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CANDU

The Advanced PWR

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CANDU

THE ADVANCED PWR

WITH PROVEN PERFORMANCE

- SIMPLE
- SAFE
- FLEXIBLE

Atomic Energy of Canada Limited
Énergie atomique du Canada limitée

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August 1989

1.0 THE CANDU PWR

The key elements and overall design of a very large fraction of most nuclear power plants are the same. For example, they incorporate a Turbine Building with a turbine and generator, maintenance facilities, administrative facilities, a pump house and a reactor containment structure.

Both the heavy water and light water type of pressurized water reactors, generally referred to respectively as CANDU and PWR, have many common features. Both, for example, use a form of water as coolant and moderator and use the heat of fission from the reactor in "light--bulb" steam generators to generate steam to drive the turbine–generator. There is no essential difference between heavy water and light water Pressurized Water Reactor power stations except in the reactor core design and in some aspects related to the heat transport system. CANDU is an advanced PWR with a proven performance record. CANDU is relatively simple, safe and provides the flexibility to serve long term requirements.

Figure 1 compares the heat transport systems of CANDU and light water PWRs and Figure 2 compares the reactor structures.

The CANDU reactor uses a large number of fuel channels (from 200 to 600), arranged in a square lattice within a horizontal cylindrical tank. This structure, called the calandria, is maintained filled with heavy water (moderator) at low temperature (near 70°C) and near atmospheric pressure. A typical CANDU reactor is shown in Figure 3; fuel channel detail is presented in Figure 4.

