Reactor, Boiler & Auxiliaries - Course 133

FUEL - PERFORMANCE & OPERATING EXPERIENCE

Before looking at the performance and operating record of CANDU fuel we shall define the parameters in common use to specify the fuel bundle and element ratings.

Fuel Element Heat Rating $\int \lambda d\theta$

As a result of the large temperature gradient in fuel elements, illustrated in the previous section, it is difficult to find precisely the heat generated by an element by specifying its temperature distribution as its thermal conductivity has to be known over a large temperature range. Rather than specify then, average fuel temperature or its maximum (central) temperature to indicate an element rating we use a parameter which can be measured experimentally.

This parameter is:

$\int_{Ts}^{Tc} \lambda d\theta$ or as it is normally written in abreviated from $\int \lambda d\theta$

where θ is the temperature, λ is the fuel thermal conductivity (kW/m/°C), Tc is the central fuel temperature and Ts is the surface temperature of the fuel.

The units of $\int \lambda d\theta$ then will be in kW/m and typical values are listed in Table I (60.1) for maximum rated (ie, outer) elements of the different bundles in use. To relate this unit to the actual fuel temperatures, Figure 1 shows the relationship of $\int \lambda d\theta$ and central UO_2 temperature.

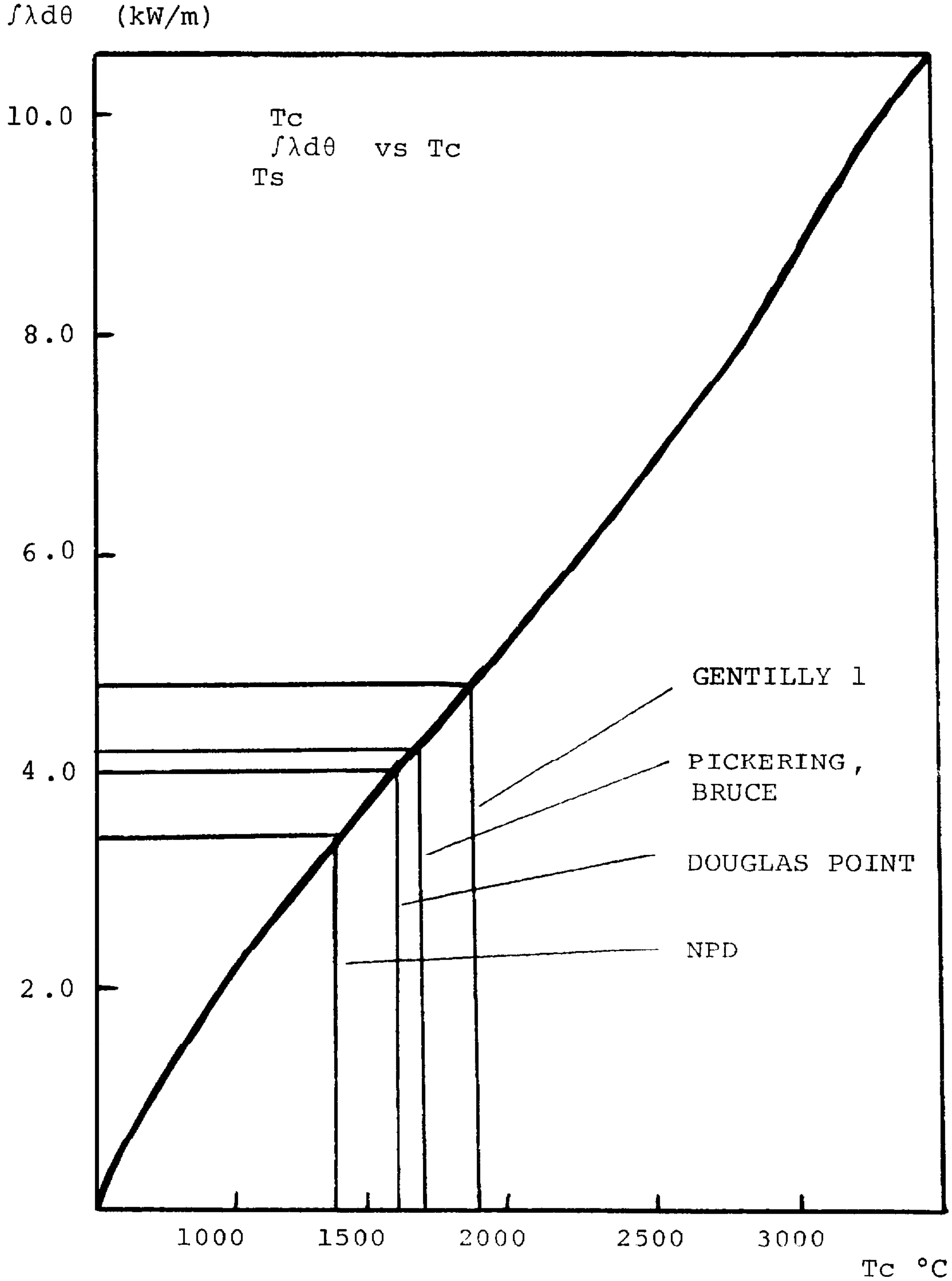
For instance at a fuel rating of 4.2 kW/m (Pickering) the central fuel temperature is about 1800°C, well below the melting point 2800°C of UO_2, but not the sheath melting temperature of 1850°C.

