LECTURE 11: FUELING STRATEGIES AND CYCLES

MODULE OBJECTIVES:

At the end of this module, you will be able to describe:

1. **The use of simulations for channel selection in fueling**
2. **Examples of specific problems solved in past fueling**
3. **Opportunities for new fuel cycles**

Fuel Management and Reactor Operation

Introduction

These lecture is of particular interest for the reactor physicist who is involved with the daily operation of a CANDU reactor, or who provides advice to the operating staff when unusual or unforseen situations develop.

Procedures for Fuel Scheduling in Ontario Hydro

- The planning and implementation of the fuel management is a co-operative effort between head office and station operating staff, with a key function being provided by the "monthly" SORO simulation. Their roles are discussed in the following.

The Role of Head Office Staff

- The activity of Head Office staff with regard to fuel management usually begins well before the reactor is commissioned.
- Studies are done, in collaboration with the reactor designers, to compare various fuel bundle shifting schemes and select the most suitable for reactor operation.
- Calculations are performed to determine the initial fuel loading and to simulate the initial core transient and the approach to equilibrium.
- Results of these studies are used, in conjunction with the data provided by the designers, to plan the fuel procurement and fabrication.
- The effects of varying fuelling rules are studied by simulating a period of operation at equilibrium. The results are reviewed and discussed with the operating staff and may be used as part of their training.
- Once the reactor begins power operation, the Head Office personnel follow the fuel management by running the SORO program, usually on a monthly basis, to simulate the actual station operation.

- Support to operating staff is also provided in the event that unusual problems lead to special difficulties in planning the fuel scheduling. Typical examples are the occurrence of fuel defects or the temporary unavailability of the fuel handling equipment.
- Complementary to this function of direct support is the collection and analysis of operating data. Activities in this area include:

(a) Fuel performance analyses. The output from the monthly SORO simulation provides the input to a program which records the operating history of each bundle which has gone through the reactor. These data are analyzed to determine the mechanisms leading to fuel defects and to provide feedback to designers on criteria for more efficient operation of the reactor.

(b) Analyses of the reactor regulating and protective systems to optimize their performance and assure that the reliability targets are met.

(c) Calculation of cobalt activity in the adjuster rods. The Pickering NGS A units are equipped with adjuster rods. The Pickering NGS A units are equipped with adjuster rods made of cobalt. These are periodically removed from the core when they reach a certain activity since the Co-60 produced has a commercial value.

The Role of the Fuel Engineer

- Each operating station in Ontario Hydro has a "Fuel engineer". This is a professional or a group of professionals who have the responsibility for planning the fuel scheduling on a daily basis and dealing with all operating problems related to reactor-physics.

- the main function of the fuel engineer is to provide the operators with a list of channels to be fuelled in the following period of operation.

- In order to determine this list at any given time, the fuel engineer must first establish the status of the core and of other systems such as ROP, reactor regulating system, etc. which are affected by fuelling.

- To determine the status of the core the fuel engineer has available the latest SORO simulation and readings from the reactor's instrumentation.

- The SORO output contains all the information needed to plan the fuel scheduling: the detailed channel and bundle power distributions, the irradiation of each bundle or channel in the core and a list of channels in descending order of burnup for each zone.

- While in general the irradiation distribution or the channel burnup provided by SORO are still approximately valid, the local bundle and channel power distribution may have changed significantly since the simulation was performed.

- The power distribution, however, can be inferred from the available reactor instrumentation readings. The instrumentation varies from station to station. Some stations such as Bruce NGS A have a flux mapping system Other stations, such as Pickering NGS A, have coolant temperature instrumentation at the outlet end of each fuel channel and at the inlet reactor headers.

- In general, a first indication of the power distribution can be obtained from the distribution of the water level in the zone controllers. A persistent low level in one zone may indicate that the zone is underpowered and needs fuelling.

- Once the status of the core is established, the fuel engineer can select the channels to be fuelled using the channel burnup list from SORO and the general guidelines discussed previously.

- Particular care is usually taken to account for the effect that fuelling may have on the ROP and control system in-core detectors. Special SORO predictive simulations can be performed or the fuel engineer can rely on the experience obtained in similar situations.

- Usually, enough channels are selected at one time to allow Refuelling at the desired rate for one week at full power operation The list of channels selected, however is re-evaluated and, if necessary, revised on a daily basis to reflect the current status of the core.

- The frequency of predictive SORO simulation usually varies with the age of the reactor and the experience of the fuel engineer. For the initial period of operation at Bruce NGS A, predictive simulations were performed twice weekly on average. This frequency has now decreased considerably.

The SORO Monthly Simulation

- Apart from the various predictive simulations which may be required, a SORO simulation is performed once a month to provide data on the operating history of the reactor for the previous month of operation.

- Some of the input data, however, are obtained directly from the station's records. These data include the sequence of channels fuelled during the month, the position of the zone controllers averaged over a period of 4 or 5 days, the reactor power history and data to identify the fuel bundles which have been loaded or discharged from the reactor during the period.

- In the simulation, a flux calculation is performed at intervals of 4 to 5 full power days. The channels fuelled during each Interval are simulated as being fuelled in a batch at the beginning of the interval.

- The output from SORO includes the power and irradiation for each bundle at each time step and several other data which are used for fuel accounting (i.e. bundle serial numbers) and long term analyses.

Accuracy of SORO and SORO Simulation

- **Given the importance of the SORO simulation in planning and following the fuel scheduling, the code has been extensively against-operating data.**

Figure 5.1 presents a comparison of channel power as calculated by SORO, and as measured by instrumented channels for the Bruce NGS A reactors. The mean diffference is -1.8% with a standard deviation of 3%. The agreement is within the error of the instrumentation.