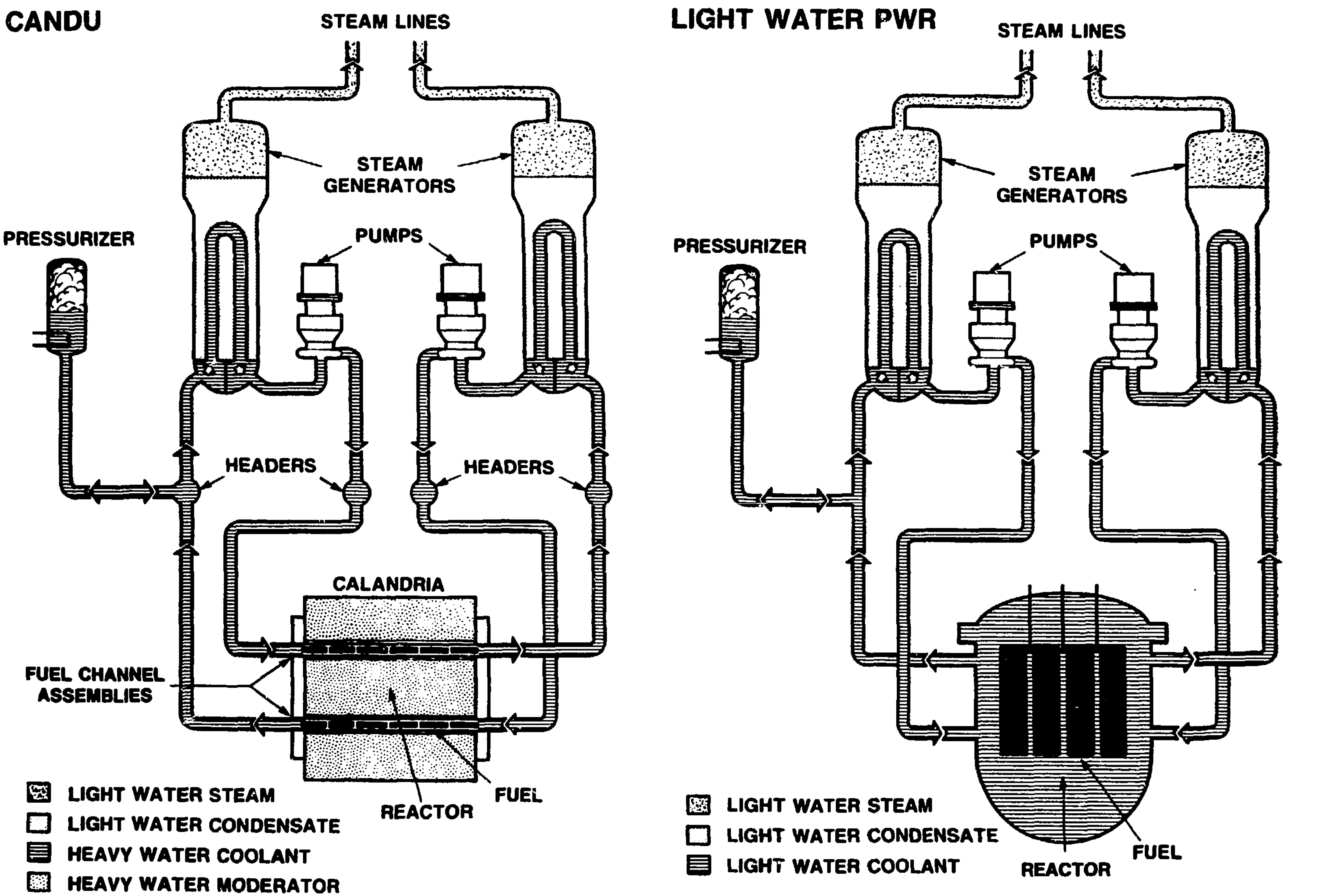
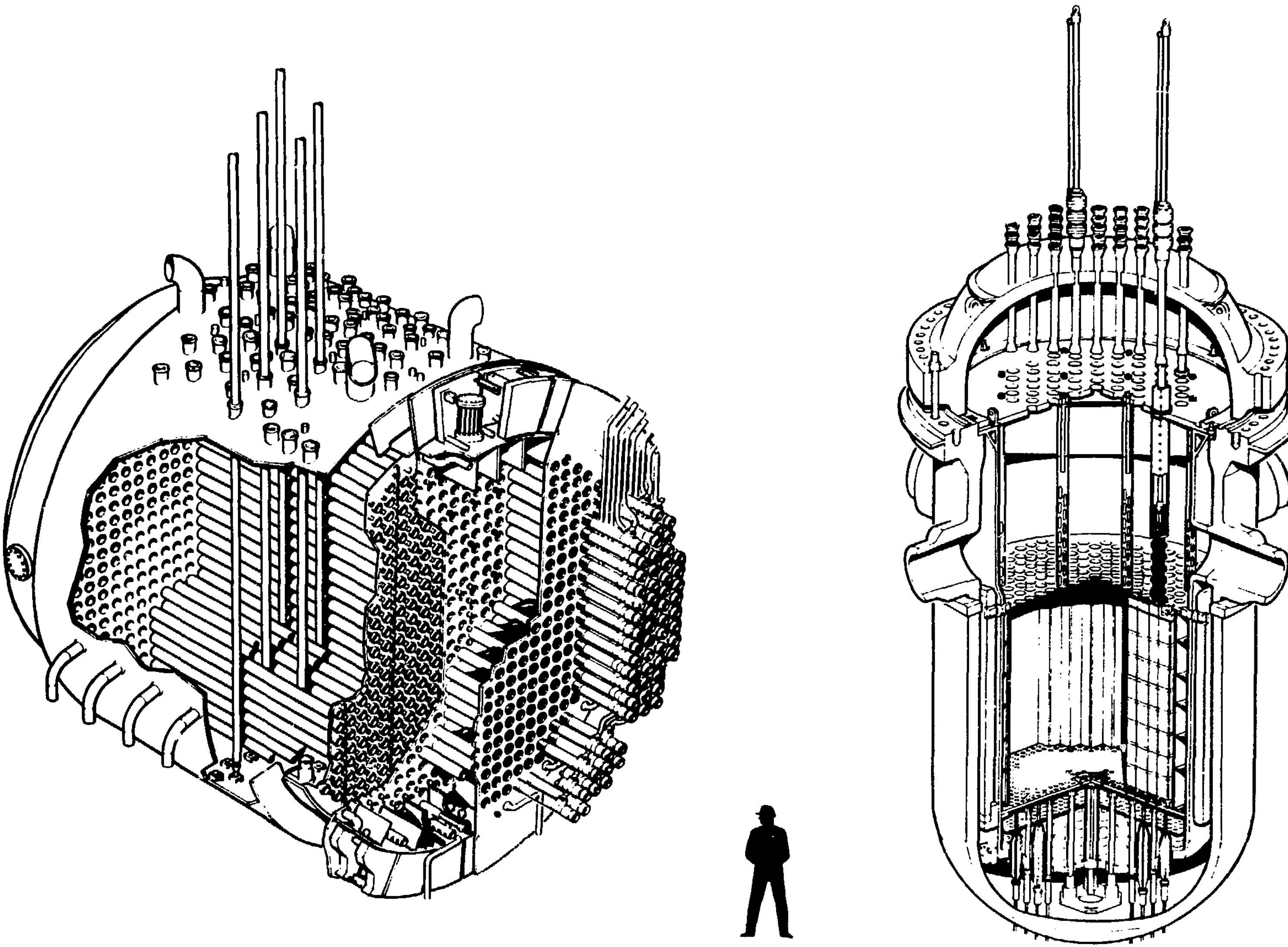