Linear Element Power q

The heat rating $\int \lambda d\theta$ does not give us directly the heat generated/unit length (called the linear element power q) but is related to it as follows:

$$q = 4\pi \int \lambda d\theta$$

Figure 1 Element Rating Temperature Relationship



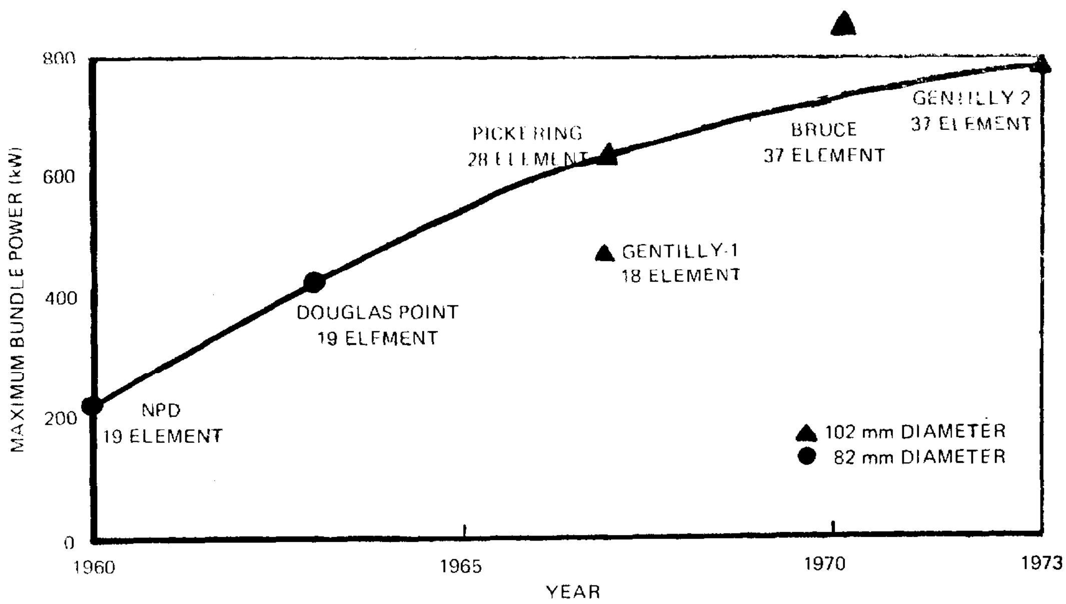


Figure 2 Bundle Power Vs Year of Design