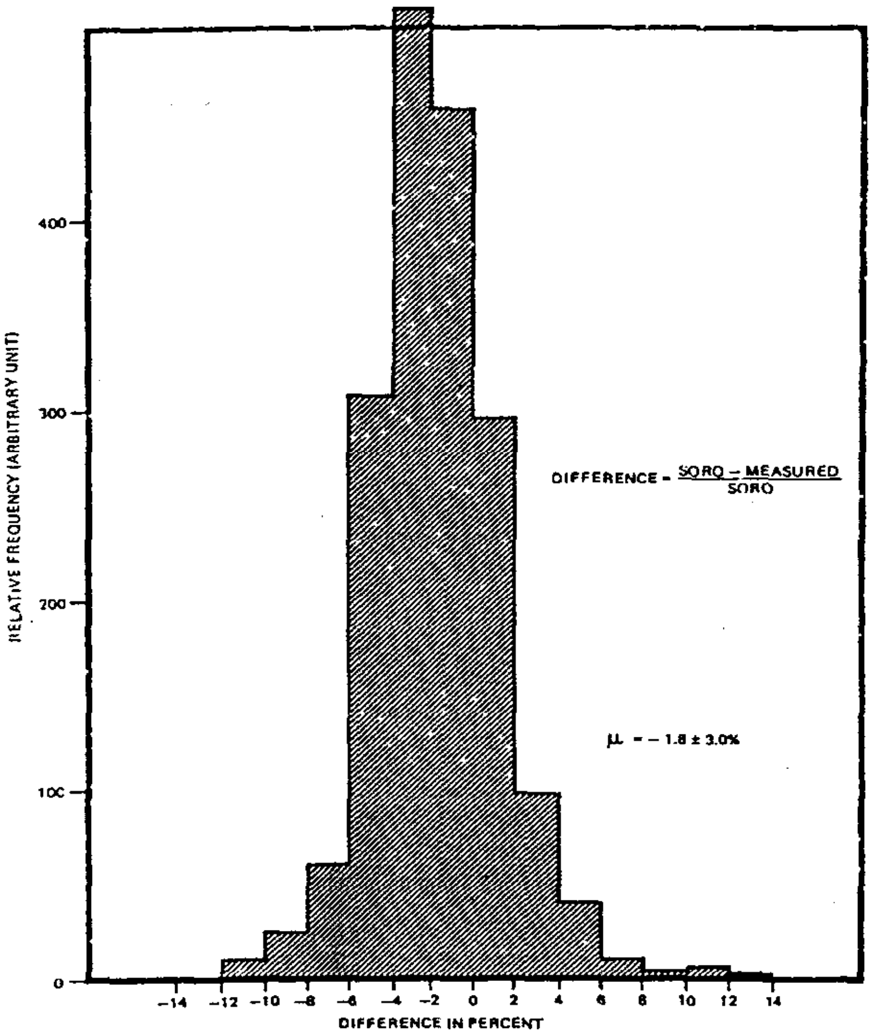
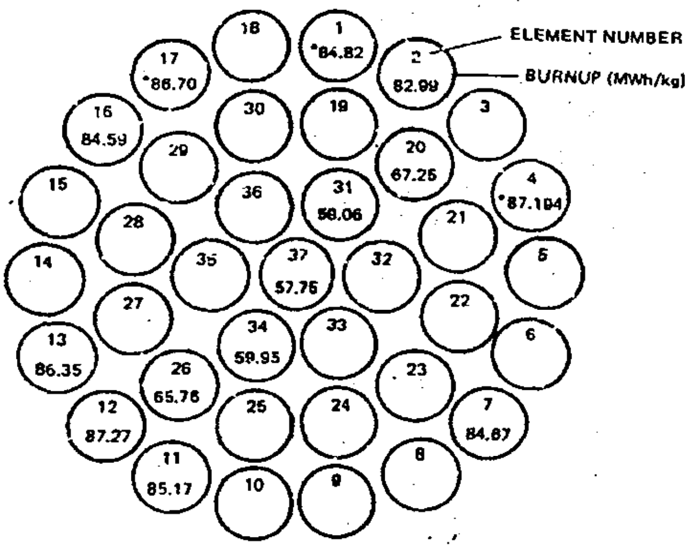


FIGURE 5.1
FREQUENCY DISTRIBUTION OF CHANNEL
DIFFERENCES (SORO AND MEASURED) FOR BRUCE A

- **Another way of verifying the SORO simulation is to compare the discharge burnup of selected bundles with that obtained by measuring, through chemical separation and mass spectrometry, the U-235/U-238 ratio and deriving the burnup from a lattice code. The results for Various elements of two Bruce NGS A fuel bundles are shown in Figure 5.2. The difference is less than 3%.**

BURNUP ANALYSIS OF BUNDLES F09048C AND F11153C



*THREE OUTER ELEMENTS OF F11153C; ALL OTHER BURNUP VALUES ARE FOR F09048C

		F09048C	F11153C
AVERAGE ELEMENT BURNUP (MW.h/kg) (BASED ON LATREP TABLES)	OUTER ELEMENT	85.17	86.24
	INTERMEDIATE ELEMENTS	66.51	-
	INNER ELEMENT	59.51	-
	CENTRE ELEMENT	57.75	-
WEIGHTED AVERAGE BUNDLE NURNUP BASED ON LATREP (MW.h/kg)		74.22	76.32
SORO PREDICTED AVERAGE BUNDLE BURNUP (MW.h/kg)		76.2	78.2
% DIFFERENCE ↑		+2.5%	+2.5%

↑ % DIFFERENCE = <u>SORO PREDICTED BURNUP - LATEREP DERIVED BURNUP</u> X 100
LATEREP DERIVED BURNUP

FIGURE 5.2
COMPARISON OF PREDICTED AND MEASURED
BURNUP FOR SELECTED ELEMENTS

- A third method of validating SORO is to compare the measured activity of the cobalt adjuster rods removed from the core with that predicted using the flux distributions calculated by SORO. A typical comparison for a set of adjuster rods is given in Table V.2. The mean and standard deviation are 1.1%,and 5% respectively.

- To illustrate how fueling performance is achieved with the methods and procedures for fuel management discussed in the previous sections, we shall now review the operating experience at the Pickering and Bruce Nuclear Generating Stations.

Fuel Management at Pickering

Initial Operation

- The Pickering core was designed to have a radially uniform discharge burnup. Adjuster rods provide radial and axial flux flattening. The first fuel charge consisted entirely of natural UO_2 bundles.

  Fuelling began at approximately 5 TWh (~130 FPD) when the excess reactivity in the core was reduced to approximately 5×10^{-3} $\Delta k/k$.

- A uniform 8 bundle shift scheme was selected as being the most suitable on the basis of the following economic factors:

(a) fuel make-up cost, that is the cost of fuel bundles inserted in the core per unit energy output;

(b) fuelling machine operating and maintenance cost; and

(c) costs associated with fuel defects.

At that time the only known cause of fuel failure associated with fuelling was large increases in fuel rating of highly irradiated bundles after fuel shifting.

- The Pickering reactors have pre-specified limits on the coolant temperature rise across each channel. If these limits are approached,

- After several months of operation, a large increase in the iodine-131 concentration in the heat transport system indicated the presence of fuel failures.

- The resulting investigation revealed two reasons for the fuel defects:

(a) excessive variations in bundle power due to adjuster rod maneuvering; and

(b) high incremental bundle powers due to the eight bundle shifting scheme.