FIGURE 1 PWR HEAT TRANSPORT SYSTEM COMPARISON



CANDU

LIGHT WATER PWR

FIGURE 2 REACTOR STRUCTURES COMPARISON

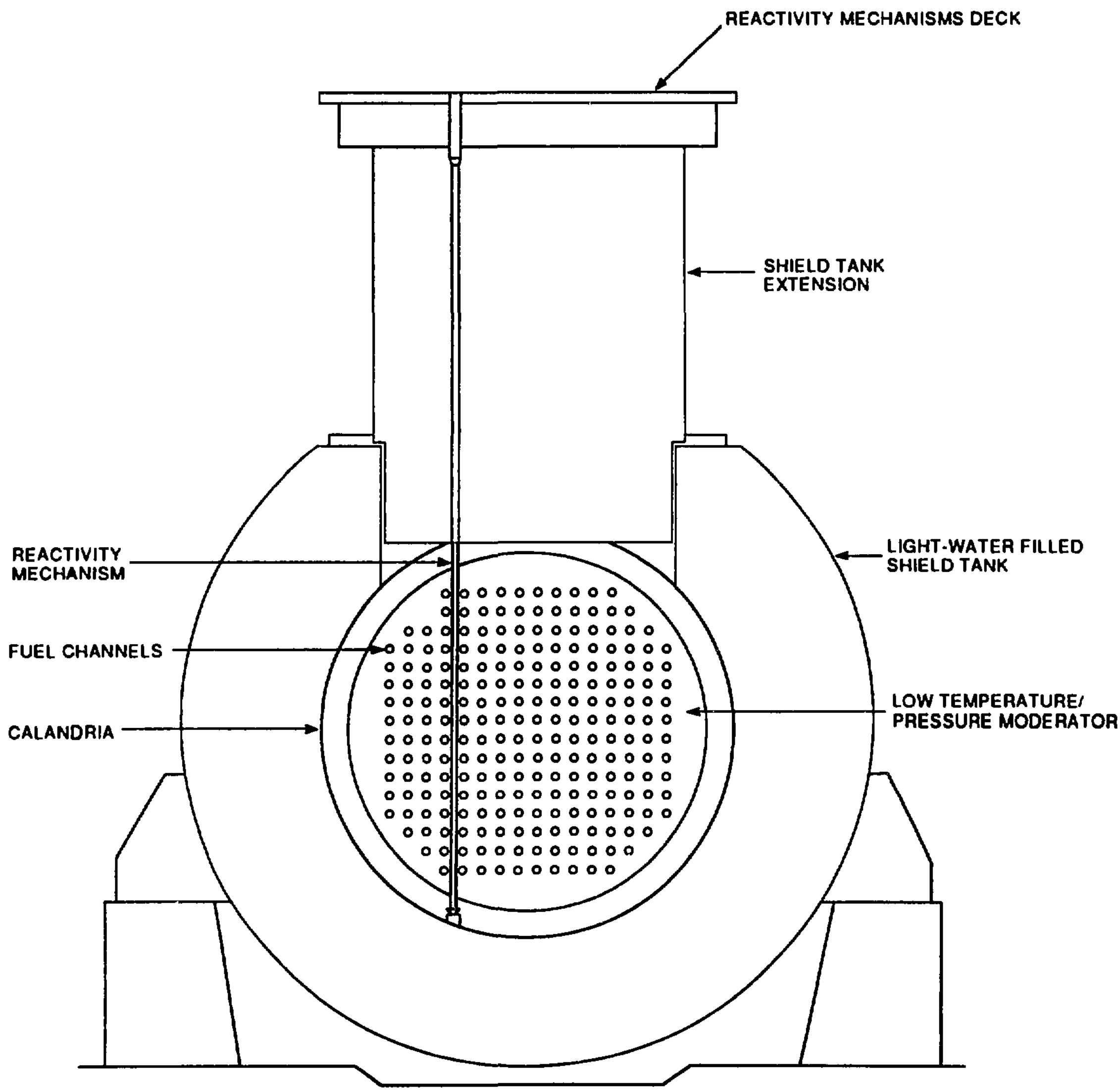


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FIGURE 3 CANDU REACTOR

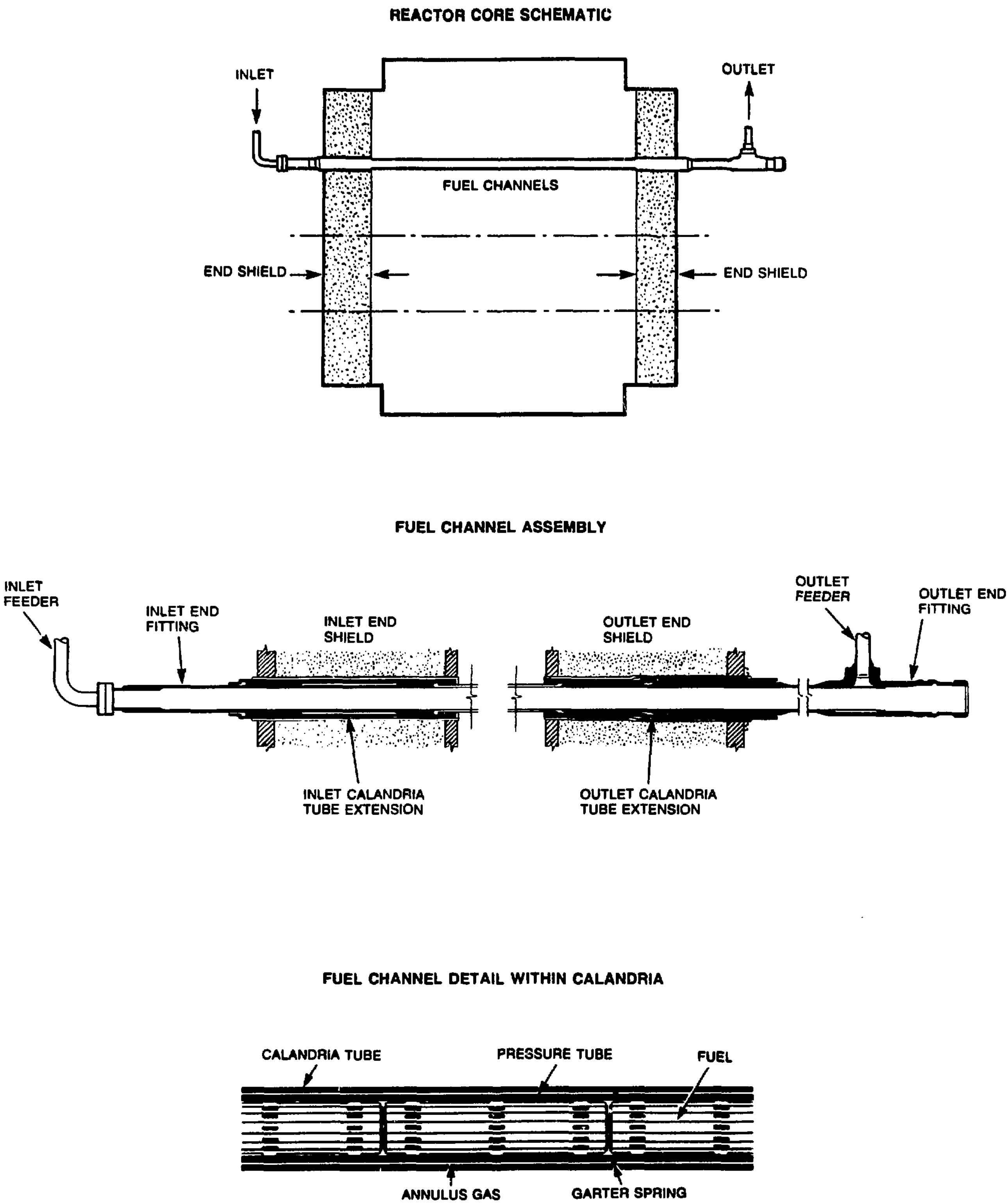

FIGURE 4 CANDU FUEL CHANNEL

2.0 CANDU – THE SIMPLE PWR

CANDU simplifications (relative to light water PWRs) include:

- Carbon steel reactor coolant system piping instead of stainless steel (more easily fabricated and inspected; it is ductile and immune to stress corrosion cracking).
- Pressure tubes instead of a massive, thick–walled, pressure vessel. Pressure tubes, the only CANDU component subjected to a combination of high stress and high radiation are easily replaced.
- Simple fuel bundle design that is easily fabricated (Figure 5) – same bundle design used throughout the core.
- Natural uranium fuel – requires no enrichment or burnable poison. Low enriched fuel can also be used.
- Simple control devices located in the cool low pressure moderator – none in the high pressure coolant.
- The reactor coolant system is free of reactivity control chemicals.
- Flexible storage arrangements for irradiated and new fuel (no concerns over criticality regardless of storage configuration because of low reactivity of CANDU fuel).

Because CANDU is a simplified PWR, the technologies required to design, manufacture and construct CANDU plants are less demanding than for other PWRs and, of course, any organization fabricating light water PWR components is inherently capable of fabricating CANDU components.

The unique CANDU heavy water technology is readily available and has been acquired and put in place by developing, or partly industrialized, countries. (Canada, at the start of CANDU development, India and Argentina, for example).

