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ATOMIC ENERGY OF CANADA LIMITED

ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

A NUCLEAR REACTOR FOR DISTRICT HEATING

UN RÉACTEUR NUCLÉAIRE POUR LE CHAUFFAGE URBAIN

A.R. BANCROFT and N. FENTON

Prepared for presentation at the 80th Annual IDHCA Conference
Virginia Beach, Virginia
1989 June 18-21

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario K0J 1J0

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Résumé

Les besoins énergétiques globaux doivent doubler au cours des 40 prochaines années. Dans l'hémisphère nord, de nombreux pays consomment plus de 25 pour cent de l'énergie primaire fournie pour le chauffage d'édifices. La satisfaction de ces besoins dans les limites de contraintes (maintenant reconnues) de développement global soutenable, donne une grande possibilité d'employer le système de chauffage urbain.

La souplesse d'utilisation du combustible, la conservation de l'énergie et des ressources et la réduction de la pollution atmosphérique par les gaz acides et d'effet de serre sont des avantages importants qu'offrent les systèmes de chauffage urbains. Parmi les principaux choix d'énergie, seules l'électricité hydraulique et la chaleur nucléaire permettent d'éviter entièrement les émissions de gaz de combustion.

Pour satisfaire le besoin d'une source de chaleur nucléaire économique, Énergie atomique du Canada limitée a conçu une installation de 10 MW convenant, comme source de chaleur, dans un réseau ou comme moyen principal d'alimentation d'importants utilisateurs particuliers. Ce réacteur produit de l'eau chaude à une température inférieure à 100°C et comprend un petit réacteur piscine basé sur le réacteur de recherche SLOWPOKE couronné de succès d'EACL. Un prototype de réacteur industriel de 2 MW est en cours d'essais à l'Établissement de recherches nucléaires de Whiteshell au Manitoba. Les frais d'investissement étant de 7 millions de dollars (canadiens), on prévoit que le coût d'énergie unitaire sera de 0.02 $ le kWh pour un réacteur en service dans un réseau de chauffage pendant une période de 30 ans. En maintenant la puissance du réacteur faible et la température de l'eau inférieure 100°C, on peut éviter presque toute la complexité des grandes centrales électronucléaires et ainsi rendre économiquement viables ces petits systèmes de chauffage nucléaire sûrs.

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Abstract

Global energy requirements are expected to double over the next 40 years. In the northern hemisphere, many countries consume in excess of 25 percent of their primary energy supply for building heating. Satisfying this need, within the constraints now being acknowledged for sustainable global development, provides an important opportunity for district heating.

Fuel-use flexibility, energy and resource conservation, and reduced atmospheric pollution from acid gases and greenhouse gases, are important features offered by district heating systems. Among the major fuel options, only hydro-electricity and nuclear heat completely avoid emissions of combustion gases.

To fill the need for an economical nuclear heat source, Atomic Energy of Canada Limited has designed a 10 MW plant that is suitable as a heat source within a network or as the main supply to large individual users. Producing hot water at temperatures below 100°C, it incorporates a small pool-type reactor based on AECL's successful SLOWPOKE Research Reactor. A 2 MW prototype for the commercial unit is now being tested at the Whiteshell Nuclear Research Establishment in Manitoba. With capital costs of $7 million (Canadian), unit energy costs are projected to be $0.02/kWh for a 10 MW unit operating in a heating grid over a 30-year period. By keeping the reactor power low and the water temperature below 100°C, much of the complexity of the large nuclear power plants can be avoided, thus allowing these small, safe nuclear heating systems to be economically viable.

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1. THE GROWING NEED FOR ENERGY

The increasing demand for economic and reliable energy supply is driven both by the growth in the world's population and by the essential role that energy plays in industrial development. With global energy requirements expected to double over the next 40 years (1), all supply sectors will be seriously challenged in their ability to meet the demand.