- The first problem was eliminated by re-analyzing the adjuster rod sequencing and associated reactor power levels, with an imposed arbitrary limit of 15% on bundle power increases

- The second cause of fuel defects was due to two effects:

(a) large permanent increase in fuel rating when bundles in position 1 are moved to position 9 by an 8 bundle shift, and

(b) a short exposure (about 15 minutes) of bundles in position 1 and 2 to high powers at the centre of the channel during the fuel movement.

- Fuel management simulations were carried out to compare the economics of 8, 10 and 12 bundle shifting in light of the increased cost associated with fuel defects.

- The 10 bundle shift scheme was found to give a small burnup penalty when compared to the 8 bundle shifting scheme, while eliminating permanent increases in bundle power due to fuel re-arrangement within the channel. This scheme was, therefore, adopted for all the high power channels in the core.

- The exposure of some bundles to high fluxes in the centre of the channel during fuel movement was shortened to about 5 minutes by a change in the sequence of operation of the fuelling machine.

- Some of the lessons learned in the area of fuel scheduling from this period of operation of the Pickering reactors can be summarized as follows:

(a) It is valuable to be able to simulate reactor operation accurately and in a timely manner. The availability of individual bundle power histories from the simulations enabled a prompt identification of the defective bundle location and provided the data to understand the underlying causes of fuel defects.

(b) It is valuable to be able to compare different bundle shifting schemes on short notice, taking into account changing operating requirements or situations unforseen during the design phase.

(c) The flexibility of the CANDU fuel scheduling allowed the station to adapt to new schemes and incorporate changing operating requirements without having to shut down the reactors.

(d) It was important to develop a fuel design more tolerant of the variations in power which can be expected from movement of the reactivity mechanisms or from the fuel shifting scheme itself.

Maximum Bundle Power History

Figure 6.1 shows the maximum bundle power as a function of integrated reactor energy for Pickering Unit 1. The shaded band is a ±10% variation about the nominal reference bundle power of 640 kW, the upper end of the band being the target power limit of 705 kW. The original objective of the fuel scheduling was to maintain the maximum bundle power close to the nominal 640 kW value. The data show that, in general, this was achieved.

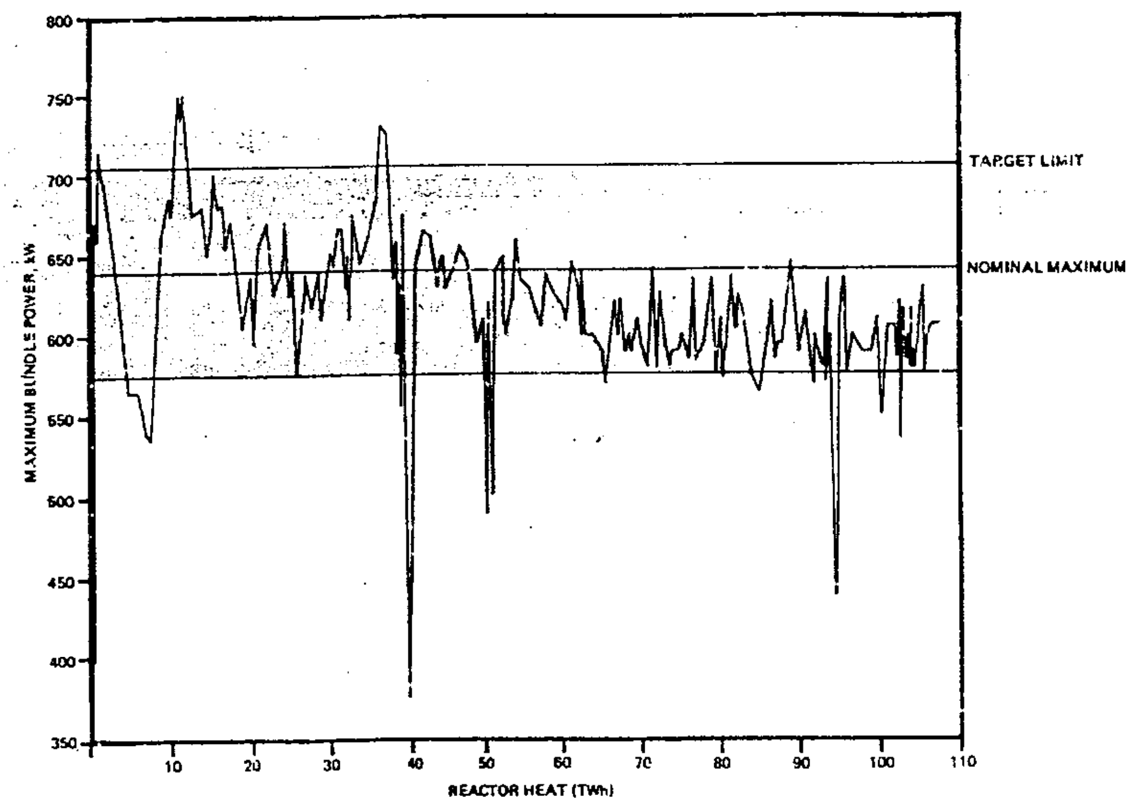


FIGURE 6.1 PICKERING
PICKERING UNIT1, MAXIMUM BUNDLE POWER

Maximum Channel Power History

- The history of the maximum channel power is given in Figure 6.2. The reference design value of 5.5 MW has been maintained, with a few exceptions, to within ±10%. As with the maximum bundle power, the band of variation around the nominal value decreased as the unit reached maturity.

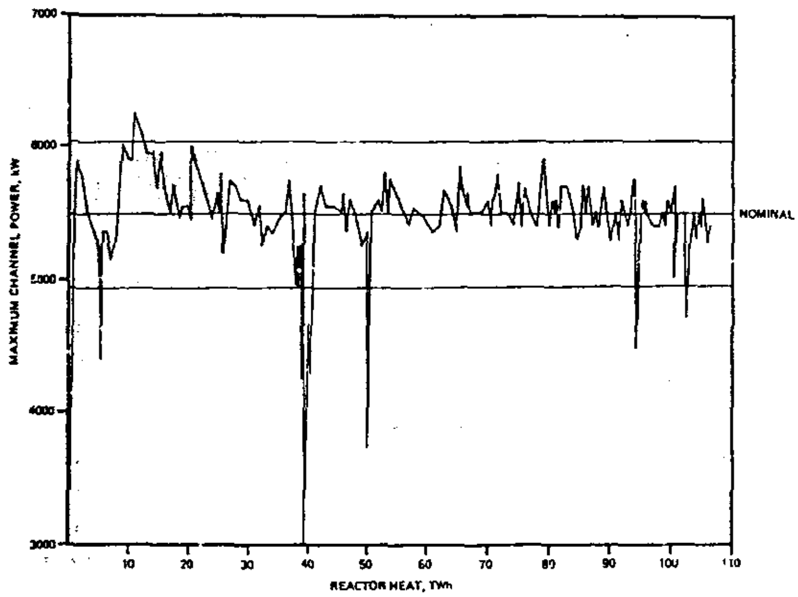


FIGURE 6.2
PICKERING UNIT 1, MAXIMUM CHANNEL POWDER

Burnup and Fuel Consumed

- Figure 6.3 shows the core excess reactivity as a function of reactor integrated power. After the initial reactivity transient due to fresh fuel had decayed, the excess reactivity in the core was maintained close to zero. Moderator poison as a means of "storing" reactivity has been used very rarely at Pickering.