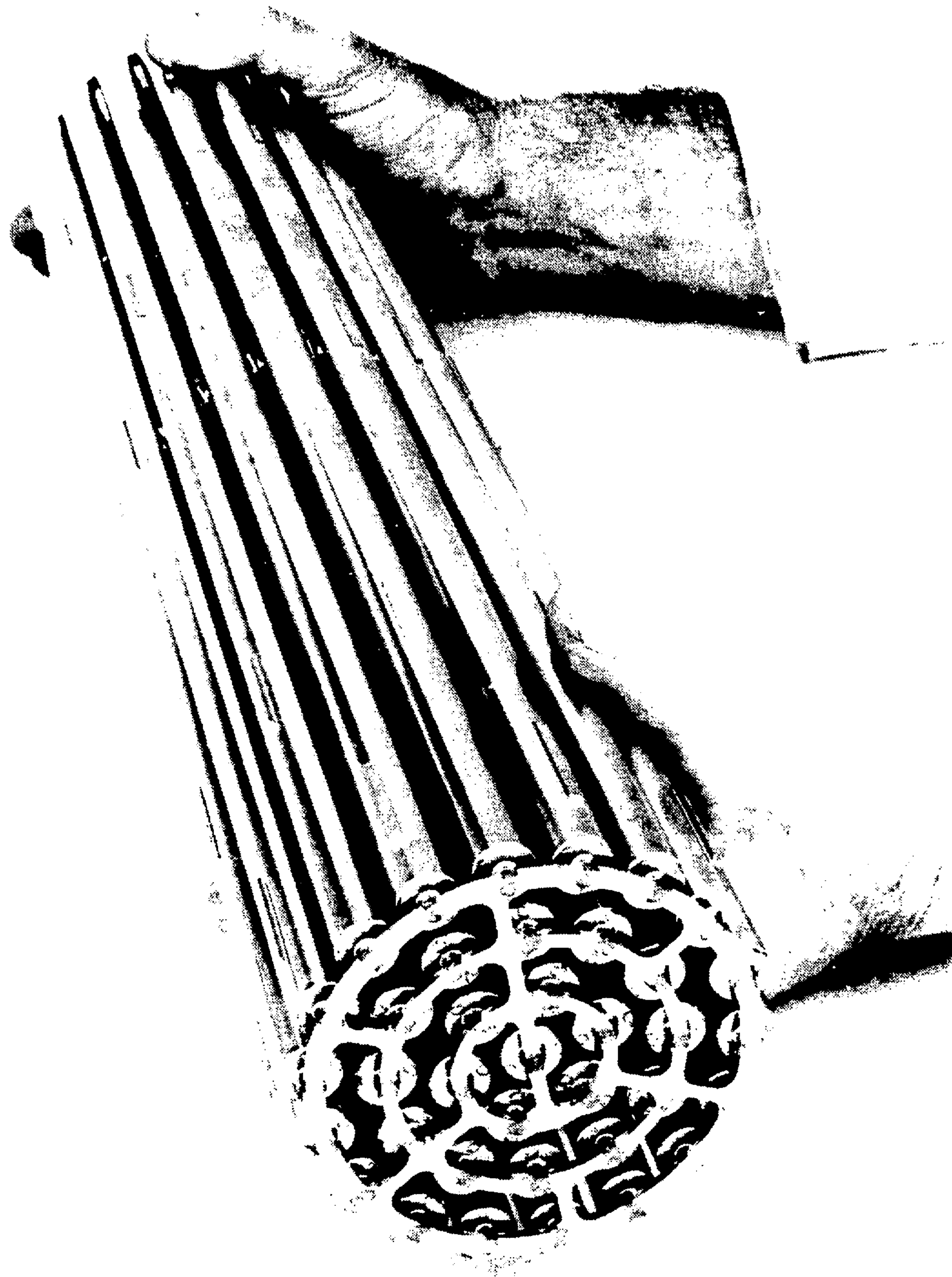

FIGURE 5 CANDU FUEL BUNDLE

3.0 CANDU PERFORMANCE

CANDU power plants have accumulated an enviable record in all key areas, including safety, capacity factor and radiation exposure to operating staff. No reactor type has equalled CANDU in any of these areas.

Although constituting about 6% of the world's reactors larger than 150 MW(e), CANDU plants consistently dominate the performance charts (Figure 6). This can be largely attributed to the performance of the components used. Although most are essentially the same as in light water PWRs, they have performed better. For example:

- Steam Generators: A tube defect rate of two orders of magnitude below the world light water reactor average.
- Reactor Coolant Pumps – There has never been a failure in a CANDU 6 plant of a pump seal, motor or other component.
- Valves: a world standard set by the bellows sealed and live loaded packing design developed in Canada.

A comparison of man–rem exposure at CANDU and other reactor type plants given in Figure 7, illustrates the excellent CANDU performance in this area.

The Top Ten

Lifetime World Power Reactor Performance to March 31, 1989*

from among 325 reactors over 150 MW

Country	Ranking	Unit	Type	Capacity Factor %†
	1.	Emsland	PWR	94.4
	2.	Pickering 7	CANDU	91.8
	3.	Point Lepreau	CANDU	89.2
	4.	Paks 4	PWR	87.5
	5.	Philippsburg 2	PWR	87.4
	6.	Paks 1	PWR	87.1
	7.	Grohnde A–1	PWR	86.7
	8.	Pickering 5	CANDU	86.5
	9.	Paks 3	PWR	86.3
	10.	Bruce 6	CANDU	86.1

**Source: Nuclear Engineering International*

$$\dagger\text{Capacity Factor} = \frac{\text{actual electricity generation}}{\text{perfect electricity generation}}$$