Many countries in the northern hemisphere consume in excess of 25 percent of their primary energy supply to satisfy their building heating requirements (2). Since the majority of the population live in urban centers, a significant fraction of these heating requirements can be satisfied by central or district heating systems. Unlike transportation, this is an important energy sector which is readily amenable to the application of small-scale nuclear technology.

2. SUSTAINABLE DEVELOPMENT

There are well-founded concerns about the increasing demands on the world's resources that must be addressed:

> Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth....
>
> Meeting essential needs requires not only a new era of economic growth for nations in which the majority are poor, but an assurance that those poor get their fair share of the resources required to sustain that growth....
>
> Yet in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. We do not pretend that the process is easy or straightforward. Painful choices have to be made. Thus, in the final analysis, sustainable development must rest on political will. (3)

The report from which the above quotation is excerpted, written in response to an urgent call by the General Assembly of the United Nations in 1983, is credited with stimulating the current wave of action by many groups and governments to address serious environmental concerns. The needs are as diverse as the regions of the world and the appropriate responses are equally diverse. The action must be based on the sound understanding of social, economic and technical considerations often expressed by concerned organizations (4). A well-coordinated response from governments is required to identify appropriate policy and institute controls (5).

Within the network of energy use, building heating and cooling is a major factor. For that application, district heating and cooling offers the opportunity for greater efficiency and reduced pollution.

3. A ROLE FOR DISTRICT HEATING

The advantages of district heating--the heating of many buildings from a central heat source--are becoming more important with the current emphasis on sustainable development. In contrast to heating and cooling buildings using individual systems, district heating and cooling offers benefits consistent with the new emphasis. These benefits are:

(i) higher efficiency in the use of fuel, especially in the case of cogeneration systems;

(ii) reduced local and global pollution because of item (i) and improved pollution control for larger systems;

(iii) greater flexibility in the use of fuel, with the ability to optimize the use of fuels in systems with several different heat sources;

(iv) reduced cost of delivered energy; and

(v) more reliable and convenient energy supply to the building owners.

These advantages are well known to users of district heating systems. The International District Heating and Cooling Association was formed in 1909 to facilitate the exchange of technical, operational and management information, mainly among North American users. One vehicle for this exchange and for the promotion of district heating is the publication of information from system operators (6). In Europe, where the variety of indigenous fuels has been limited, district heating has had generally greater acceptance. Use in Scandinavian countries is extensive (7). In Denmark, 42 percent of buildings are supplied by heat distribution systems. The Western European countries with the largest connected heating capacities are Germany with 36 GW, Sweden with 26 GW, France with 16 GW and Denmark with 15 GW. Use in Eastern Europe is also extensive, especially in Czechoslovakia, Hungary, Poland and the USSR.

4. PERFORMANCE REQUIREMENTS

To meet the needs for heating buildings, a heat source must have a number of important features.

(i) It must have appropriate capacity to supply groups of buildings or to fit into a district heating system. An appropriate unit size for many applications is 10 MW, as single or multiple units.

(ii) It must deliver heat at a temperature appropriate to the building heating system. Steam and hot water in the range 50-150°C are used in a variety of applications. Hot water at 65-85°C is in line with the current trend to lower- temperature hot-water distribution systems.

(iii) It must be capable of being sited close to urban loads. As with combustion units, a nuclear heat source must be safe.

(iv) It must be economical, which means having acceptable capital, operating and fuelling costs.

5. THE SLOWPOKE ENERGY SYSTEM

The SLOWPOKE Energy System is a simple nuclear heat source capable of supplying 10 MW of thermal energy in water at 85°C. As shown in Figure 1, it is a pool-type reactor designed to operate at atmospheric pressure, thereby eliminating the need for a pressure vessel. Consequently, loss-of-coolant caused by depressurization is impossible.

