AECL-8906

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

TECHNOLOGY TRANSFER FROM CANADIAN NUCLEAR LABORATORIES

Transfert de technologie de laboratoires nucléaires canadien

R.D. MacDONALD, W. EVANS, J.R. MacEWAN and J.G. MELVIN

Presented at the Third International Conference on Nuclear Technology Transfer (ICONTT III) held in Madrid, Spain, 1985 October 13-18.

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

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Résumé

Le Canada a développé un système unique d'énergie nucléaire, le réacteur CANDU. En fournissant ses connaissances technologiques aux dessinateurs, constructeurs et opérateurs du réacteur, la Compagnie de la Recherche de l'EACL (CR-EACL) a joué une rôle majeur dans le programme CANDU. Cette technologie a été transférée de nos laboratoires à nos compagnies-soeurs de l'EACL et aux industries et aux entreprises de service publique domestiques. Au fur et à mesure que des CANDUs furent construits dans des pays outre-mer, la CR-EACL a mis sa technologie à la disponibilité des agences et des entreprises de service publique étrangères. Récemment, la compagnie a entrepris une nouveau programme de transfert, la R&D commerciaux pour clientes nucléaires et non-nucléaires. Pendant les années du développement du système CANDU, la CR-EACL a acquis de la technologie et des habiletés techniques qui sont particulièrement précieuses pour d'autres pays qui ne font que s'embarquer dans leurs propres programmes nucléaires. Ce rapport décrit les trente années d'expérience de la CR-EACL avec le transfert technologique.

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ABSTRACT

Canada has developed a unique nuclear power system, the CANDU reactor. The AECL - Research Company (AECL-RC) has played a key role in the CANDU program by supplying its technology to the reactor's designers, constructors and operators. This technology was transferred from our laboratories to our sister AECL companies and to domestic industries and utilities. As CANDUs were built overseas, AECL-RC made its technology available to foreign utilities and agencies. Recently the company has embarked on a new transfer program, commercial R&D for nuclear and non-nuclear customers. During the years of CANDU development, AECL-RC has acquired the skills and technology that are especially valuable to other countries embarking on their own nuclear programs. This report describes AECL-RC's thirty years' experience with the transfer of technology.

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A. Introduction

Canada is one of the few countries to have developed and placed on the international market a unique nuclear power system, the CANDU-PHW* reactor.(1) The Canadian nuclear power program was launched early in the 1950s when Canada, with a population of about fifteen million and a sparse industrial infrastructure, was virtually a developing industrial country. Today, 30 years later, Canada has a sophisticated nuclear industry that employs about 30 000 people, has major export sales and a nuclear R&D infrastructure that provides both long-term and day-to-day support. CANDUs in Canada now produce as much electricity in a year as the total yearly electricity production in the country at the start of the program. In parallel with this development, Canada has become a major supplier of isotopes and equipment for medical, industrial and research applications of nuclear radiation.

B. History

In 1945, at the end of World War II, Canada found itself with a nuclear R&D laboratory at Chalk River centered on the (then) 20 MWt NRX reactor fuelled with natural uranium metal and moderated by heavy water (D_2O). The remote location of the laboratory and the small Canadian industrial base forced a high degree of self-sufficiency in developing our skills and facilities. In those early days the program, managed by the National Research Council, was focused on research in reactor and nuclear physics, radiation chemistry and in building the facilities and plant needed to support our research tasks, although programs in nuclear engineering and fuel reprocessing were active. In 1952, the Canadian government formed the Crown Corporation, Atomic Energy of Canada Limited (AECL), to develop the peaceful use of nuclear energy centered on a natural uranium - D_2O moderated reactor for the generation of electricity.

From the start, the Canadian nuclear programs depended on (a) the strong interdisciplinary R&D teams of the Chalk River Nuclear Laboratories (CRNL), (b) a far-sighted Canadian utility, Ontario Hydro with a strong commitment to nuclear power as an economical substitute for imported coal, (c) industries that were eagar to share in developing the technology of

* CANDU-PHW stands for the CANDU reactor system, CANada, Deuterium, Uranium; the reactor uses heavy water as the moderator and natural uranium as the fuel. Pressurized Heavy Water (PHW) is the coolant. CANDU is a registered trademark of Atomic Energy of Canada Limited.

nuclear power, (d) a responsible regulatory agency dedicated to public safety, and throughout a government that persevered in supporting a program it saw as important to Canada's energy future. All were essential to the successful design, development, construction and efficient operation of the CANDU reactor. From the mid-fifties to the mid-seventies, AECL evolved from a research and an embryonic engineering organization to one that has a full range of applied R&D supporting the development of the CANDU system. During this period AECL expanded and was organized into three closely knit companies:

(a) **AECL-Research Company (AECL-RC)**

(b) **AECL-CANDU Operations (AECL-CO)**

(c) **AECL-Radiochemical Company (AECL-RCC)**

The missions of these AECL companies along with the components of the Research Company are shown in Figure 1.

The emphasis within the Research Company changed again in the late 1970s when, to implement a government policy of user pays and to make itself less dependent of government funding, the company formally initiated a policy of carrying out commercial R&D for outside customers.

The lessons learned by AECL during the development of the CANDU system may be useful to other countries embarking on their own nuclear programs. These lessons essentially relate to two areas: (a) the design, operation and management of complex R&D facilities, and (b) mechanisms for transferring technology into the program from outside sources and from the laboratories into industry and utilities both at home and abroad. In this paper we will describe the Research Company's thirty years of experience in technology transfer. Technology transfer from other parts of AECL is discussed in companion papers at ICONTT III by J. Donnelly, R.E. Hill and R.E. Green (2)(3)(4).

C. Technology Transfer from Other Countries

The Canadian nuclear program benefited from early collaborative programs with the United States (U.S.) and the United Kingdom (U.K.) These programs developed from a mutual interest of all three parties in both applied and fundamental nuclear technology, and in sharing their unique and expensive R&D facilities. U.S. and U.K. liaison offices were established in Canada with the Canadians later setting up a similar office in the U.K. These offices were invaluable in stimulating the transfer of technical information and assisting in the negotiations of bilateral agreements. Staff exchanges between the three countries allowed individuals to develop close personal contact with colleagues working on similar scientific problems.

