- ensure that the necessary infrastructure for providing adequately trained personnel is in place;
- determine priorities for the areas of technology to be transferred and ensure adequate allocation of funds and human resources;
- determine the most effective recipients who will receive and eventually develop the technology; and
- monitor and coordinate the actual technology transfer process.

## 5.0 A Framework For Success

Well over 100 billion US dollars have been spent in developing nuclear technology to its present state. Therefore, careful consideration should be given by all to building on the experience and expertise which exists in the world's nuclear community.

Experience has shown that the transfer of nuclear technology is a very demanding task requiring large commitments of both financial and human resources. Success in such a large undertaking can only be achieved if the right framework or environment is put into place. This framework will have several essential components:

Comprehensive National Planning. The receiver of the technology must carry out a thorough review of the objectives it sees for the technology transfer program, the present capabilities which can be applied to the development of a nuclear power program and more importantly the gaps which exist.

Organize To Develop Infrastructure. Experience shows that establishing a lead agency to coordinate the technology transfer enhances the chance of success. This agency will eventually put in place the complete infrastructure to support a nuclear power program.

Commit Resources. Within the scope of the technology transfer program decided upon, it is essential to make a firm commitment of both financial and human resources.

Firm Management. Because of the large scope and diversity technology transfer program in terms of resources, the program is a project in its own right which may equal the nuclear power plant project in terms of complexity and importance. Dedicated, effective and efficient project management by both receiver and supplier is imperative for program success.

Develop Relationships. The success of the program will depend on the will of both parties to succeed. In this respect, the development of relationships between parties which are based on mutual trust and respect is most important.