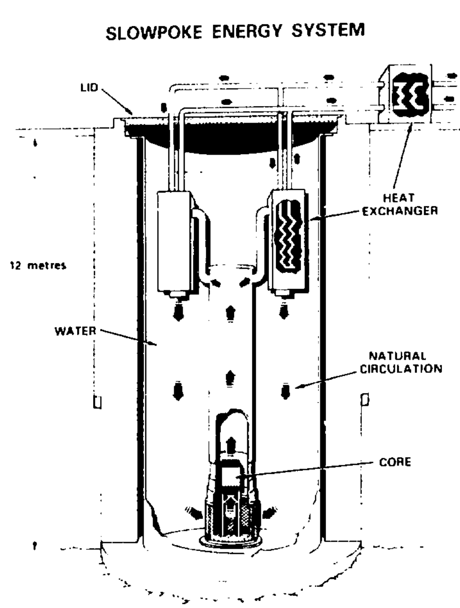

FIGURE 1: Schematic Diagram of the SLOWPOKE Energy Concept

The reactor core, coolant riser duct and the primary heat exchangers are installed in a steel-lined concrete container. This double containment of the pool water prevents loss-of-coolant caused by leakage.

The pool water serves as the moderator, heat transfer medium and shielding. Primary heat transport from the core is by natural circulation of the pool water through the plate-type heat exchangers. Natural circulation ensures core cooling without the need to depend on the reliability of pumps or the integrity of electrical supply for the pump motors.

The secondary circuit delivers the heat to the distribution system by way of the secondary heat exchanger. Thermal power is measured in the secondary circuit for the purpose of metering.

In the event of loss of secondary flow, such as a power interruption to the pumps, the large pool volume delays core temperature rise. As a result, thermal transients extend over many hours. This factor, combined with unique design features that limit reactivity change rates to very low values, eliminates the need for the fast-acting shutdown systems that are essential for pressurized power reactors.

The pool water is continuously pumped through ion exchange columns to maintain water chemistry and to control corrosion. The ion exchange columns can also remove fission products from defective fuel and gadolinium nitrate, should the liquid-absorber shutdown system be actuated.

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.

A goal of the SLOWPOKE Energy System design is to fully automate all essential systems, thus allowing the unit to be operated for extended periods of time without an operator in the reactor building.

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 operation with local surveillance. Meeting the regulatory requirements implies system diversity, component redundancy, a rigorous safety analysis and overall defence in depth. This is accomplished by inherent safety features, engineered control systems, operating conditions and administrative practices.

The inherent safety features of the SLOWPOKE Energy System 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, the primary heat transport system is 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; and
- separate and diverse shutdown systems dedicated to safety.

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.

6. TECHNOLOGICAL BASE

The SLOWPOKE heating reactor concept has the advantage of a sound technological base. For over 30 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 introduced in 1972 and remains part of the AECL product line.

6.1 SLOWPOKE Research Reactors

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 at the Chalk River Nuclear Laboratories in Ontario, eight units have been installed (8), all in urban locations, and they have accumulated more than 70 reactor-years of reliable operation. They are the only reactors in the world to be licensed for unattended operation for periods up to 72 hours.

6.2 SLOWPOKE Demonstration Heating Reactor

The realization that many of the key design criteria of the research reactor are the same as those required for a nuclear heat source, led the developers to optimize the reactor for heat production rather than neutron production, while retaining the essential safety features of the concept. This work culminated in the decision to construct and operate the SLOWPOKE demonstration heating reactor at AECL's laboratory facilities at the Whiteshell Nuclear Research Establishment in Manitoba.

Construction of the demonstrator started in the spring of 1985 and the reactor started operation on 1987 July 15. The SLOWPOKE Demonstration Reactor is designed to operate at 2 MWt and incorporates the key technical features of the research reactor. The primary purpose in designing, constructing and testing this facility is to validate, in a very demonstrative way, that the technical, economic and safety criteria for the nuclear heating reactor concept can in fact be met. A photograph of the facility taken during the final stages of commissioning is shown in Figure 2.