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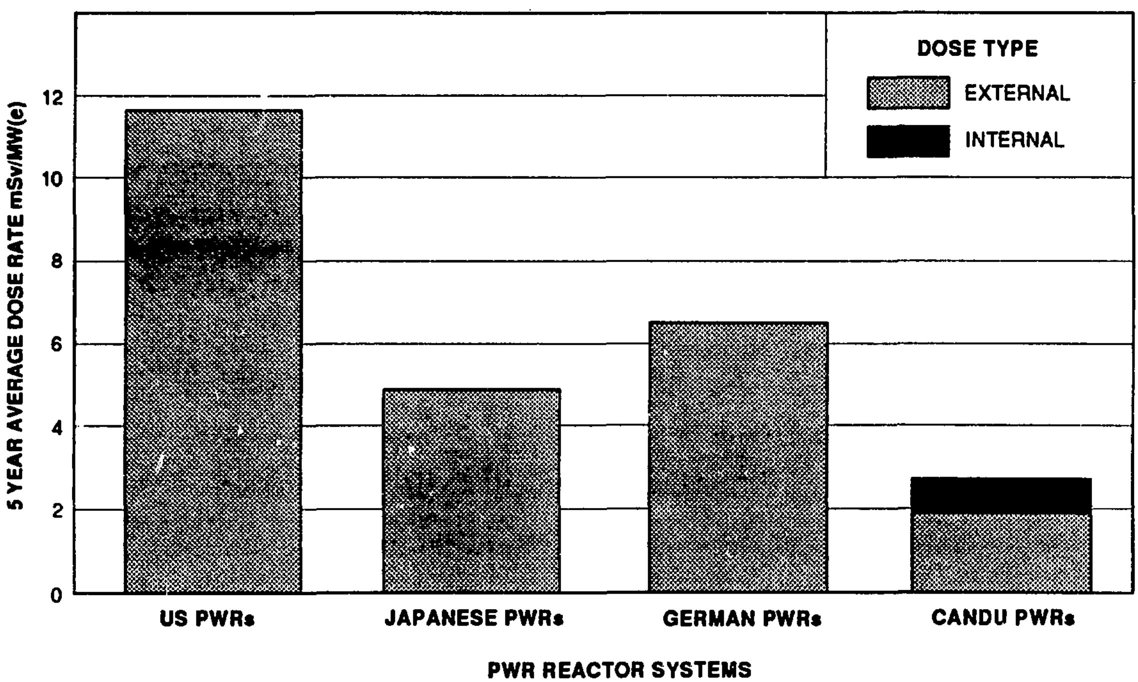
FIGURE 6 CANDU CAPACITY FACTOR

A COMPARISON OF THE 5 YEAR AVERAGE DOSES* OF CANDU AND PWRs



*MOST RECENT DATA USED IN COMPARISON

US TO END OF 1985 GERMAN TO END OF 1984

JAPANESE TO END 1986 CANDU TO END 1987

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FIGURE 7 MAN-REM COMPARISON

4.0 CANDU – INHERENT SAFETY FEATURES

The CANDU PWR has several inherent safety features. These include:

- Small excess reactivity in the reactor at all times during station life, because of on–power refuelling.
- All reactivity regulation devices have a low worth, due to limited excess reactivity, hence, the magnitude of a reactivity induced transient is limited.
- All reactivity regulating devices, including shutdown systems have a constant reactivity value over the life of the plant, because reactor reactivity is maintained constant.
- Long neutron life slows the rate of potential reactivity excursions.
- Immunity to many postulated transients including a rapid cooldown of the heat transport system.
- The moderator system which can remove decay heat under such severe conditions as a loss of coolant accident coincident with a failure of the emergency core cooling system.
- All reactivity control devices are in the cool, low–pressure moderator. No rod ejection concern.
- Comprehensive neutronic data for reactor control, facilitated by simple low–cost detection systems located in the cool, low–pressure moderator.
- A fuel channel lattice which is optimised for maximum reactivity. Any event that relocates the fuel reduces reactivity.
- Low radiation fields in the reactor coolant, because of on–line failed fuel detection and removal, and because of the absence of chemicals for reactivity control.
- Ease of handling of new and irradiated fuel. No criticality concern regardless of storage configuration.

5.0 SEVERE ACCIDENT TOLERANCE

There are three categories of events that can lead to severe core damage: uncontrolled power excursions, loss of heat removal capability and loss of coolant. CANDU reduces the probability of severe core damage through a combination of inherent and engineered safety features.

CANDU dramatically reduces the probability of an uncontrolled power excursion through the depth and redundancy of the reactor shutdown systems. In addition to the normal reactivity control system, CANDU has two independent fast–acting shutdown systems, each capable of shutting down the reactor and maintaining it subcritical for all design basis events. Because of this feature, failure to shut down is a small contributor to the overall core damage frequency.

For loss of heat sink events and loss of coolant accidents with coincident failure of emergency core cooling, the cool, low pressure moderator system provides fuel cooling. In addition, the light–water–filled shield tank, which envelops the calandria, provides an additional line of defence, should the moderator system also fail (Figure 3).

The severe core damage frequency for currently operating CANDUs is estimated at 4 x 10^{-6}/reactor year. For future reactors, this frequency is reduced by at least one order of magnitude. These values compare extremely well with the design target of 10^{-5} established by EPRI for the advanced PWR and BWR.

