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L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

SLOWPOKE – A NEW CANADIAN HEAT SOURCE

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RÉSUMÉ

L'Énergie nucléaire est prête à contribuer à satisfaire les besoins d'énergie du Canada et du monde. Elle s'avère déja comme étant un producteur d'électricité important, ayant fourni, en 1985, 15 pour-cent de l'électricité produite dans le monde et 12,8 pour-cent de celle produite au Canada. L'Énergie Atomique du Canada, Limitée a maintenant un nouveau produit, le Système Énergétique SLOWPOKE, qui fournit de la chaleur à basse température pour le chauffage des immeubles et le chauffage industriel. À mesure que les besoins énergétiques du monde augmentent, les systèmes de chauffage nucléaire tels que SLOWPOKE doivent contribuer à les satisfaire d'une façon importante.

La puissance du Système Énergétique SLOWPOKE lui permet de débiter jusqu'à 10 mégawatts d'eau chaude à une température allant jusqu'à 90°C et convenant pour les grands immeubles et les procédés industriels. Il est conçu pour fonctionner sans la présence permanente de personnel spécialisé et, du fait de sa sûreté inhérente, pour être implanté près des utilisateurs. Au prix de 2 cents le kWh, la chaleur concurrence le pétrole, le gaz et l'électricité dans la plupart des régions du Canada et du monde.

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SUMMARY

Nuclear energy is ready to contribute to a second sector of the energy requirements of Canada and the world. Already it is established as an important producer of electricity, accounting in 1985 for 15 percent of the world's production and 12.8 percent of Canada's. Atomic Energy of Canada Limited now has a new product, the SLOWPOKE Energy System, that provides low temperature heat suitable for building and process heating. As the world energy demand increases, nuclear heating systems, such as SLOWPOKE, are expected to make an important contribution.

The SLOWPOKE Energy System is sized to deliver up to 10 megawatts of hot water at up to 90°C, appropriate for large buildings and industrial processes. It is designed for operation without the full-time attendance of dedicated staff and, because of its inherent safety, for siting close to users. At less than 2 cents/kWh, the heat is competitive with oil, gas and electricity in most regions of Canada and the world.

EXPECTATIONS FOR NUCLEAR POWER

Although the application of nuclear fission power to heat buildings and low-temperature processes has enormous potential, the technology is still very much in its infancy. This results from the technical and economic criteria for such applications being very different from those of the traditional role for nuclear energy in electricity generation. Current fossil fuel prices, together with the financial implications of emission controls, particularly on coal combustion, lead to building heating costs in many countries that exceed the cost of heat from dedicated nuclear systems. Furthermore, the forecast increase in fossil fuel prices creates a future economic environment in which the application of nuclear technologies to heat buildings will become even more attractive.

During the last forty years, the emphasis for commercial nuclear power development has been on electricity production. By the end of 1985, there were 374 operating reactors with a total generating capacity of approximately 250 Gigawatts. With this available capacity, the global nuclear share of the total electricity generated was 15%[1]. In Canada, which has abundant hydro capacity, the share was 12.8%[2]. However, most energy is not used as electricity and the contribution of nuclear power to the world's total energy requirements in 1985 was less than 5%. Even with the high growth scenarios of the International Atomic Energy Agency[1] and the World Energy Conference[3], the nuclear electrical contribution to the world energy requirements for the year 2000 is still less than 10%.

Many countries in the northern hemisphere consume more than 25% of their primary energy to heat their buildings[4]. Since the majority of the population live in urban centers, a significant fraction of the heating requirements can be satisfied by distributed or district heating systems should low cost heat sources be available. Unlike the transportation industry, this energy sector is amenable to substituting nuclear energy for the traditional fossil fuels provided certain technical, economic and safety criteria can be met and public apprehension overcome. Thus, the potential for nuclear heating from a global perspective must be considered to be of a similar magnitude to that already achieved by nuclear electrical generation.

SLOWPOKE ENERGY SYSTEM

In a major departure from traditional nuclear power technology, Atomic Energy of Canada Limited (AECL) has developed the SLOWPOKE Energy System - a nuclear heat source specially designed to satisfy the needs of local heating systems used by buildings and institutions. By delivering 10 MW of thermal energy in water at 85°C, over 150 000 square metres of floor area can be economically heated with an inflation resistant fuel source[5].