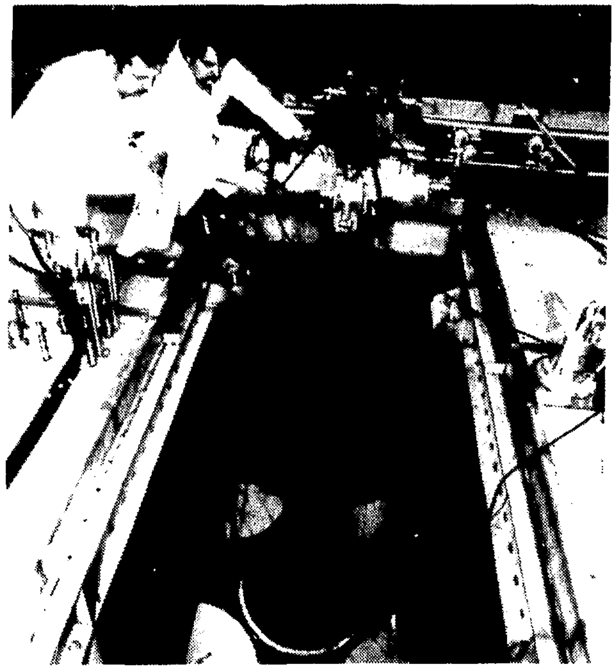

FIGURE 2: Photograph of the SLOWPOKE Demonstration Reactor at Atomic Energy of Canada Limited's Laboratories at the Whiteshell Nuclear Research Establishment, Manitoba

The demonstrator is currently undergoing high-power operating tests. It is providing important physics and thermalhydraulic information that is being used to validate the method and computer codes used to design and analyze SES-10. As well, the demonstrator is giving valuable operating experience.

A hot-water distribution system has been installed between the reactor and two buildings of the Whiteshell complex. The method of heating these buildings has been modified so the buildings can be heated by the SLOWPOKE system or from the normal site-heating system. Commissioning is in progress and SLOWPOKE-generated energy will be used during the next heating season.

6.3 The SLOWPOKE Energy System

Based on the lessons learned from the design, construction, licensing and operation of the SLOWPOKE Demonstration Reactor, the design of the 10 MW commercial-size unit is well advanced. A parallel component development and testing program has been implemented for those systems that have been changed from the demonstration system.

The 10 MW SLOWPOKE Energy System is designed to be a base-loaded heat source, with fossil-fuelled peaking and backup boilers as part of the same heating plant. It can be housed in a separate building or building extension that measures 10 x 15 metres, as shown in Figure 3. The reactor core and safety systems are being designed to remain fully functional during and after seismic events in Canada, Europe and Asia.

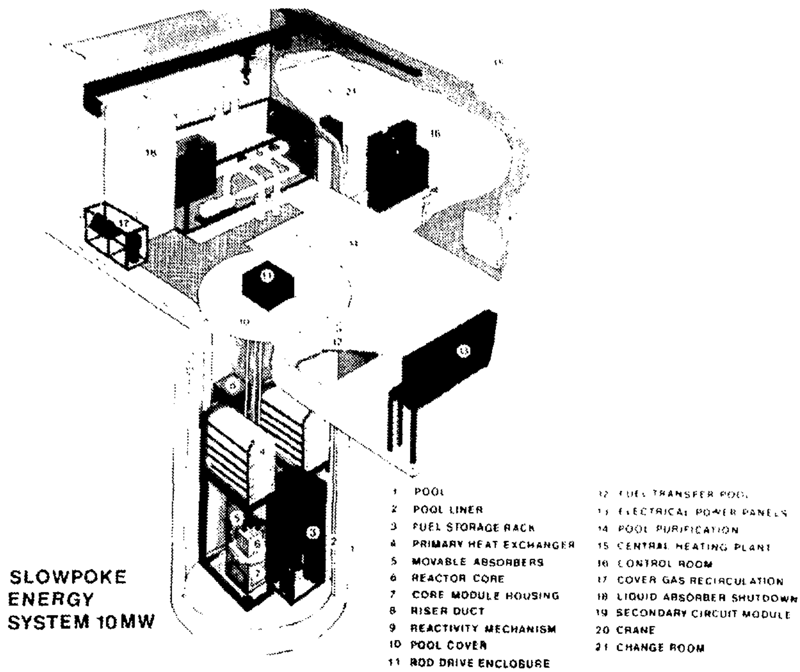

FIGURE 3: Cutaway View of the 10 MW SLOWPOKE Energy System as a Commercial Installation