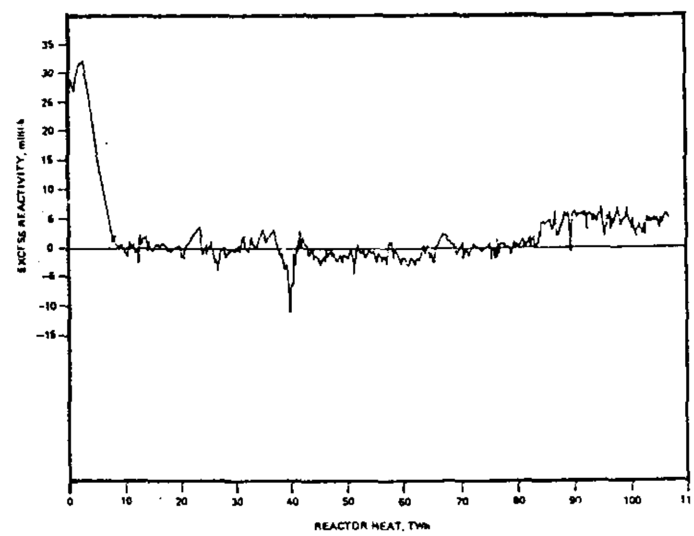


FIGURE 6.3
PICKERING UNIT 1, CORE
EXCESS REACTIVITY

- **Figure 6.4 shows the average monthly discharge burnup as obtained by the SORO simulation. Figure 6.5 shows the fuel added versus reactor heat. Also plotted is the line of "ideal fuel added" assuming a burnup of 175 MWh/kg. The data indicate that the burnup is in the range 170-175 Mwh/kg.**

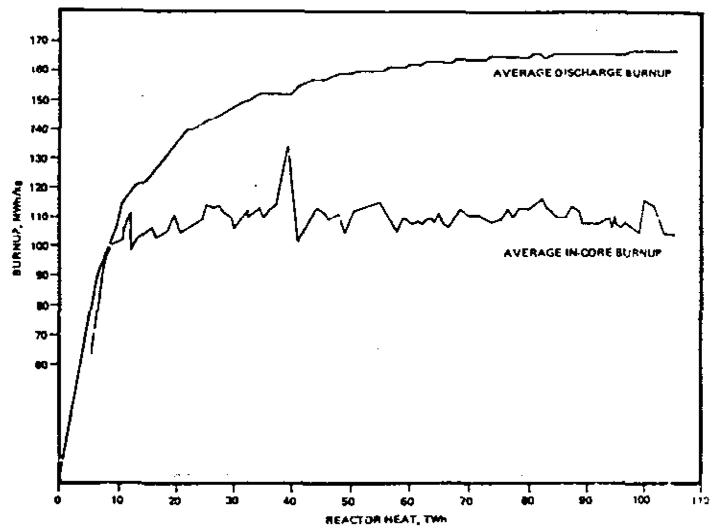


FIGURE 6.4
PICKERING UNIT 1, BURNUP

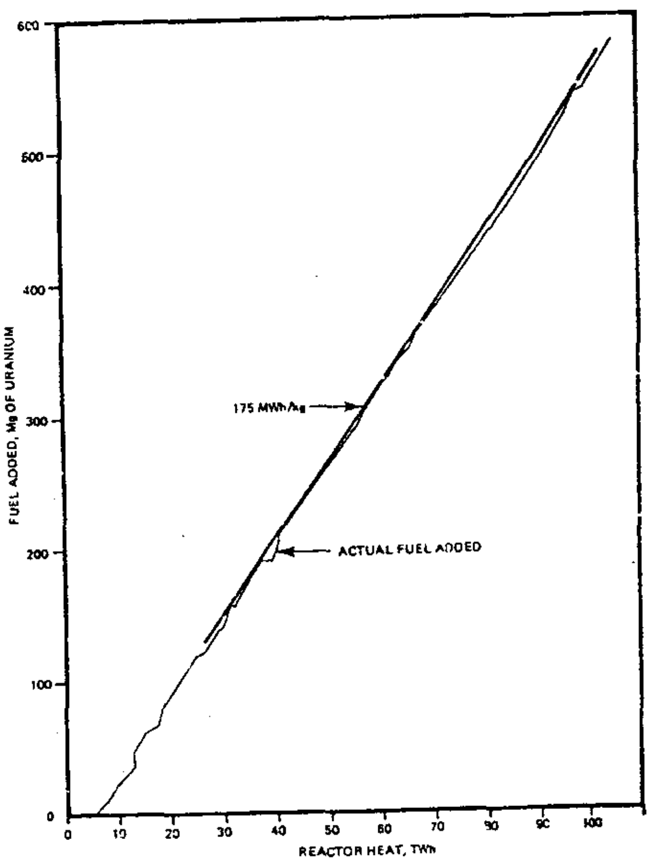


FIGURE 6.5
PICKERING UNIT 1, FUEL USAGE

Fuel Defect Performance

- The performance of the fuel at Pickering after the initial problems were solved has been extremely good. the total number of defective bundles, including suspected ones, was 112 up to the end of June 1978. This gave a defect rate for the 4 units of 0.12%.

Fuel Management at Bruce

- The Bruce units were the first CANDU reactors to incorporate a regional overpower (ROP) system for overpower protection. Early fuel management studies indicated that controlling and minimizing the CPPF was imperative to maintain an adequate operating margin at the ROP in-core detectors.

- The ROP detectors are calibrated on a frequent basis to reflect the CPPF existing in the core. Large variations in the CPPF would increase the frequency of time consuming calibrations and the probability of spurious activation of the shutdown systems.

- The fuelling schemes used at Pickering (8 or 10 bundle shift) would produce unacceptably high CPPF in Bruce A. On the other hand schemes involving a small number of bundles, 2 or 4, tend to increase the fuelling machine usage.