Both the U.S. and the U.K. took advantage of the high flux and versatility of the NRX and NRU research reactors at CRNL by establishing loops in the reactors for fuel experiments. The two-way technology transfer associated with these loops played an important part in the Canadian fuel development program.

Joint (Canada, U.S., U.K.) research programs using the complementary skills and facilities of the parties were perhaps the most successful way technology was transferred into the Canadian program. An important feature of these programs was that Canada received and enhanced the technology as a fully working partner and was able to adapt it to Canadian conditions and goals. This enabled Canada to share in the two pioneering developments of UO_2 as a power reactor fuel and of zirconium alloys, for pressure tubes and fuel sheaths. Collaborative irradiation experiments in NRX played a big part in the early development of fuel for both heavy water (HWR) and light water (LWR) power reactors as well as establishing basic coolant water chemistry that minimized the corrosion of reactor components. The extent of the foreign participation in our fuel development program is evidenced by the twenty-three persons attached to our fuel organizations at CRNL between 1959 and 1969, Figure 2.

An essential requirement for successfully importing technology is that the recipient country has a nucleus of competent people in the appropriate field. This base is necessary for the intelligent purchase of the technology and later for its absorption and support. Off-shore technology often must be adapted to conditions prevailing in the recipient country; understanding the underlying principles of the technology can be the key to successful adaptation and subsequent problem-solving. Canada imported the Girdler-Sulphide (GS) technology for producing heavy water from the United States in the 1980s(5). The first Canadian GS plant, adapted to local conditions, was sufficiently different from the U.S. model to have serious process problems during its startup period. A combined effort by experts from AECL and industry, including a large science and technology support team from the Research Company, was needed to bring the plant successfully on-line. The RC team was subsequently used to support the other Canadian heavy water plants. By now the Canadian technology for heavy water production is substantially different from the original U.S. technology although both are based on the same GS process.

D. Technology Development and Transfer Within Canada

The CANDU reactor was developed under very specific ground rules including a definite need in Ontario for nuclear electricity to reduce dependence on imported coal, explicit reactor cost and performance targets and a budget that was small by international standards. These rules led to a single goal for the Canadian program, a working power reactor which, to suit Canadian expertise and resources, was based on strict neutron economy using natural uranium fuel and a D_2O moderator, i.e., a CANDU. In achieving our goal, we have developed a unique and successful reactor with a diversified supporting technology that has applications to other nuclear reactor systems.

An essential cornerstone of our success has been the partnership in both the design/construction/operation of CANDUs and in the subsequent technology development with the major electric utility, Ontario Hydro. This utility contributed its practical experience of engineering and operating large process systems while AECL supplied its basic science and nuclear technology. Later in the nuclear power program the same close relationship was established between AECL and two other Canadian utilities, Hydro Quebec and the New Brunswick Electric Power Commission. The laboratory and utility match-up is extremely important to any country, especially those without large engineering/manufacturing companies, embarking on its own nuclear power program.

An example of successful technology transfer between the AECL laboratories and the Canadian utilities is provided by our reactor water chemistry program. The CANDU reactor uses heavy water both as a moderator and as a primary coolant in separate circuits. The separation of these systems is unique to CANDU and allows the chemistry of each circuit to be optimized to minimize corrosion and the transport of radioactivity. Our early experience with the prototype CANDU reactor at Douglas Point showed that a build-up of radioactive corrosion products in the piping circuits could demand radiation protection procedures that would complicate maintenance work. Various fixes to the radiation problem were initiated; shielding was placed on piping lines, a more efficient purification circuit was installed and large ion exchange columns were used. An important part of the solution was a joint AECL-Ontario Hydro task force, charged with finding a solution based on water treatment and the removal of the corrosion products. The R&D component of the program was assigned to the Research Company.

The water chemistry developed and tested by the AECL laboratories as a response to the problem was acquired by the Canadian utilities through staff attached to the programs at CRNL. The utilities also speeded up their absorption of technology by hiring experienced staff from the AECL-RC laboratories. Similarly, a joint program between AECL and Ontario Hydro in decontaminating the Douglas Point CANDU reactor technically benefited both parties. Reports and computer codes were passed by the laboratories to the utilities. The generic work on water chemistry has continued to be the responsibility of the AECL-RC. The utilities are continually brought up to date on AECL-RC technology by regular meetings of chemistry technical committees attended by representatives of the laboratories, designers and utilities. These meetings, which started in the late 1960s, have proven to be a very effective way of moving the latest science from our laboratories into the power stations and in turn bringing operating experience from the utilities into our R&D program.

The achievements of our water chemistry program have been significant. The man rem exposures to workers at our reactors have been markedly reduced; nowhere is this more evident than in our older power stations where current exposures compare favourably with those achieved elsewhere.

New reactors with better materials, system layout and equipment reliability and maintainability have exposure numbers that are an order of magnitude lower than our first reactors. Our water chemistry program has also contributed to Ontario Hydro's excellent operational experience with steam generators; to date only 0.018% of the tubes have been plugged in the thirteen operating reactors of this utility's power stations, about 1/100 of the plugged and sleeved tubes in competing reactor types (6).

Rapid feedback from CANDU utilities in Canada to the reactor designers, regulators, AECL sister companies and other segments of the Canadian nuclear community has been enhanced recently by a computer-based information exchange system called CANNET. Technical data, regulatory changes, and reactor status reports are routinely exchanged between participants. It is planned in the near future to expand CANNET to include foreign CANDU utilities.

A second cornerstone in the development of CANDU has been AECL's cooperation with Canadian industry. From the inception of the Canadian program, the exchange of ideas and skills between AECL and industry was necessary to the development of the laboratories, their equipment and facilities. Transfer of nuclear technology to industry became official government policy when Canada decided to establish its own domestic nuclear industry. Because of the relatively small technological base of Canadian industry in the 1950s, AECL faced a real challenge in transferring technology on the schedule demanded by CANDU development. Various methods were used: industry personnel were attached to AECL laboratories and facilities, development contracts were placed with manufacturers and closely supervised by R&D staff at AECL, and information was exchanged through reports, computer codes and manuals, conferences and meetings.