6.0 CANDU – FLEXIBILITY FOR THE FUTURE

The efficient utilization of the neutrons produced by fission in CANDU, unequalled by any other reactor type, allows the fuel cycle flexibility necessary to serve long–term energy requirements without the need for fast breeder or other new and complex technologies.

CANDU can, for example:

- Operate on a simple once–through natural uranium fuel cycle (Figure 8).
- Operate on a slightly enriched fuel cycle (in a range up to ~1.5% U235) with or without reprocessing (Figure 8).
- Use spent LWR fuel, with certain fission products removed (U236 has a very low cross section in CANDU and need not be removed) (Figure 9).
- Use recovered uranium from LWR reprocessing (Figure 9).
- Operate as a breeder or near breeder on thorium based fuel cycles.

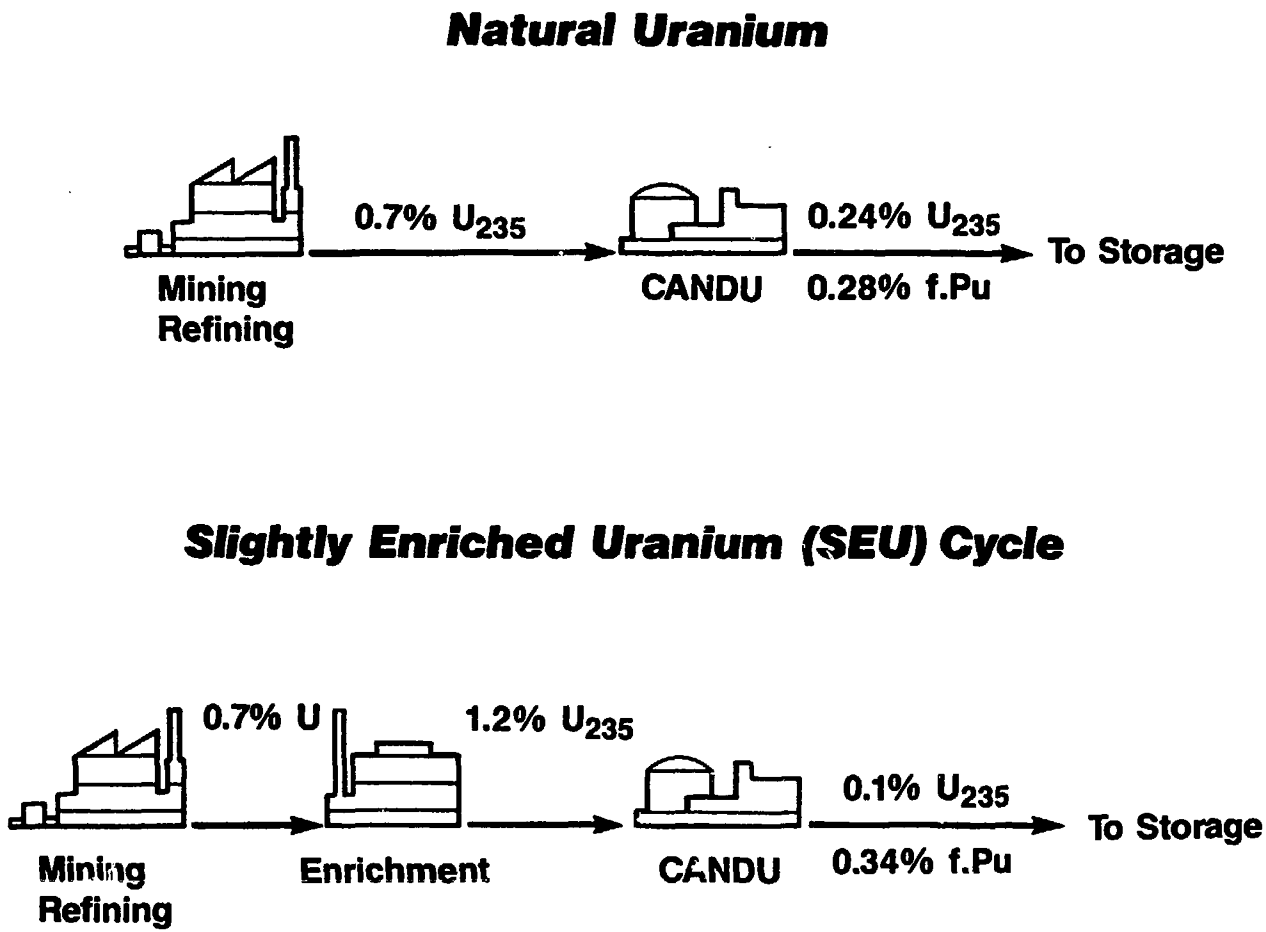

FIGURE 8 CANDU ONCE THROUGH FUEL CYCLES

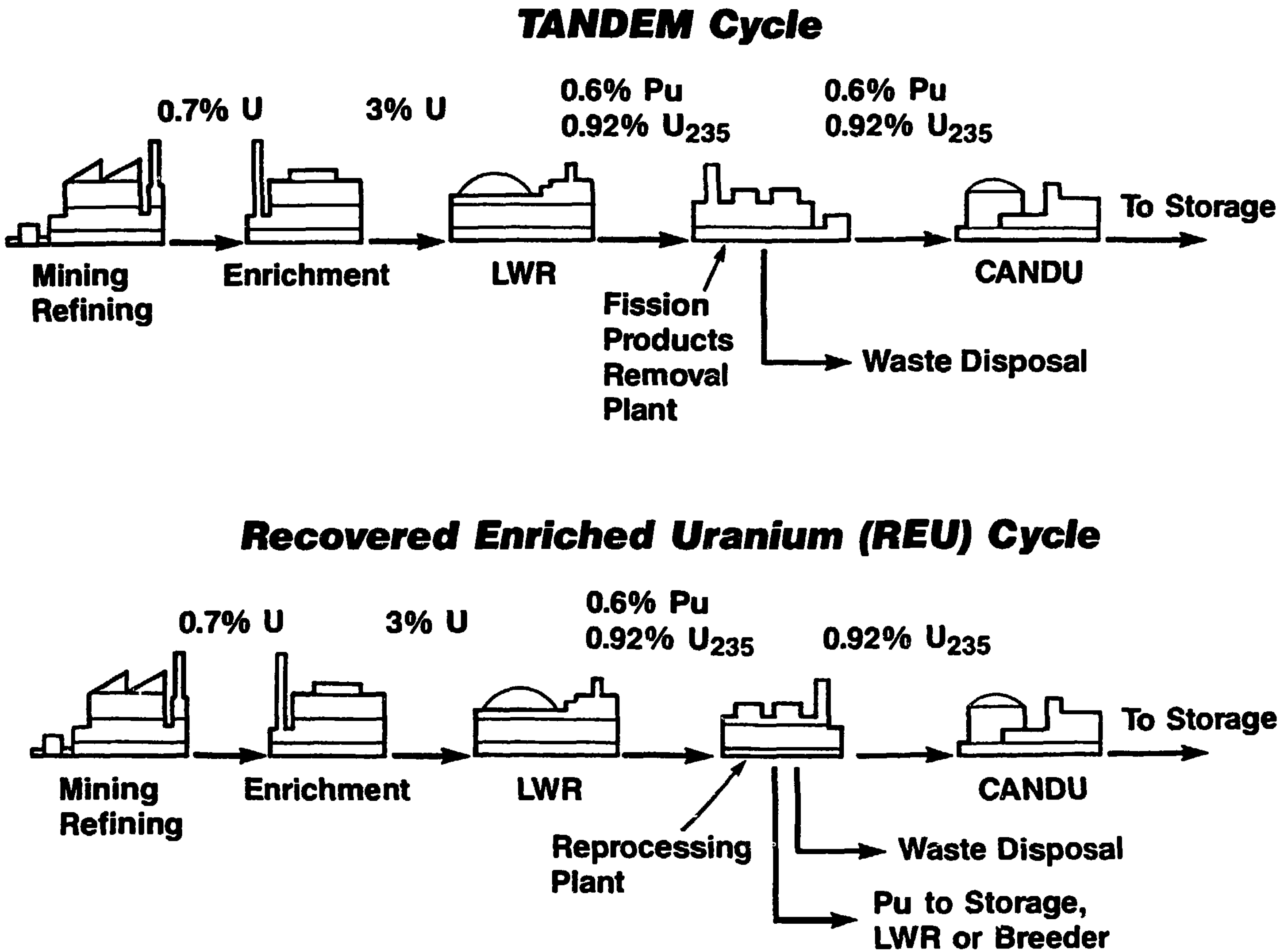

FIGURE 9 CANDU-LWR FUEL CYCLES

7.0 CANDU – THE ADVANCED PWR

CANDU 3, the latest CANDU power plant design, compares very favourably with requirements established by EPRI in the United States for advanced PWRs and BWRs. The following tables compares key requirements.

Requirement	Advanced PWR	CANDU 3
Safety Targets		
• core damage frequency	$< 10^{-5}$	$< 10^{-6}$
• maximum dose for events $> 10^{-6}$	25 Rem	25 Rem
Availability		
• capacity factor	87%	94%
• refuelling interval	2 years	0
• maintenance outage interval	2 years	3 years
• inadvertent trips	< 1/year	< 1/year
Design Life	60 years	100 years
Construction Time	54 months	35 months
Rad waste volume	< 2500 ft^3	< 1200 ft^3

8.0 CANDU – AVAILABLE NOW

CANDU 3, the latest CANDU power plant design, has a net electrical output in the range of 450 MW. The CANDU 3, using only proven system components and concepts, makes many significant advances. These include a 35 month construction schedule, ease of maintenance and life extension, state–of–the–art control and man–machine interface systems, a lifetime capacity factor target of 94% and enhanced plant safety.

CANDU 3 is an advanced PWR that meets the relevant EPRI requirements for the Advanced PWR. And it is available now.

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