- **From a number of studies performed during the final design phase, it was concluded that the most suitable scheme was a mixed 4 and 8 bundle shifting. As indicated in Figure 6.6 the channels in the inner part of the core are fuelled with a four bundle shift, while the outer channels are fuelled with an eight bundle shift.**

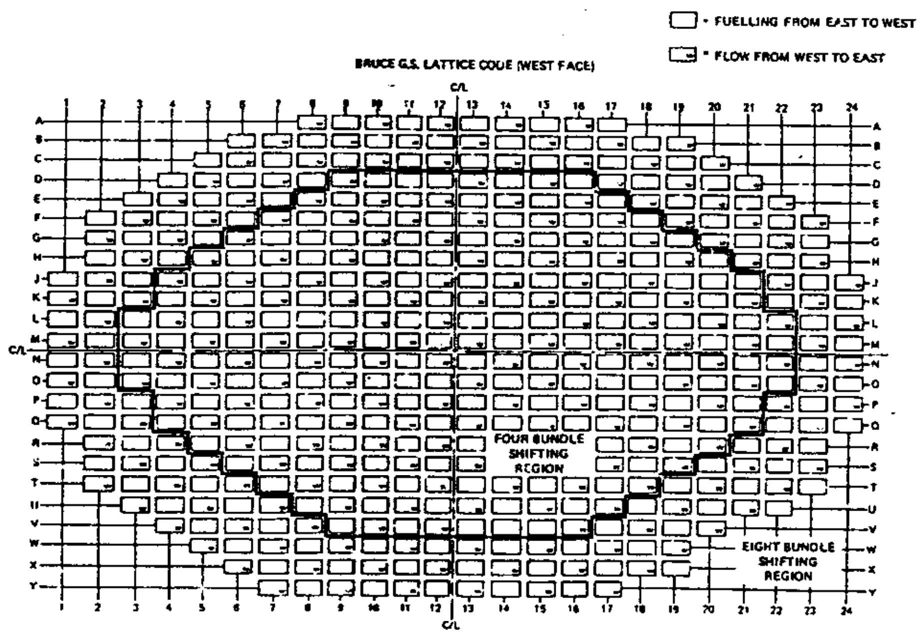


FIGURE 6.6
BRUCE A FUEL SHIFTING REGIONS

- The studies showed that this scheme has the following characteristics:

(a) It yields a discharge burnup comparable to that obtainable from a uniform 2 or 4 bundle shifting and slightly higher than that of an 8 or 10 bundle shifting scheme.

(b) The (CPPF-1) is approximately half that of an 8 or 10 bundle shift.

(c) The probability of fuel defects due to fuelling was acceptably low.

- Some operational difficulties associated with fuelling have been encountered, however, with the reactor regulating system and the ROP system. A brief discussion is outlined below.

Reactor Regulating System

- The reactor regulating system employs in-core, self-powered detectors to provide an estimate of the power in 14 zones (regions) of the core which are controlled by the 14 light water zone controllers.

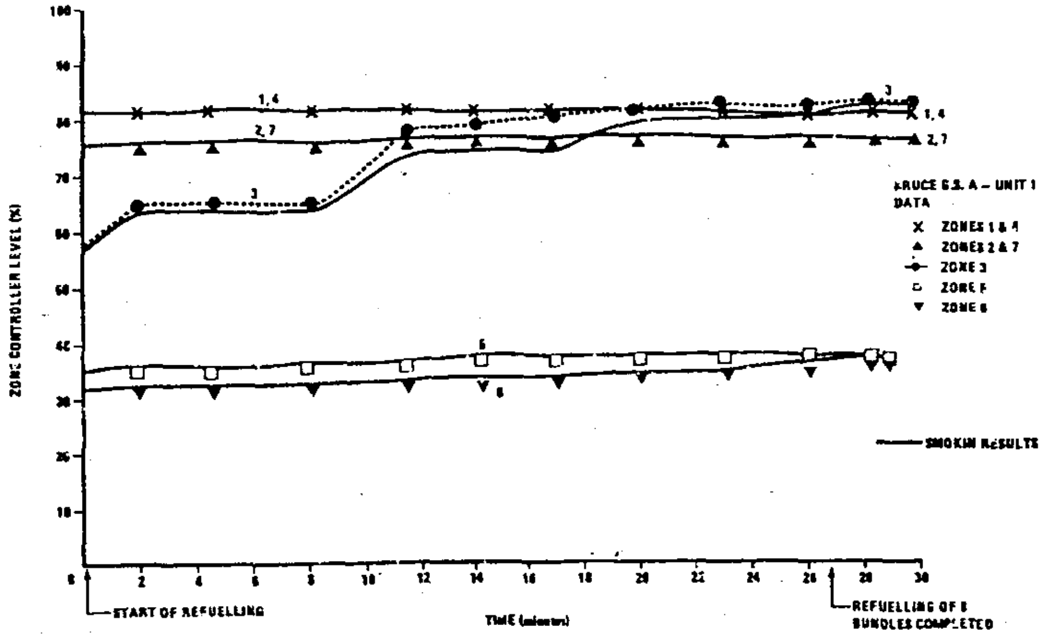


FIGURE 6.7
ZONE CONTROLLER LEVEL TRANSIENT FOR SINGLE CHANNEL REFUELLING (ZONE 1 TO 7)

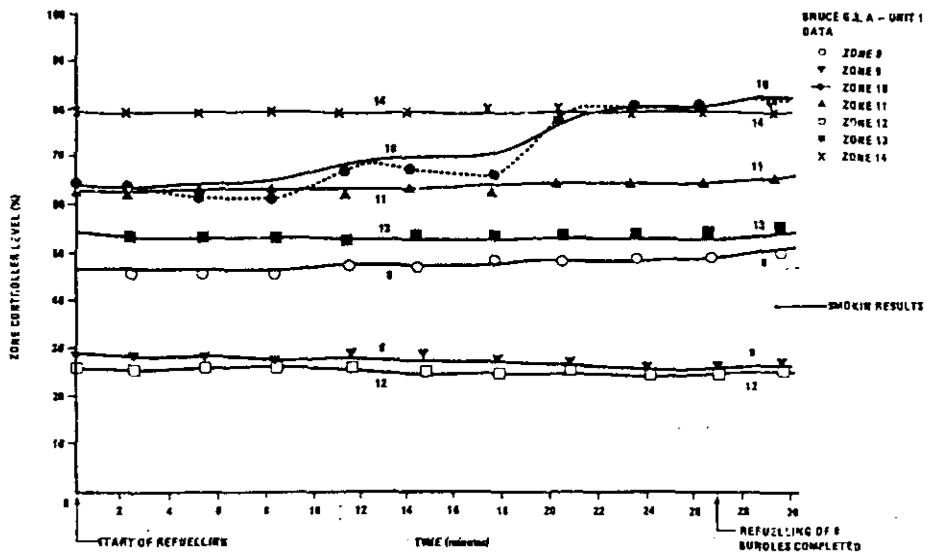


FIGURE 6.8
ZONE CONTROLLER LEVEL TRANSIENT FOR SINGLE CHANNEL REFUELLING (ZONE 8 TO 14)

- The flux detectors are continuously calibrated to estimates of the thermal power in each zone. The calibration factors are derived from 3 or 4 fully instrumented channels (inlet and outlet flow, inlet temperature and temperature rise measurements) located in each zone.