One of our most successful experiences with technology transfer is the development of an indigenous Canadian fuel industry. The fuel for a CANDU reactor consists of natural UO_2 pellets clad with a Zircaloy sheath to form a fuel element. A number of these elements, typically 37, are assembled together in a fuel bundle 0.5 m long and 103 mm in diameter (7). This fuel, unique to CANDU, was designed, developed and tested under a wide range of normal and transient conditions by AECL laboratories.

As early as 1959, it was decided that the responsibility for fabricating CANDU fuel and developing manufacturing technology would be vested in Canadian industry. AECL-RC would have the task of transferring fuel "know-how" to Canadian industry, designers and utilities while retaining responsibility for improving fuel design and developing fuel for advanced reactors. This transfer of technology was accomplished mainly through the attachment of staff to CRNL. In the most active years of fuel design and testing between 1959 and 1981, a total of 63 engineers were attached to our fuel program by Canadian fuel manufacturers. Figure 3 shows the cumulative person years of attachment to our fuel program for both Canadian industry and utilities. These attached staff participated in all aspects of fuel technology, from design through pilot fabrication and irradiation testing to post-irradiation examinations. By 1978, as the transfer of fuel technology was essentially completed, the number of attached staff had decreased to one or two a year working on irradiation experiments.

Another important tool used to transfer fuel technology to industry was AECL-RC funded R&D contracts placed with selected Canadian manufacturers to develop fabrication procedures and expertise. Many of these contracts were for scaling up to industrial standards processes developed in our laboratories. Between 1957 and 1981, contracts worth about $46M Cdn. were placed with the Canadian fuel manufacturers; Figure 4 shows this contract spending by year. As expected, the contract spending peaked in the mid to late 1960s as new fuel designs were developed and fuel manufacture started for Ontario Hydro's Pickering and Bruce reactors. The Canadian fuel manufacturers are now responsible for their own improvements to fabrication techniques and equipment (8); to date they have produced some 500 000 fuel bundles.

Throughout this period, AECL scientists and engineers published many reports and technical specifications on CANDU fuel. About half the documents were available without restrictions while most of the remaining were written specifically for Canadian industry and for utilities with CANDU reactors.

What did AECL accomplish? By 1984, the Canadian fuel industry consisted of three separate companies in three provinces, employing a total of 630 persons and doing about $60M Cdn. of business each year. The Canadian fuel manufacturers have played a vital role in developing novel fabrication and production techniques for the large scale manufacturing of CANDU fuel elements and bundles. These manufacturers also have the capability of doing independent R&D on fuel assemblies especially in the areas of hydrodynamics, vibration and fretting, and sintering and pressing of fuel pellets. The fuel manufacturing industry is now mature with automation replacing labor intensive techniques leading to reduced costs and improved quality. AECL will benefit from their experience as we develop the techniques, equipment and facilities for advanced fuel cycles based on plutonium and thorium.

Another success story on a smaller scale was the transfer of the CRNL developed self-powered flux detector (9) to a Canadian firm. The technology was transferred through a combination of AECL sponsored R&D contracts and staff attachments, starting in 1965. The firm now markets these detectors to nuclear installations world-wide.

Many of our R&D contracts have been used to build up groups having technical expertise important to the Canadian nuclear industry and often they have stimulated general industrial growth. This is illustrated by quoting from a letter that R.S. Boorman, the Executive Director of the New Brunswick Research and Productivity Council, wrote to the "Canadian Consulting Engineer" in 1984 December:

> I can assure you that my organization, the New Brunswick Research and Productivity Council (RPC) which deals directly in technology, both in engineering and innovation, received great benefit from our association with the Point Lepreau (a CANDU reactor) project. We gained particularly from our association with Chalk River Nuclear Laboratories (Atomic Energy of Canada Limited) and from the New Brunswick Electric Power Commission.....
>
> New Brunswick and Nova Scotian organizations were invited to second staff for a year to CRNL. There they would be exposed to the expertise and equipment that had been developed over the years in support of Ontario's nuclear program.....
>
> After the year of secondment, the staff returned to their parent organizations, which then received on-going contracts over a period of several years until local contract volume had grown to the point where AECL support could be withdrawn without jeopardizing the future of the activity.
>
> Our involvement at Point Lepreau was probably the single most important factor in the transition of the Research and Productivity Council from a "provincial" institution to an international contract research organization. Since 1974, our revenue-to-provincial-grant ratio has increased from 2/1 to 18/1. At present, with our revenue of $6 million per year and our provincial grant at $300 000, we are essentially a self-sufficient industrial performer.....
>
> With this maturity, we have been able to advance our innovative process technology to the fore and this year alone, have been successful in attracting $52 million to New Brunswick to construct pilot plants to transfer RPC technology to industry. Tendering on one of these projects has been completed and we are pleased to note that approximately 70 percent of the goods and services purchased were from New Brunswick companies.

A third cornerstone to the success of CANDU in Canada was the evolution of the nuclear regulatory agency, the Atomic Energy Control Board (AECB) (9), into a body with a regulatory system that has a philosophy and structure compatible with the CANDU reactor and the protection of the Canadian public. Although an independent Crown Corporation, the AECB drew heavily on AECL for key scientific and engineering staff in its early years. Regular meetings between the AECB and staff from AECL's laboratories have kept each abreast of the other's R&D programs that deal with licensing issues. The two have an agreement on the exchange of scientific information through reports, codes and the CANNET system. The AECB operates an Orientation Centre to familiarize new CANDU owners with its regulatory philosophy and practices.

The transfer of AECL's technology doesn't stop with Canadian industries and utilities but extends to universities, the school systems and the public at large. AECL regularly places R&D contracts with Canadian universities where centres of technical excellence are able to perform work supporting our R&D programs. Over a twenty-year period, the AECL laboratories have funded university contracts at an average rate of $1.71M Cdn. per year; see Figure 5. Our interaction with the universities is an excellent model of two-way technology transfer. AECL technology is made available to the universities and their technology is passed through the contracts to the laboratories. Much of this technology then finds its way to Canadian industries. For example: through our contracts, the University of Manitoba has developed an expertise in high temperature solution chemistry that it is now applying outside the nuclear industry. Ecole Polytechnique in Montreal now consults internationally on sub-channel flow and heat transfer, an area of study initially funded by AECL.