During the design process, particular attention has been paid to partitioning the various systems into separate modules, to facilitate off-site manufacturing and testing. This approach is also convenient for joint overseas projects where local manufacturers will be supplying much of the plant. In fact, since the manufacturing technology that is required is not as sophisticated as the high-temperature and high-pressure engineering needed for conventional nuclear power stations, a high degree of local content can be achieved even for the first unit in most countries.

The use of factory-fabricated modules contributes to the short construction time of one year that is proposed for the commercial units.

7. ECONOMICS

The analysis of the competitive position of the SLOWPOKE Energy System relative to conventional fossil fuels or other nuclear heating concepts must include the capital investment, the fuel costs, the operating and maintenance requirements and the load factor.

The capital cost of a SLOWPOKE Energy System in Canada is about $7 M, depending on the nature of the site. This capital cost, when combined with the low operating expenses, results in the unit energy cost of heat from a SLOWPOKE Energy System of less than $0.02/kWh, Canadian, for a unit built in Canada with a load factor of 80 percent. This total-unit energy cost includes the capital, fuel, operating and maintenance, spent-fuel management and the decommissioning of the facility at the end of its useful life. The economic analysis is based on a 30-year amortization period for the capital and a 5 percent discount factor.

Comparison with the cost of heat from fossil-fuelled systems is based on the world price of crude oil. Furthermore, to eliminate potential confusion in comparing overall costs, only the variable cost of heat from oil is used--no allowance being made for the capital cost of the oil boiler or its operating and maintenance costs. This approach is taken to permit a realistic comparison of the effect of substituting a SLOWPOKE Energy System into an existing heating system and simply displacing oil purchases.

In examining the utilization of existing heating systems, oil and natural gas are the predominant fuels. A comparison of the heat cost from these fuels and the SLOWPOKE Energy System, as shown in Figure 4, shows that the SLOWPOKE is competitive now and that the savings to be realized increase considerably as the world price of crude oil increases according to current forecasts (9).