- A typical response of the zone controllers to a fuelling operation is shown in Figures 6.7 and 6.8. Zones 3 and 10, which are close to the channel being fuelled, change in level by approximately 20%. The remaining controllers show little change.

- The figure shows a comparison of actual data with a simulation using the SMOKIN code (18). This code is often used in conjunction with SORO to predict the control system configuration after fuelling.

- Ideally, the fuel scheduling provides the means of controlling the power distribution and, hence, of maintaining an approximately uniform level distribution in the controllers.

- At Bruce, however, individual controllers have displayed a tendency to drift to extreme level over a period of fuelling.

- A fuelling operation causes a redistribution of the flux and power distribution in the core. The perturbation consists of both a global tilt component and localized flux peaking component.

- Since the number of controllers is limited, only the global tilts can be effectively controlled. Localized flux peaks due to the fine structure in the irradiation distribution cannot be controlled.

- If these are not calibrated out of the detector signals, an inappropriate control action might be taken which can cause the controllers to drift to extreme values.

- Some test data collected at Bruce are shown in the upper part of Figure 6.9. It can be seen that the change in level in the controllers is strongly influenced by the distance between the channel.

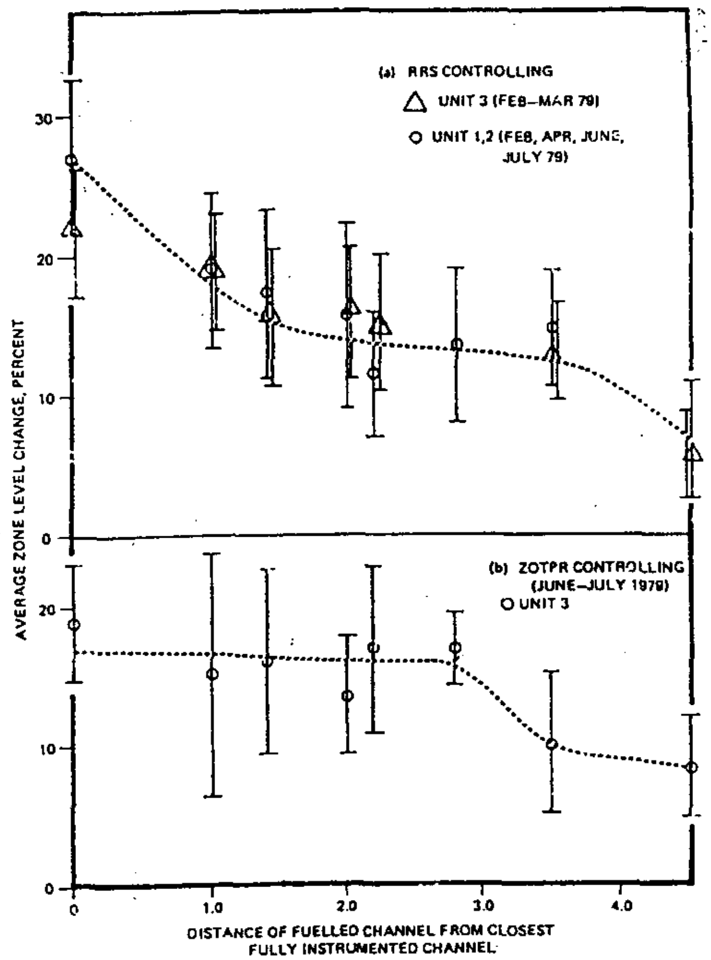


FIGURE 6.9
BRUCE NGS-3
AVG ZONE LEVEL CHANGE (FUELLED ZONE)

- The lower part of Figure 6.9 shows the response of the zone controllers when the zonal power is estimated from the 'temperature rise across each channel in the zone and the instrumented channels. The response is fairly independent of the distance up to about 3 lattice pitches.

- This type of calibration, which is also used at Pickering, is only one of the solutions to the problem.

-

- If some channels are boiling at the outlet end, the power estimate from temperature measurements will be unreliable.

The Regional Overpower System

- The occasional difficulties in maintaining a reasonable distribution of zone controller levels have also caused additional problems in maintaining an adequate margin at the ROP detectors. Since the desired fuelling pattern could not always be maintained, relatively high CPPF's were occasionally encountered.

- Moreover, particular care had to be taken in fuelling channels close to ROP detectors. The observed changes in detector reading following fuelling close to a detector is in the range 1.5 to 6 percent. Of this change, up to 2 percent has, in some cases, been attributed to control system action.

- Improvements were obtained through modifications of the spatial control algorithm.

Maximum Bundle Power History

- Maximum bundle power as a function of integrated energy for Bruce Unit 1 is presented in Figure 6.10.