Another facet of our relationship with universities is the employment by the laboratories of graduate and undergraduate students for terms between three and four months. These students work directly in our R&D programs to the mutual benefit of both parties. University professors are encouraged to spend their sabbatical leave working at our laboratories, and AECL staff members have become Adjunct Professors at Canadian universities. Since the mid-1950s staff and students from Canadian and foreign universities have been using laboratory facilities, especially our research reactors and accelerators to carry out their research and thesis programs. A joint AECL-RC and university committee has been formed at CRNL to schedule university experiments in our facilities.

Currently AECL-RC and two Canadian universities are cooperating in a program to construct and operate a unique two-array spectrometer for analysing the nuclei of elements using the heavy ions available from the CRNL Tandem Accelerator Superconducting Cyclotron (TASCC) (11). Both CRNL and the universities are contributing the technology needed by this challenging project. The $5 million Cdn. cost is shared equally between AECL and Natural Science and Engineering Research Council of Canada which is providing half the funds on behalf of the universities. This cooperation is an example of AECL's growing partnership with Canadian universities, a relationship which has been evolving and benefiting both parties over the past forty years. In this sense, the AECL-RC laboratories serve as national centers for the promotion of scientific excellence.

The laboratories have initiated several programs to explain our science and technology to the Canadian public. One of the most successful is the Speakers' Bureau, through which working scientists and engineers from the laboratories give invited talks to citizen groups, schools, service clubs and conventions all across Canada. CRNL and Whiteshell Nuclear Research Establishment (WNRE) annually host 3-day symposia for high school science teachers from several provinces of Canada, where the topics are recent advancements in nuclear and non-nuclear science. The teachers use this material to revise and revamp science courses for their students. The CRNL Science Teachers' Seminar is now ten years old and over 1500 teachers have been exposed to AECL-RC's science and technology. AECL-RC staff visit schools throughout Canada explaining nuclear science and technology; during the 1984/1985 school year, our staff gave presentations to over 30 000 students. Over the same period, about 100 groups of university, college and school students toured the Research Company's laboratories.

In summary, the success of the CANDU system in Canada has evolved from a combination of AECL's technolcgy, the experience of Canadian utilities and the industrial "know-how" of Canadian manufacturers and constructors.

E. Technology Transfer to Foreign Countries

AECL laboratories have been transferring technology to foreign countries almost from the inception of the company, beginning with research reactor technology.

The AECL-RC is a world leader in designing and operating small, medium and large sized research reactors. The research reactors, NRX (25 MW) and NRU (125 MW) at CRNL, provide the laboratories with versatile irradiation facilities including in-reactor loops, neutron radiography, isotope production and neutron beams. The laboratories currently have about 125 reactor years' experience operating and working with large research reactors.

It was our early experience with NRX that led Canada in 1956 to collaborate with India on the design and construction of the CIRUS reactor (12) at the Trombay laboratory. The provision of this research reactor to India under the Colombo Assistance Plan in 1956 was at the time the largest program for the transfer of nuclear technology in the world.

Canadian industry provided assistance during the construction of CIRUS. CRNL took the leading role in training Indian reactor operating and support staff and between 1957 and 1963, 46 Indian personnel were attached to the laboratories. The Indians, consisting of professional and technical staff, were trained in operations at the NRX and NRU reactors as well as in support operations such as reactor physics, fuel fabrication, mechanical maintenance and hot cell operation. AECL-RC staff also assisted during the commissioning phase of the CIRUS reactor in India.

In 1968 the Taiwanese government purchased a heavy water research reactor from Canada. The design and construction of the reactor were handled by Canadian industry with management from AECL. AECL-RC was again responsible for training Taiwanese staff and providing a commissioning team of 28 AECL-RC personnel for Taiwan. Between 1970 and 1972 a total of 33 Taiwanese staff trained at CRNL.

A new generation of research reactors is currently being developed by the Research Company. The MAPLE* family (13) of multipurpose research reactors features strong neutron fluxes per unit power for a variety of irradiation facilities, with rated thermal power outputs ranging from roughly one to twenty megawatts. The MAPLE reactor tecnology will be demonstrated at CRNL in MAPLE-X, a 10 MW version optimized for radioisotope production. Hand in hand with the initiative to construct and market these new reactors is a program for transferring related nuclear technology abroad.

Countries now requiring a versatile multipurpose research reactor will be able to participate fully with the AECL development team in realizing a MAPLE facility that meets their specific program needs. Through staff attachments, they will have the additional opportunity to experience the construction, commissioning and early operation of the MAPLE-X prototype. Furthermore, the Research Company is in a position to facilitate technology-transfer programs covering the many areas of nuclear science and engineering associated with contemporary uses of research reactors.

A new thrust in the AECL-RC is being aimed at developing small reactors to provide heat and/or electricity for applications such as isolated communities, shopping centres and apartment complexes. Other uses such as desalinization and process heating are also being explored. The demonstration heat/electricity reactor based on our successful SLOWPOKE design (14) is being built at WNRE. Because of the potential uses of this reactor system worldwide, AECL is having discussions on cooperative programs with other countries which have a mutual interest in small reactors.

The transfer of power reactor technology abroad received added emphasis in the mid-1970s with the sales of CANDU reactors to Argentina, Korea and Romania. Although the bulk of the technology transfer was the responsibility of our sister company, AECL-CO, the Research Company was assigned several specific technical areas such as generic fuel technology to pass along to our customers.

* The MAPLE-X research reactor is an open-tank-in-pool type reactor that is distinguished by the combination of light- and heavy-water-moderated core regions within a heavy-water radial reflector. It operates with compact cores containing low-enrichment uranium in the form of cylindrical UO_2 pellets or U-Si-Al-dispersion rods. It relies on separate reactivity-control systems for regulation and safety and embodies strong design measures to preclude accidental loss of coolant from the core.