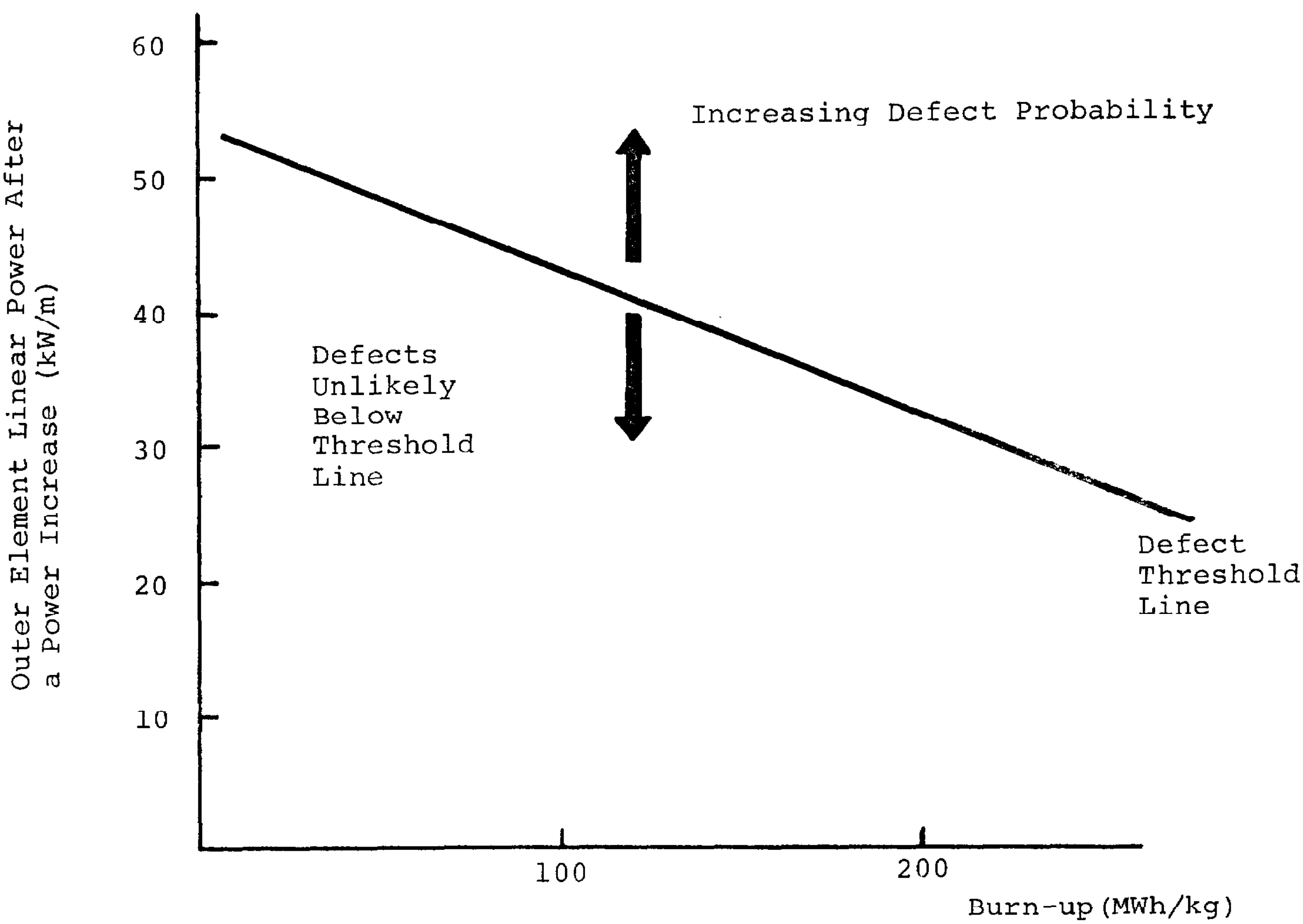


Figure 3 Experimental Defect Criteria

Hence taking the Pickering example again with $\int \lambda d\theta = 4.2$ kW/m the maximum linear element power q will be

$$q = 4\pi \times 4.2 = 52.8 \text{ kW/m}$$

for the maximum rated elements giving for 49.5 cm long elements a maximum element power of 26.2 kW.