Design Criteria

Since the purpose is to supply low grade heat to users who are located throughout a series of buildings or building complexes, there are a number of design requirements that are different from nuclear electricity generation.

The economics of hot water heat distribution systems dictate that the heat source must be located close to the load and hence to people. This means that a major factor must be unquestionable safety. Radiological protection must be achieved by the action of processes that are intrinsic to the heat source and not dependent on specially engineered electro-mechanical systems. The goal is to limit the consequences from all credible and even incredible accidents to a level that is acceptable to the people who live closeby. In addition to the engineering challenge, this presents a social challenge in expressing the safety features in a way that is readily understood by people with limited knowledge of nuclear technology.

From an analysis of the annual heat load curves in many buildings in several countries, it has been concluded that a nuclear heating system satisfying approximately 50% of the peak heat demand and used in a base load capacity could provide up to 90% of the annual heat requirements. By using a low capital cost fossil fired system to satisfy the peaking requirements and to serve as a backup to the more capital intensive nuclear heating system, the overall system redundancy requirements can be met at the lowest cost. For such a system, AECL has concluded that the optimum size is in the 2-10 MWt range. At this low power level, the reactor can be designed with inherent safety features that cannot be achieved at higher power levels.

The technological challenge was to implement the engineering design of a nuclear heat source that can be economically competitive with fossil fuelled systems. The key to achieving this goal was to eliminate complex systems and keep operating costs to a minimum. The SLOWPOKE Energy System was therefore designed to eliminate the need for a team of dedicated, hands-on operating staff being in full time attendance while the reactor is operating. In practical terms, the SLOWPOKE Energy System is being considered much like the oil, coal or natural gas boilers it is designed to replace. The concept of walk-away safety is implicit in unattended operation and in gaining the public acceptance that is required.

System Description

In keeping with these design requirements, the 10 MWt SLOWPOKE Energy System, designated SES-10, is a pool-type reactor designed to operate at atmospheric pressure. This eliminates the need for a nuclear pressure vessel. Consequently, loss-of-coolant caused by depressurization is impossible. The reactor core, coolant riser duct and the primary heat exchangers are installed in the pool contained inside a steel-lined concrete vault. This double containment of the pool water prevents loss-of-coolant caused by leakage. The arrangement of SES-10 is similar to the 2 MWt demonstration reactor illustrated in Figure 1.

The pool water serves as both the heat transfer medium and the shielding. The core is cooled by natural circulation of the pool water through the plate type heat exchangers. There is therefore no risk of loss-of-cooling by mechanical or electrical failure.

The pool water is continuously pumped through ion exchange columns to maintain water chemistry and control corrosion. The ion exchange columns can also remove fission products from defective fuel and other impurities. The reactor pool is covered by an insulated lid, enclosing a gas space over the pool. The air and water vapour are continuously circulated through a purification system and hydrogen recombiner. After filtering and monitoring, a small fraction of the circulating cover gas is vented by way of the building ventilation exhaust system.

The goal of the SES-10 design was to fully automate all essential systems, thus allowing the unit to be operated for extended periods without an operator in the reactor building. Essential instruments will be monitored at one or more remote locations and a licensed operator will always be on call, either by telephone or personal paging system. A single remote monitoring centre could manage the heating and ventilating requirements of many building complexes in a number of towns, cities or regions. Local staff would be responsible for maintaining and testing equipment and responding to specific alarm conditions. It is anticipated that these local responsibilities can be undertaken by the existing heating plant staff. Although the local staff will have the authority to shut the reactor down in the event of an abnormal condition being observed, the licensed operator will have to be present for startup.

Safety Principles

One of the fundamental driving forces of the design is the safety philosophy. The primary goal is to meet all Canadian regulatory requirements in a manner that permits unattended operation with remote monitoring for periods of weeks or longer. This implies system diversity and defence-in-depth as the overall safety philosophy.