While the global recession has slowed the orders of CANDU (and other power reactors), our assistance to countries with emerging nuclear programs has continued at a high level. Because of AECL's experience with establishing and managing two complex R&D laboratories, our expertise and technology are especially valuable to many developing countries faced with the problems of building their first nuclear centers. A commercial agreement to supply Indonesia with an electro-mechanical laboratory is a recent example. CANDU technology, with its emphasis on natural uranium fuel, pressure tubes and small sub-components, can be very attractive to a country with a small industrial base starting out on the road to nuclear generated electricity (1).

Transfer of technology is tempered by Canada's sensitivity to non-proliferation issues: Canada is a founding member of the IAEA and a signatory of the United Nations Nuclear Non-proliferation Treaty (NPT). Our technology will only be transferred to countries that have signed the NPT or have initiated NPT type full-scope safeguards and to countries willing to sign a bilateral agreement with Canada ensuring the peaceful use of our nuclear technology, fuel, materials and equipment.

The transfer of our technology abroad has not been in isolation from the rest of the Canadian nuclear community. Effective cooperation has been received from our sister AECL companies, other Canadian government departments, the AECB, Canadian industries, utilities and universities. This cooperation among all segments of the Canadian nuclear program has been and continues to be one of the strengths of the CANDU system.

Over the past five years, the AECL laboratories have become increasingly active in technology transfer projects sponsored by the IAEA. The laboratories have hosted several IAEA-backed specialists' meetings on topics such as "Defective Fuel in Water-Cooled Reactors" and "Distributed Systems for Nuclear Power Plants" and have accepted a number of people on IAEA training fellowships in areas of technology ranging from physics to biology to reactor water chemistry. A recent milestone for the laboratories was the participation by lecturers from both the AECL-RC and AECL-CO as a part of a major IAEA training course on Water-Cooled Power Reactors. Facilities at CRNL were used for some of the lectures and visits were arranged to both Canadian laboratories and CANDU power stations.

A detailed example of how we transfer technology abroad is the transfer of fuel technology to our overseas CANDU customers.

Under the terms of the CANDU sales agreements with Argentina, Korea and Romania, AECL was committed to transfer generic fuel technology, including computer codes that predict fuel performance, to these new customers. Most of this responsibility fell to the AECL laboratories.

Manufacturing technology for CANDU fuel is owned by three Canadian manufacturing firms and is not included in the transfer of AECL-RC fuel technology.

Staff from all three countries were attached to the fuel programs at AECL-RC laboratories, mainly CRNL. The cumulative attachment years for our foreign customers are shown in Figure 2. The length of time an attached person spends at the AECL laboratories is very important. If the objective is to transfer a specific skill or method, a period of six months or less may be sufficient. Frequently, however, the aim is for the attached person to participate in a current research project, thus acquiring broader experience and contributing to our R&D programs; this requires a considerably longer period, usually in excess of nine months. One of the most important parts of any attachment at the laboratories is the "hands-on" experience received by the foreign staff. There is no substitute for operating actual equipment in a hot cell, polishing a metallographic sample or participating in an in-reactor experimental fuel test.

Numerous reports, specifications and computer codes were supplied and reviewed with each foreign CANDU owner. Much attention was paid to the selection of reports so that all relevant aspects of fuel technology were covered and the recipients could appreciate the development and testing required to build the foundations of the CANDU fuel design.

An additional step was a fuel seminar consisting of twenty lectures prepared by AECL staff on basic fuel topics and given by a team of Company experts to the staff of Korean national laboratories in Daeduk. After completing the lectures, the experts participated in extensive discussions and consultations at the Korean centre. This successful fuel seminar was repeated in a shortened version in Romania.

All three CANDU overseas owners have now fabricated prototype CANDU fuel bundles in their own laboratories and their bundles have been proof-tested by irradiations in our research reactors with the cooperation of AECL-RC staff.

F. Commercial R&D Activities

The start of the 1980s saw a new thrust of the AECL laboratories into the area of commercial R&D. One purpose is to transfer part of the R&D funding burden from the government to the users of the technology. A second purpose stems from the growing recognition that much of our technology has applications in non-nuclear and non-CANDU industries. In this context, our technology has a monetary value based on its development costs and can profitably be marketed.

Since commercial R&D was initiated, the laboratories have been increasingly successful in selling services and expertise; commercially generated R&D funds now account for about 20 percent of the total AECL-RC annual budget. One of the most encouraging features of our commercial initiative is the business that we are receiving from non-nuclear industrial sectors such as the oil and gas and chemical process industries, indicative of the value to other industries of technology developed in the nuclear industry. This wider application of nuclear technology is especially relevant to developing countries where a nuclear program could have technology spin-offs to other areas of the nation's economy.

The principal form of commercial technology transfer from the AECL-RC is through licensing our equipment and technology to industries both at home and abroad. Licensing has proven to be a successful commercial endeavour for the laboratories generating a growing stream of revenues per year in royalties. The majority of licenses are given to Canadian firms; however, if a suitable Canadian company does not exist, then licenses are negotiated with foreign companies. The licensing agreements ensure that we participate in the financial exploitation and transfer of our technology. After the licenses are established, the Research Company continues to provide technology backup to the firms often through commercial R&D contracts.

One example was the licensing of our ion source technology (15) in 1984 to a U.S.-based manufacturing company. An AECL-RC developed ion source, with an ion current about five times greater than other sources, is a basic component of a machine that implants oxygen ions in silicon wafers for semiconductors. The source technology was transferred through visits, reports, engineering drawings, a prototype machine and follow-up R&D contracts to the AECL-RC. This project was a good example of how technology transfer can proceed when the recipient organization has knowledgeable people involved.

Although not as efficient as licensing, commercial R&D contracts for industrial customers do ensure that our technology makes its way outside the laboratories. Individual R&D contracts range from several thousand to several millions of dollars in value and in a typical year, the laboratories work on about 350 R&D contracts. Some examples at the lower end of the dollar scale are jobs such as evaluating weld failures in baby food cans for $3k, and detecting defects in mine-hoist cables ($2k). Larger jobs include the investigation of corrosion inhibitors for steam lines in a plant for extracting oil from tar sands ($240k), a densitometer for measuring the separation of heavy oils ($400k) and a hydrogen-oxygen recombiner, using our wetproofed catalyst (16), for a chemical plant in the U.S. ($1.5M) Most of these contracts give a high degree of technical satisfaction to the laboratory staff and allow our people to advance their scientific knowledge.