Bundle Power

To obtain the maximum linear (or total) bundle power knowing the maximum elements, rating we cannot merely multiply by the number of elements because the inner elements operate at lower ratings as a result of the flux depression in the fuel, which has to be calculated.

For instance the maximum bundle power for the Pickering bundles (Table I) is 1325 kW/m giving 636 kW/bundle maximum, this being fixed from the AECB license limit of 705 kW/bundle.

The increase in bundle power that has been made available over the years is illustrated in Figure 2 and ranges from NPD 220 kW to Bruce 900 kW.

Fuel Bundle Performance

Some bundles when irradiated have become defective during operation and have been discharged before their terminal burn up (in MWh/kgU) has been reached. The percentage of fuel that has defected is small as seen from Table I.

The cause of these defects has been traced to bundles whose power is increased substantially after a prolonged period of low power.

These power changes can occur from the following conditions:

(a) insertion or withdrawal of boosters or adjusters

(b) changes due to moving fuel along a channel

(c) incorrect fuelling procedures.

Operating experience has indicated that steady power operation of a bundle below or at the maximum rating does not cause fuel defects.

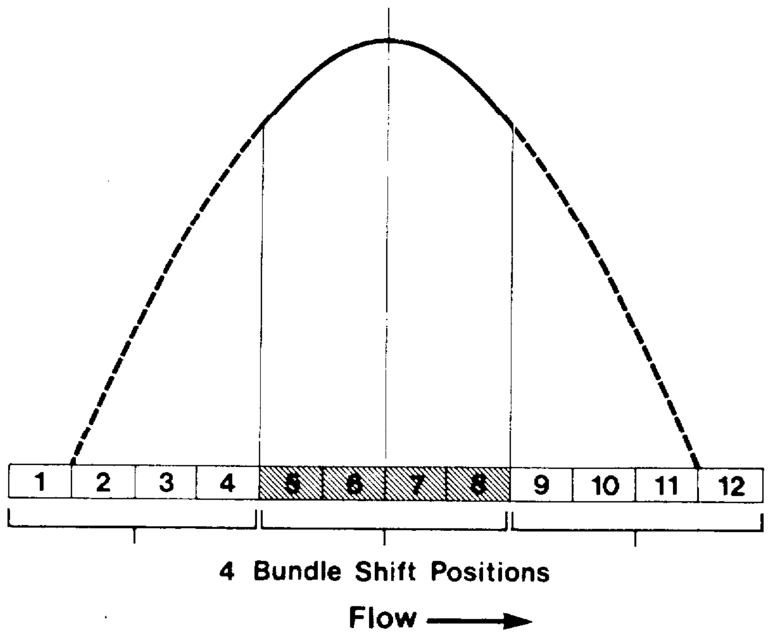


Figure 4 Douglas Point Axial Flux Profile

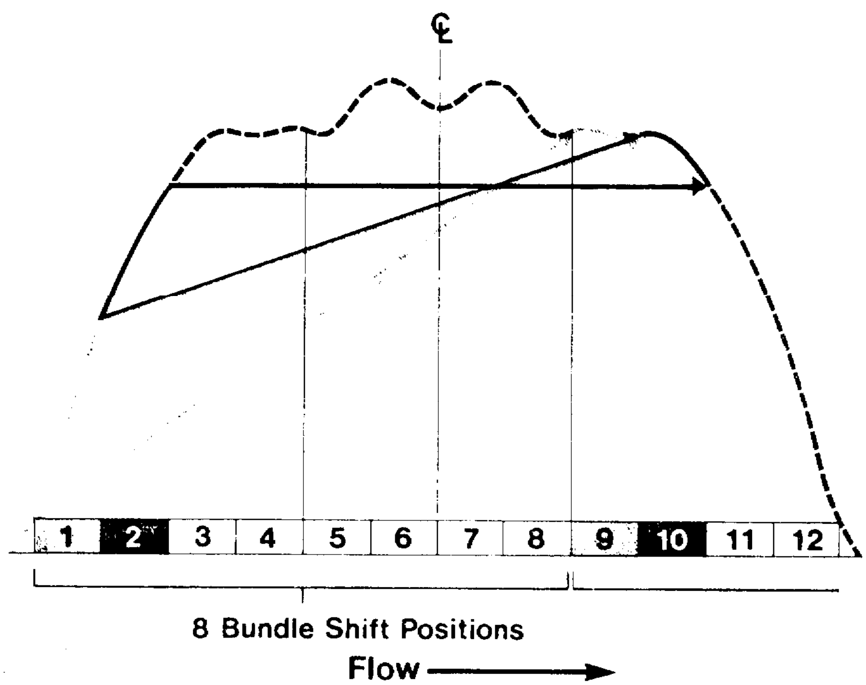


Figure 5 Pickering Axial Flux Profile

Defect Criteria

The defect criteria that have been established from operating experience at Douglas Point and at Pickering is shown in Figure 3. This shows us the outer element rating versus burn-up and indicates a decrease in element rating that an element can withstand when the rating is increased up to the defect threshold line.

To reduce the probability of defects then the following operating procedures have been adopted to reduce the effect of the types of power changes, causing defects, listed above, the aim being to achieve a target defect rate of less than 0.1% for a mature station.

(a) the use of CANLUB fuel, described in the previous section

(b) the withdrawal sequencing of adjusters and the allowable reactor power during and after the transient are optimised, from the defect experiences to try to minimize overpower effects.

(c) the change from 4 bundle fuelling shifts at Douglas Point and from 8 bundle shifts at Pickering.

The latter fuelling procedures are shown in Figure 4 and Figure 5 illustrating the channel axial flux profiles at these stations. For Douglas Point (and also NPD and Bruce A)this is a symmetric approximately cosine profile but for Pickering the profile is more flattened due to adjuster usage.

For a 4 bundle shift at Douglas Point then bundles #1 and #2 will be moved up to positions #5 and #6 experiencing large power increases. These bundles were then found to be defective (outer elements only).