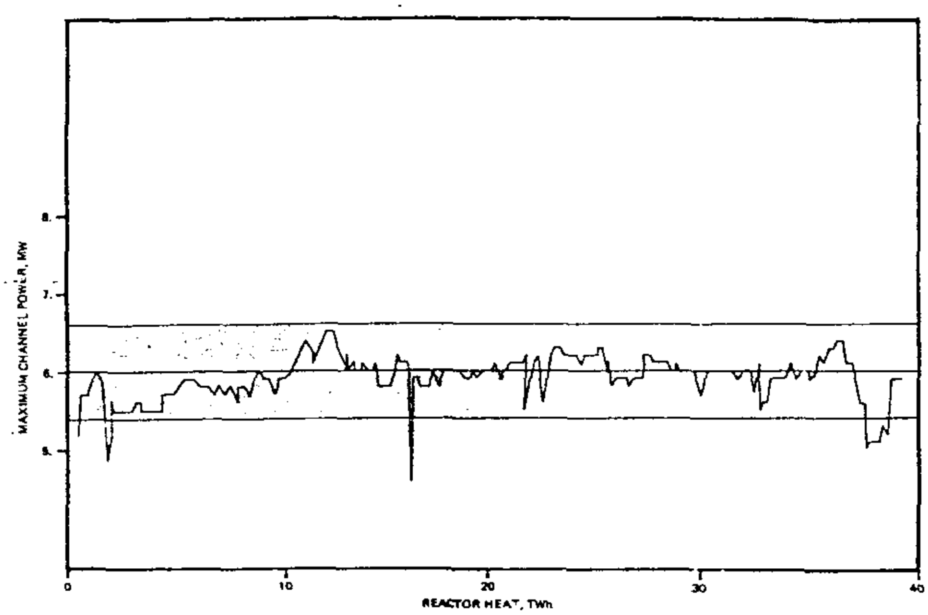


FIGURE 6.10
BRUCE UNIT 1,
MAXIMUM BUNDLE POWER

- It can be seen that after the onset of fuelling the maximum bundle power increased fairly rapidly to a value of approximately 800 kW +10%.

- The variations in Bruce are somehow larger than Pickering due to the fact that no special attempt was made to strictly control the bundle power. The operational margin on maximum bundle power is larger in Bruce that it is in Pickering.

Maximum Channel Power History

- Because of the relatively narrow margin on the ROP system and the need to minimize the CPPF, good control was kept on the maximum channel power.

- As can be seen from Figure 6.11, the target value of 6.0 MW has been maintained with a few exceptions, within a very small band.

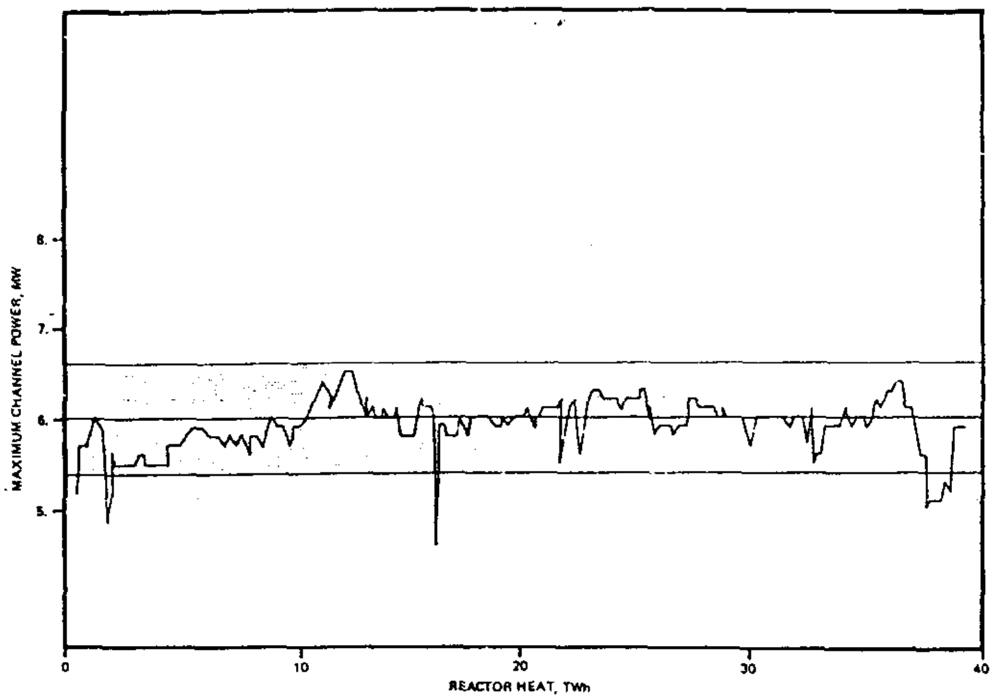


FIGURE 6.11
BRUCE UNIT 1,
MAXIMUM CHANNEL POWER

Burnup and Fuel Consumed

- Figure 6.12 shows the fuel usage, burnup, and core excess reactivity as function of reactor integrated power. The upper portion of the figure shows the core excess reactivity. After the initial reactivity transient due to fresh fuel had decayed, the excess reactivity in the core was maintained close to 5 x 10^{-3} k/k.