The inherent safety features of the SES-10 design include a negative fuel temperature reactivity coefficient and negative coolant temperature and void reactivity coefficients, all of which attenuate power transients following loss-of-regulation. In addition, primary heat transport is by a natural circulating system requiring no external power source to maintain coolant flow through the core during operation or shutdown.

The engineered systems include:

- the robust fuel,
- a double containment pool with no penetrations,
- a large pool volume to mitigate the consequences of any transients,
- slow reactivity addition rates,
- a fully redundant control system,
- separate and diverse shutdown systems dedicated to safety, and
- a cooling system to remove fission product decay heat during shutdown.

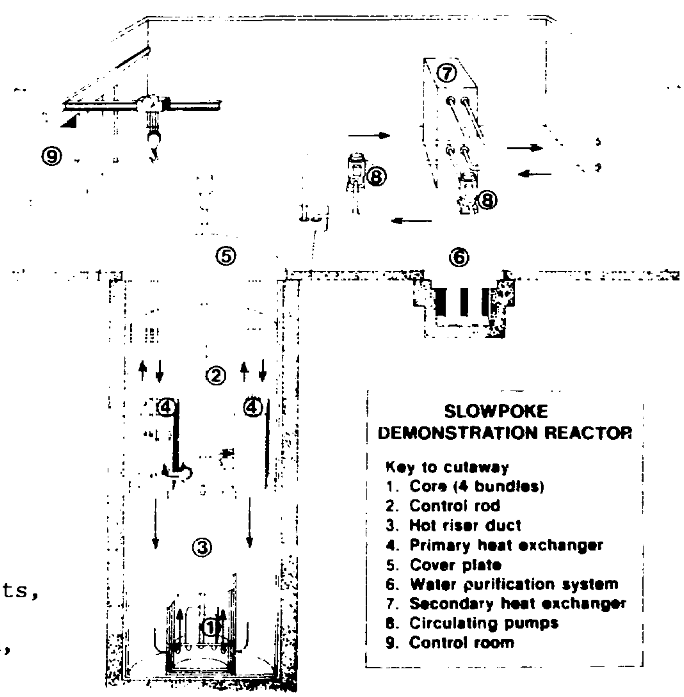

Figure 1

The normally accepted codes and standards have been used for the design and fabrication of components and systems. A quality assurance program has been instituted for all aspects of the commercial installations.

CONCEPT DEMONSTRATION

The SES-10 concept has the advantage of a sound technological base. For over twenty years, AECL has been involved in the development of small nuclear reactors. This program has led to the progressive evolution of the SLOWPOKE concept. The first product was the SLOWPOKE Research Reactor which was first introduced commercially in 1972 and remains part of the AECL product line[6].

The realization that many of the key design criteria of the research reactor were similar to those required for a heating reactor, led the developers to optimize the reactor for heat production rather than neutrons and yet retain the essential safety features of the concept. This work culminated in the construction and operation of the SLOWPOKE demonstration heating reactor at the Whiteshell Nuclear Research Establishment (WNRE) in Manitoba[7].

SLOWPOKE Research Reactor

The SLOWPOKE Research Reactor is a low cost, pool-type reactor producing a thermal neutron flux of $10^{12} n.cm^{-2}.s^{-1}$ in the beryllium reflector surrounding the core. It is used primarily for neutron activation analysis and as a university teaching and research tool. Since the startup of the prototype in 1970, eight units have been installed in urban areas and have accumulated over 60 reactor-years of reliable operation. They are also the only commercial reactors in the world to be licensed for unattended operation for periods up to 72 hours.

SLOWPOKE Demonstration Reactor

The SLOWPOKE Demonstration Reactor (SDR) was designed to operate at 2 MWt and incorporates the key technical features of the research reactor, namely; atmospheric pressure, natural convection cooling, remote monitoring instead of an on-site operator and unquestionable safety. The primary purpose in designing, constructing and testing this facility is to validate that the technical, economic and safety criteria for the nuclear heating reactor concept can be met.

The SDR facility, for which key design parameters are given in Table 1, is shown schematically in Figure 1. In addition to being used as an experimental and developmental tool, SDR is to be used as a full scale demonstration of building heating. Several of the buildings at the Whiteshell site are being converted to hot water heating to use the full 2 MW of thermal energy in a base load capacity.