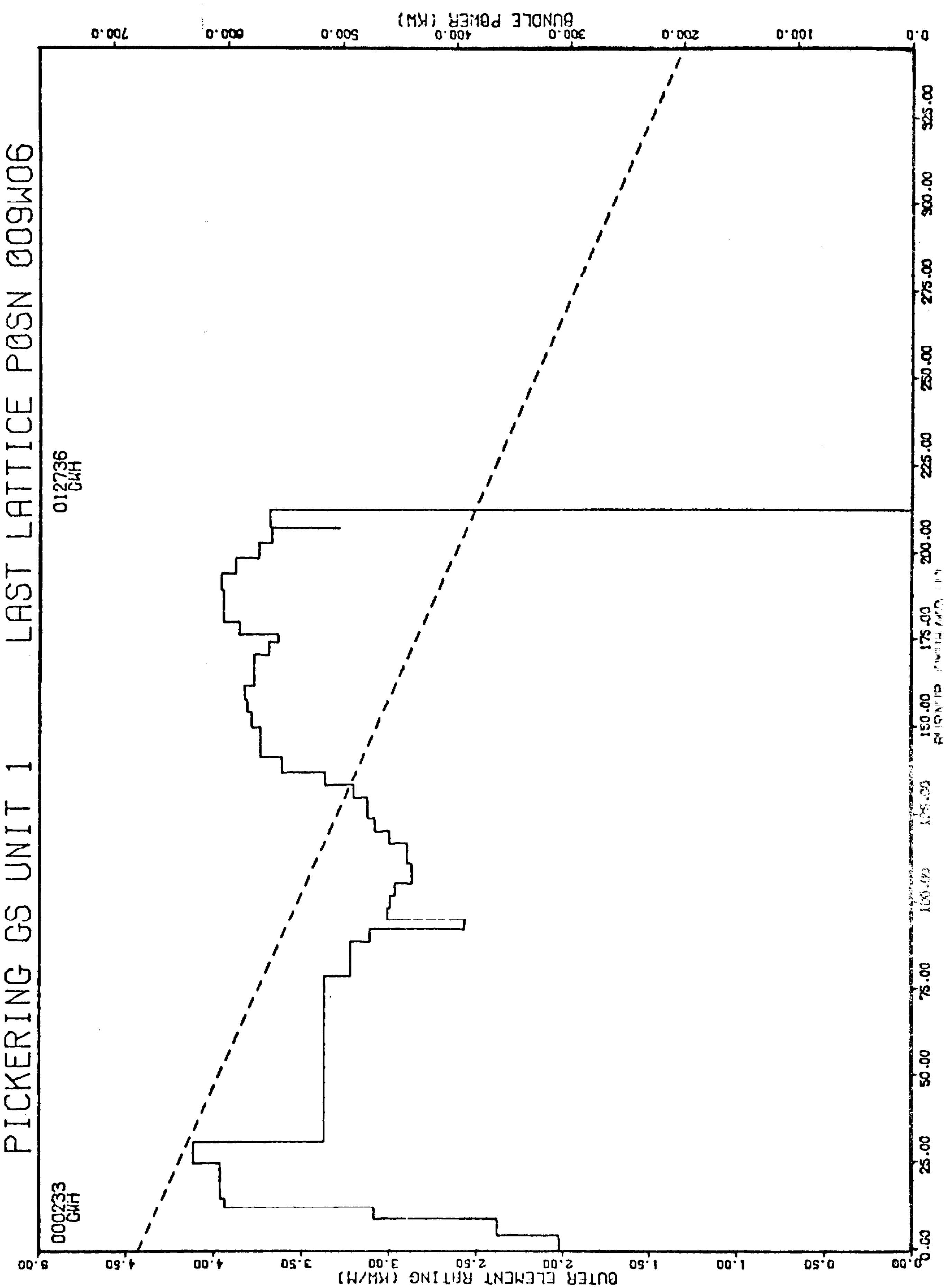
Successful eight bundle shifting at Douglas Point, established since 1971, is now almost exclusively used reducing the defect rate.

For an 8 bundle shift at Pickering the largest power increases are seen in bundles #9 and #10 and indeed most defects have been observed in these bundles. As a result 10 bundle shifting is now used at Pickering for the high power channels.

(d) Fuel management techniques are based on the following, more general considerations:

- fuelling priority is given to high burn-up channels
- equal numbers of east, west channels are fuelled together

Figure 6 Power History of Bundle 08850C



- equal numbers of channels/zone are refuelled
- maximum separation is kept between recently fuelled channels

Each fuel bundle has a record kept of its power history in the core and a typical history of a defective bundle at Pickering is shown in Figure 6.

ASSIGNMENT

1. To avoid the defects caused by 4 and 8 bundle shifting at Douglas Point and Pickering why do we not replace the complete channel with fresh fuel?

2. What may be the consequences of not observing the techniques for fuel management listed in (d) above?

TABLE I

CANDU FUEL PERFORMANCE DATA

(To December 1974)

Station	Bundles in Core	Irradiated	Discharged	Defective	% Defective
Douglas Point	3632	10,509	6877	72	0.68
Pick					
Unit 1	4680	15,012	10,332	94	0.63
Unit 2	4680	13,646	8,966	1	0.01
Unit 3	4680	9,818	5,138	6	0.06
Unit 4	4680	9,296	4,616	0	0.00

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