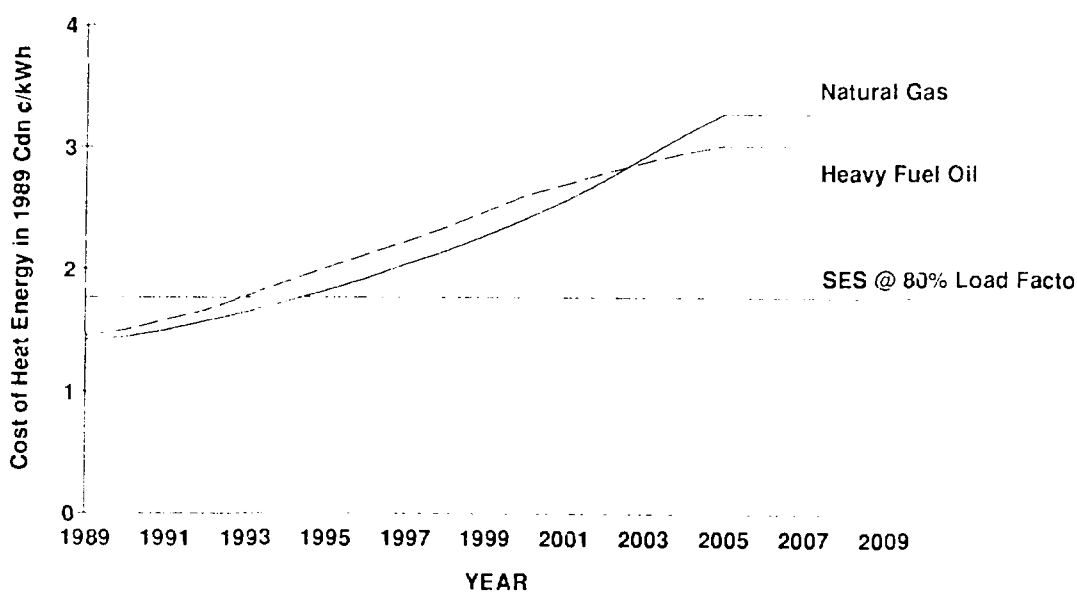

FIGURE 4: **Cost of Heat Energy from Various Fuels for District Heating Companies and Large Users**

8. URBAN SITING

In addition to financial savings and fuel security, the general public can be expected to consider the environmental impact and relative risks associated with adopting any new heating technology. Nuclear heating is no exception and, in fact, may be at a disadvantage as a result of the current image of the nuclear industry--a series of megaprojects so expensive and so complex that only governments and major utilities are prepared to finance the investment required.

The SLOWPOKE Energy System can bring nuclear technology close to the public, not as remote megaprojects, but as small energy systems located close to the people they serve. This implies that not only must the safety and environmental issues be thoroughly reviewed by technical experts, but they must also be expressed in a manner that can be understood by individual members of the general public with limited or no technical knowledge.

Canada's nuclear plant approval process involves the Atomic Energy Control Board and the Federal Environmental Assessment Review Office. The role of each body can be generally described as relating to technical and community standards, respectively. These authorities are a good reflection of the perceptions of the public they serve. The Atomic Energy Control Board assesses the safety of the reactor facility from a technical point of view. The Federal Environmental Assessment Review Office process requires public input on siting; the industry supporters must satisfy the public that the facility is safe and has acceptable environmental impacts.

A major consideration in the public information program is the environmental impact. The SLOWPOKE Energy System is a heat source free from the pollution problems of conventional fossil fuels, such as coal, oil or natural gas. It does not emit chemicals which contribute to urban air pollution, acid rain or the greenhouse effect. It presents an opportunity to enhance the environment by improving the quality of air in urban areas and reducing the global load of carbon dioxide.

Nuclear heating with simple, safe systems offers the opportunity to significantly reduce the dependence on combustion fuels. The SLOWPOKE Energy System has performance characteristics that make it well suited for heating buildings in the urban environment.

9. REFERENCES

(1) Frisch, J.R., ed., Energy 2000-2020: World Prospects and Regional Stresses, London, Graham and Trotman, 1983.

(2) Lynch, G.F., et al., Unattended Nuclear Systems for Local Energy Supply, Paper 4.2-2, Thirteenth Congress of the World Energy Conference, Cannes, 1986.

(3) Our Common Future, World Commission on Environment and Development, pp. 8,9, Oxford University Press, 1987.

(4) National Academy of Sciences, National Academy of Engineering and Institute of Medicine, Global Environmental Change, (Recommendation to President-Elect George Bush), National Academy Press, 1988.

(5) National Task Force on Environmental Economy, Report to the Canadian Council of Resources and Environment Ministers, 1987 September 24.

(6) R. Brynolfson, Measuring Up: The IDHCA 1987 Survey of DHC Utilities District Heating and Cooling Journal, Vol. 74, No. 2, p. 28, 1988.

(7) N. Nedergaard, The District Heat Situation Among Unichal Members, International District Heating, Vol. 17, pp. 334-339, 1988 September/October.

(8) Hilborn, J.W. and Burbidge, G.A., SLOWPOKE: The First Decade and Beyond, Proceedings of the International Symposium on the Use and Development of Low and Medium Flux Research Reactors, Cambridge, Massachusetts, 1983.

(9) National Energy Board, Canadian Energy - Supply and Demand, 1987-2005, Report No. NE23-15/1988E, Department of Supply and Services, Ottawa, 1988.

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