G. CONCLUSIONS

1. In developing the CANDU reactor, Canada has established a nuclear industry consisting of four distinct branches.

   (a) an engineering and contracting firm (AECL-CO) that markets the CANDU reactor and ancillary plants,

   (b) a nuclear utility/industry infrastructure,

   (c) a multidisciplinary nuclear research organization, and

   (d) a competent and independent regulatory body.

2. During the CANDU development program, AECL was forced to cope initially with the lack of an extensive technological base in Canadian industry. Thus our experience in establishing a Canadian nuclear industry is valuable to other countries facing similar problems.

3. Key requirements for the effective transfer and diffusion of nuclear technology from a research organization to start a nuclear power program are:

   (a) close collaboration between the people doing the technology development, the reactor design, and an electric utility,

   (b) exchange of personnel between the suppliers and users of the technology, and

   (c) an effective and rational regulatory system.

4. AECL has experience in the transfer of technology to other countries on two levels:

   (a) the CANDU system where technology is transferred in collaboration with our sister companies and industry, and

   (b) nuclear R&D capabilities comprising research reactors, laboratories, equipment, methods and management.

5. AECL can transfer technology under several forms of agreements. Our first priority is to transfer technology to customers of the CANDU reactor under the umbrella of a bilateral agreement or under the auspices of the IAEA. We can also provide consultation, design and training for countries establishing their own nuclear R&D laboratories.

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FIGURE 1

AECL COMPANIES RESPONSIBLE FOR THE CANDU SYSTEM

1. AECL RESEARCH COMPANY (AECL-RC)

Mission

- The national laboratory for basic research in the nuclear sciences biology, chemistry, physics and materials.
- Supports the design, manufacture and operation of CANDU's and D_2O plants through programs in applied science and engineering.
- Responsible for the transfer of research and development technology to utilities and industry.
- Develops new applications for nuclear technology to provide social, economic and industrial benefits.

Head Office (RCHO)
Ottawa, Ontario

Chalk River
Nuclear Laboratories
(CRNL)
Chalk River, Ontario
(2300 employees)

Whiteshell Nuclear
Research Establishment
(WNRE)
Pinawa, Manitoba
(1100 employees)

2. AECL CANDU OPERATIONS (AECL-CO)

Mission

- Designs nuclear generating stations in cooperation with utilities and industry.
- Provides and procures equipment, engineering and consulting services for both domestic and foreign customers of CANDU reactors.
- Constructs and operates heavy water production plants and supplies heavy water to domestic and overseas utilities with CANDU reactors.

- Coordinates the development of D_2O technology within Canada and is reponsible for transferring this technology abroad.

- Markets the CANDU reactor system, evaluates potential reactor uses, provides procurement services and project management for CANDU customers.

3. AECL RADIOCHEMICAL COMPANY (AECL-RCC)/MEDICAL PRODUCTS DIVISION

- Produces and distributes radioisotopes and radiopharmaceuticals.

- Designs and markets medical radiotherapy systems.

- Designs and markets gamma irradiation equipment for research and industrial processes.

- Markets SLOWPOKE reactors for research and industrial uses.