These test and demonstration programs have been designed to verify all the essential features of reliability, availability and maintainability of SLOWPOKE Energy Systems in commercial applications.

ECONOMIC ANALYSIS

A SLOWPOKE Energy System naturally requires a substantially lower capital investment than a nuclear electric power station such as a CANDU or a PWR. However, it is also very important to note that the capital investment in terms of $/MW of thermal capacity is also significantly lower. This is the result of many factors including elimination of the complexity of pressurized systems and short construction times (approximately one year). This leads to the conclusion that dedicated nuclear heating systems, such as SES-10, are economically competitive even with large nuclear co-generation plants.

TABLE I

THE KEY DESIGN PARAMETERS FOR THE SLOWPOKE DEMONSTRATION REACTOR

CORE (Square cross-section)		FUEL ELEMENTS (UO_2, Zr clad)	
Thermal Power	2 MWt	Length	487 mm
Length and Width	284 mm	Diameter	13.1 mm
Height	495 mm	Mass of Uranium	0.51 kg
Mass of Uranium	100 kg	Maximum Fuel Temp.	1350°C
Enrichment	4.9%	Maximum Heat Flux	105 $W.cm^{-2}$
Number of Fuel Bundles	4	Average Heat Flux	50 $W.cm^{-2}$
Number of Elements/Bundle	49	Average Burnup	15 $MW.d.kg^{-1}$
Energy Production	4.0 MW.a		
POOL		BUILDING	
Diameter	4300 mm	Length	13.7 m
Water depth	9040 mm	Width	11.5 m
Water volume	131 300 L	Height	10.4 m
Cover gas volume	15 400 L	Volume	1640 m^3

This low capital cost, when combined with the low operating expenses resulting from unattended operation, results in the unit cost of heat supplied by a SLOWPOKE Energy System being as low as 1.2 cents/kW.h. The actual cost for a specific application depends on unit size and load factor, as shown in Figure 2. For example, an SES-10 system used to heat a building with a 40% load factor could provide hot water at approximately 2 cents/kW.h.

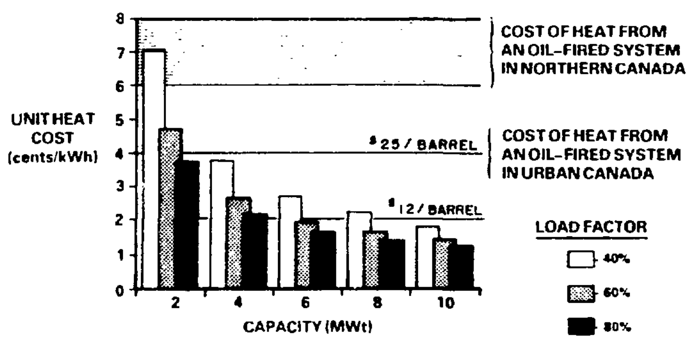

Figure 2: Unit Heat Cost from SLOWPOKE Energy System

Also evident from Figure 2, the cost of heat from systems greater than 6 MWt is competitive with oil fired systems even with oil prices as low as Canadian $15 per barrel (equivalent to US $12 per barrel). An attractive market segment, even with depressed oil prices, is remote communities where oil is the primary fuel and transportation costs dominate the pricing structure. The unit heat cost from oil-fired systems in several of the larger communities in Northern Canada is included in Figure 2 for comparison. It is anticipated that this data is also representative of the general situation around the world.

This analysis confirms the viability of small nuclear heat sources as an economically attractive alternative to conventional heating systems in many countries.

CONCLUSION

The SLOWPOKE Energy System is a major step forward in demonstrating the technical and economic viability of applying small nuclear energy systems to building and process heating applications. Furthermore, the low capital investment required for a SLOWPOKE Energy System, coupled with the possibility of a relatively high degree of localization, even for the first unit, are seen as attractive features to facilitate early adoption by other countries that are striving to relieve their dependence on fossil fuels.

The demonstrated performance of the SLOWPOKE research reactors in university communities over the last 16 years, together with the successful operation of the SLOWPOKE demonstration heating reactor, provides the confirmation of unquestionable safety that is required for public acceptance.

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