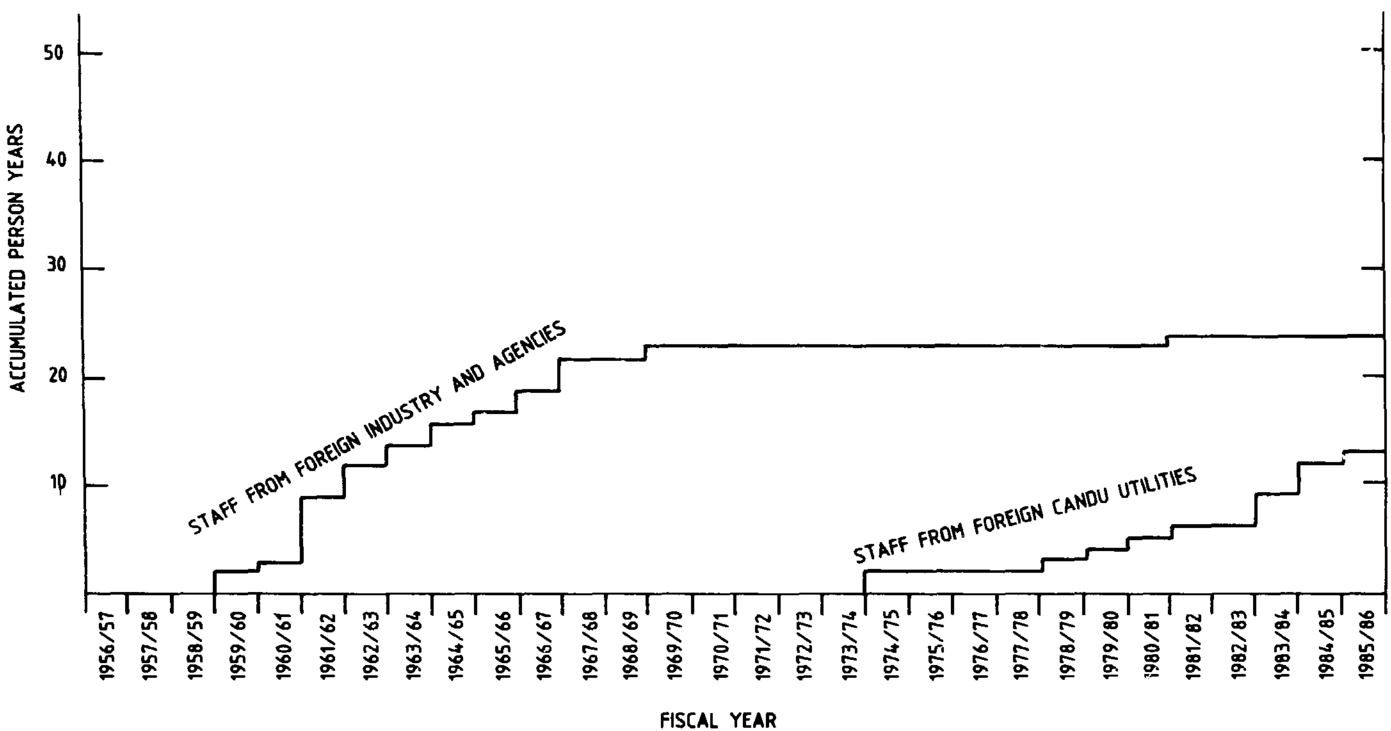

FIGURE 2 STAFF ATTACHED TO THE FUEL PROGRAM AT AECL-RC LABORATORIES FROM FOREIGN UTILITIES, INDUSTRY AND AGENCIES

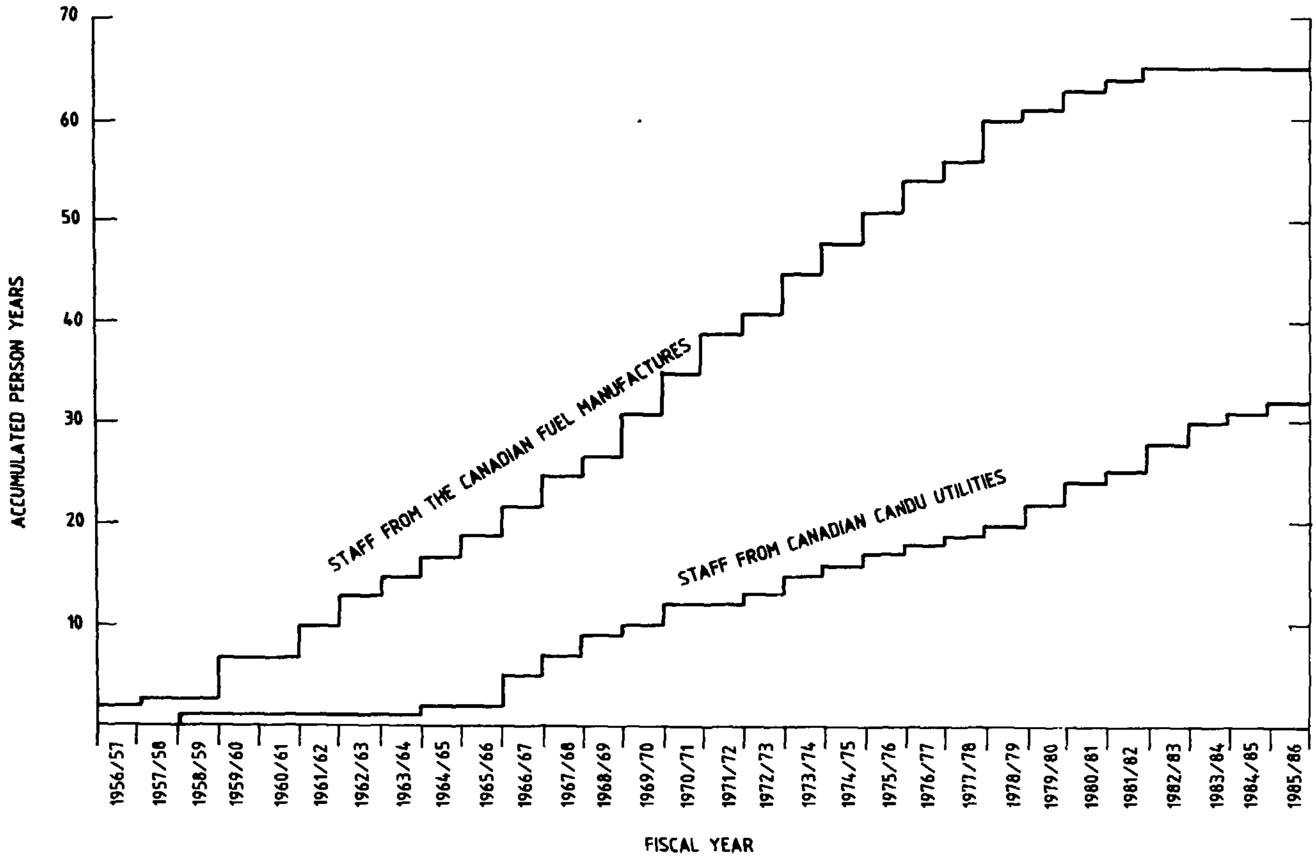

FIGURE 3 STAFF ATTACHED TO THE FUEL PROGRAM AT AECL-RC LABORATORIES FROM CANADIAN MANUFACTURES AND UTILITIES

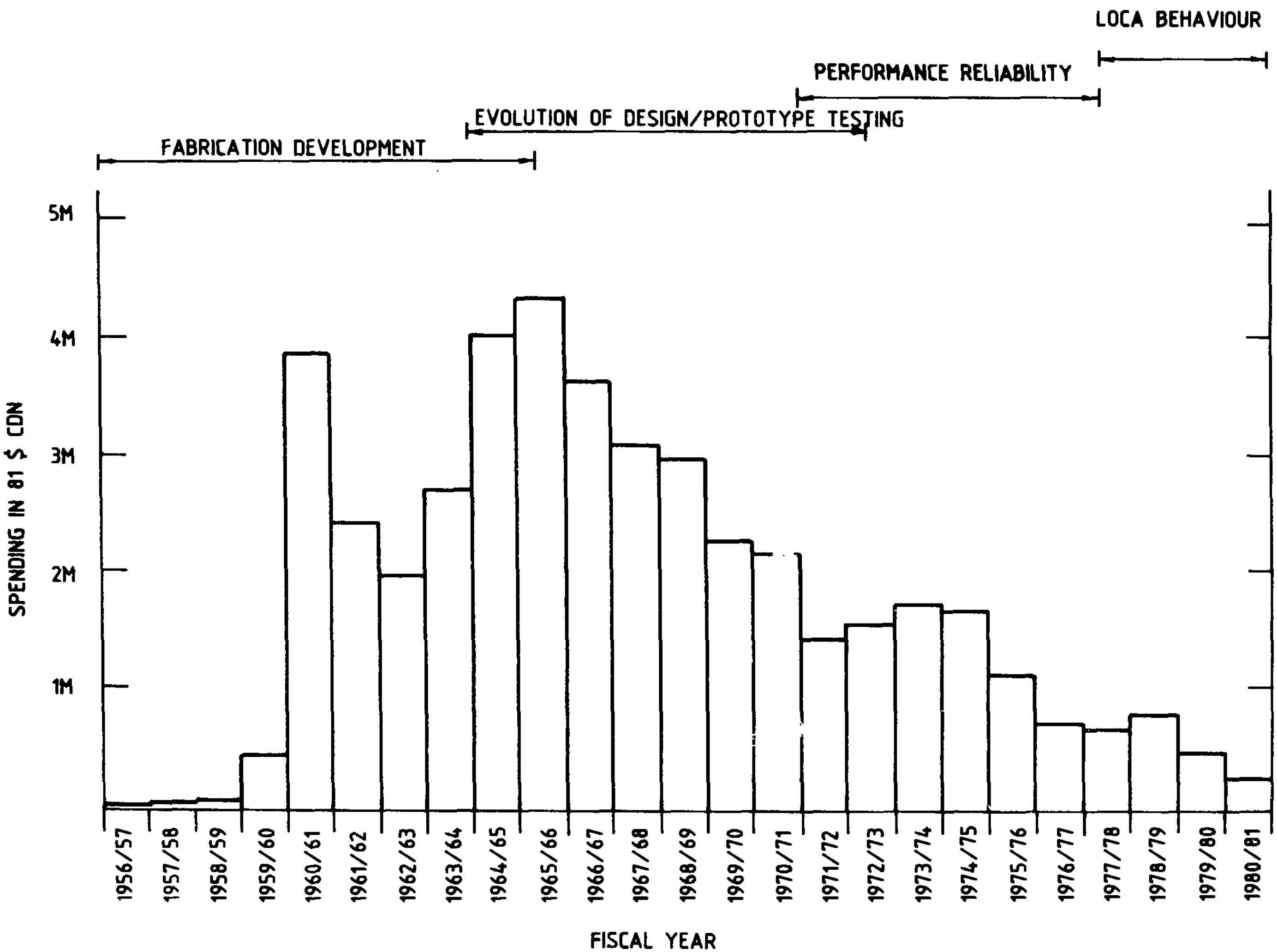

FIGURE 4 AECL-RC CONTRACT SPENDING WITH THE CANADIAN FUEL MANUFACTURES

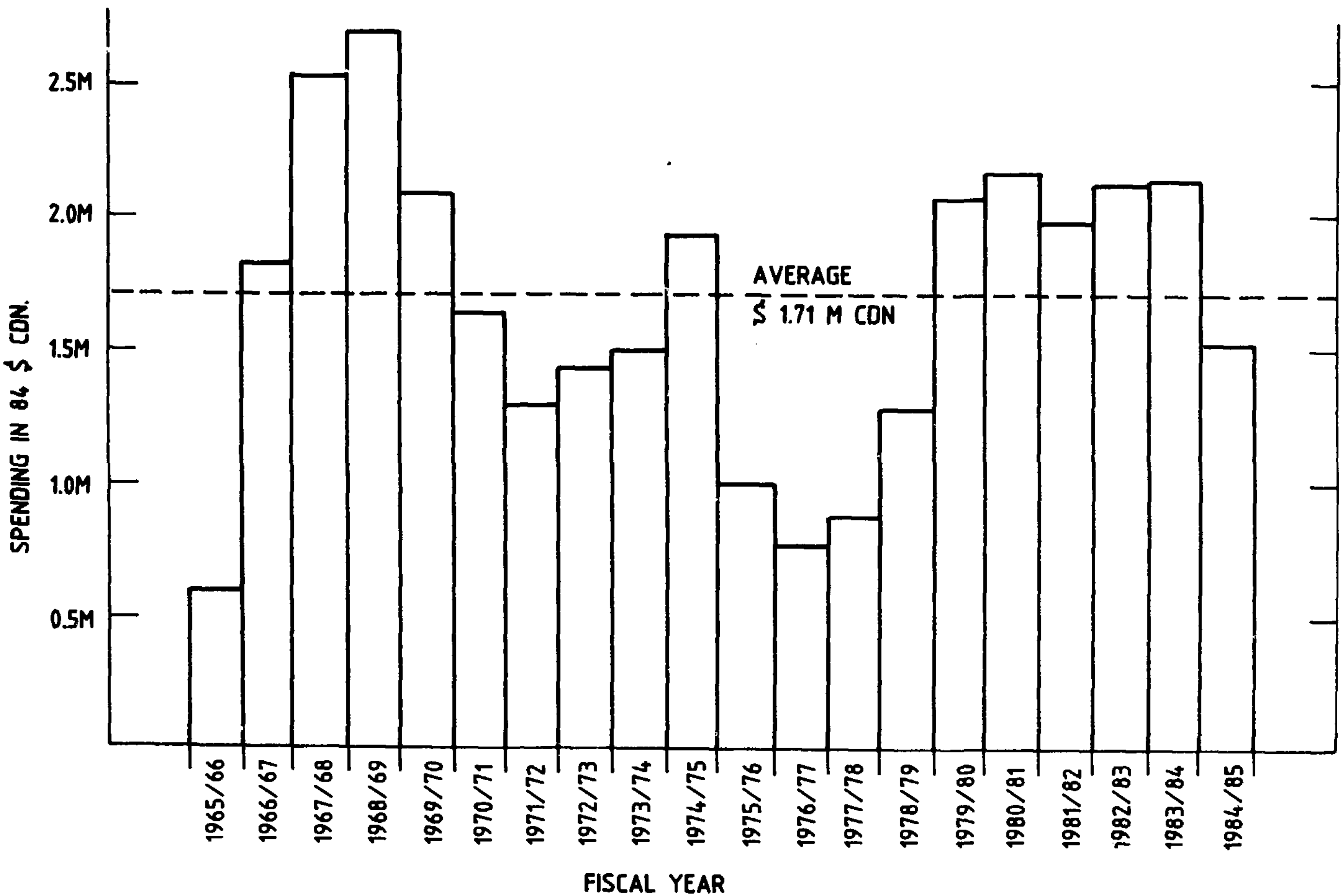

FIGURE 5 AECL-RC SPENDING ON R+D CONTRACTS AT CANADIAN UNIVERSITIES BETWEEN 1965 AND 1985

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