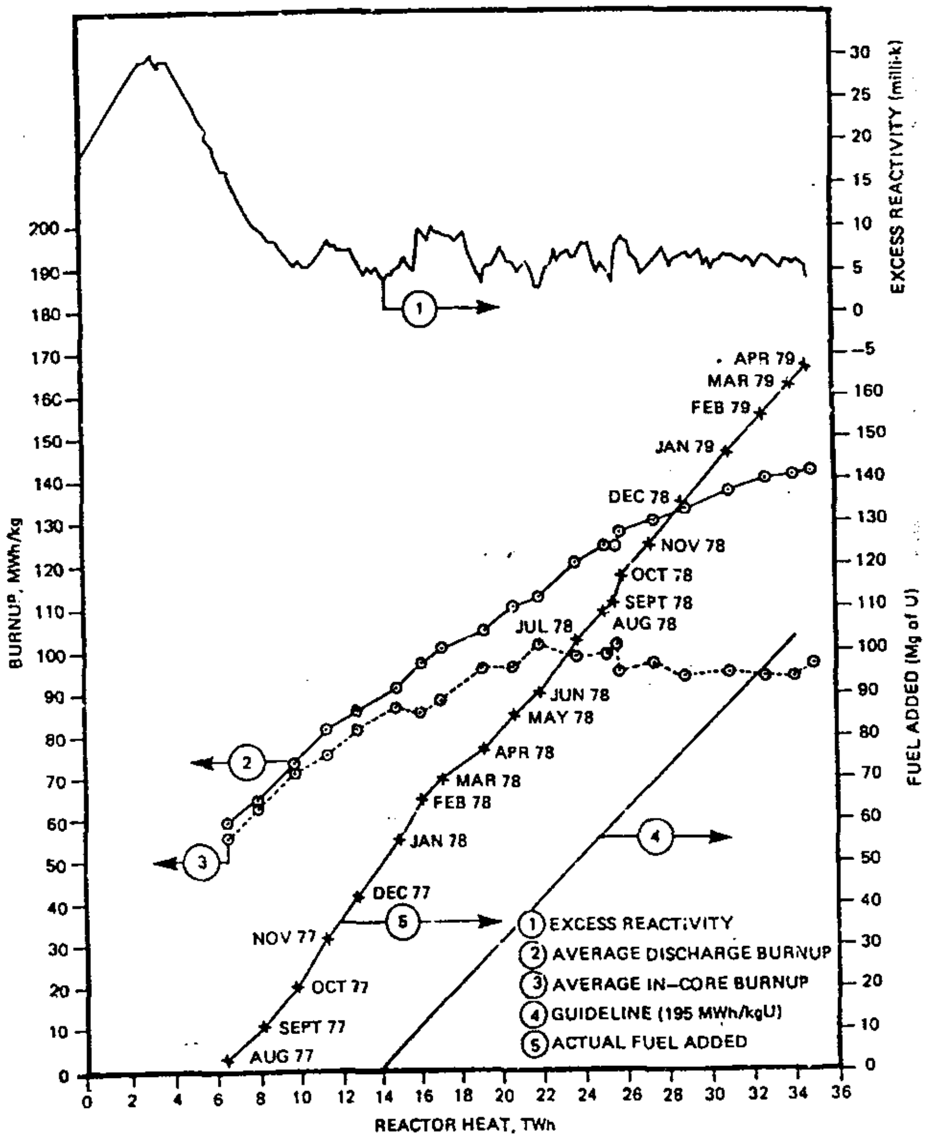


FIGURE 12
BRUCE UNIT 1 FUELLING PERFORMACE

- This excess reactivity is held in soluble boron in the moderator to provide additional "shim" reactivity when fuelling machines are unavailable. The Bruce reactor does not have adjuster rods for shim purposes. Power shaping is provided principlely by burnup flattening.

- The lower portion of the figure shows the average monthly discharge burnup as obtained by the SORO simulation, and the fuel added versus reactor heat curve. Also, plotted is the line of "ideal fuel added", for a burnup of 195 MWh/kg. With boron in the moderator, the actual fuel added data indicate a burnup of about 175 MWh/kg.

Fuel Defect Performance

- Overall defect rate was .11%, comparable to Pickering. Bruce uses 37 element CANLUB fuel. Most of the 9 confirmed defects were due to manufacturing defects in the fuel bundles and are not related to fuelling.

Channel Power Peaking Factor

Figure 6.13 shows-the channel power peaking factor as calculated by SORO.

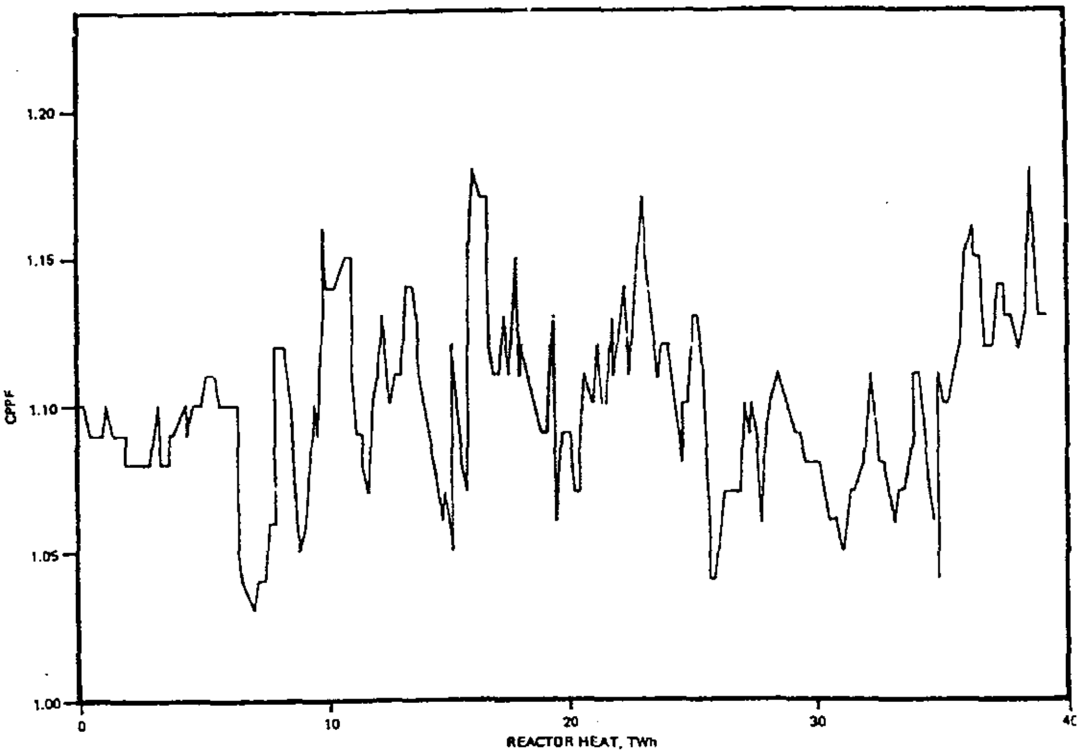


FIGURE 6.13
BRUCE UNIT 1,
CHANNEL POWER PEAKING FACTOR

FUTURE FUEL CYCLES

- Many perturbations move the reactor away from equilibrium fueling
- I want to briefly review strategic changes in fuel cycle that can be introduced after years of operation.

- CANDU reactors are particularly flexible for these changes because of their on-power fueling. The timing of the change and its rate can be adapted to the objectives of the new cycles.

- Just a listing of these potential changes gives a measure of the flexibility.

Table 1. Potential Fuel Cycles

Cycle	Objectives
Slightly Enriched Fuel (SEU)	Increased power, decresed used fuel out
Mixed Oxide Fuel (MOX)	Dispose of weapon plutonium
Actinide Burner (AB)	Convert non-fissile actinide to fissile
Thorium Fuel	Convert fertile thorium to fissile uranium

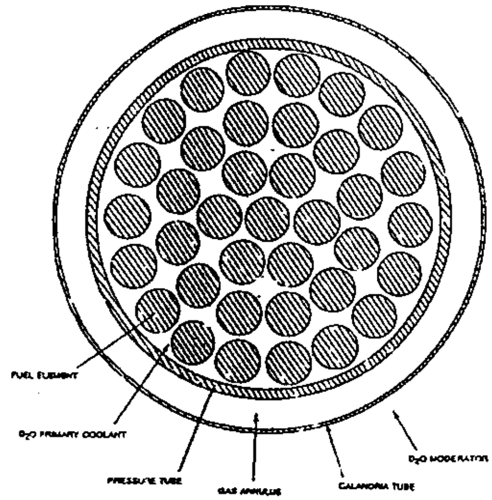
CANDU Advanced Fuel Cycles are all fuel cycles other that Natural Uranium Fuel Cycle

- Initial Fissile Content >0.7%
- Sources of Fissile Material
  - Uranium Enrichment Plants (U^{235})
  - Reprocessed LWR Spent Fuel
  - Weapons Plutonium
  - U^{233} from Breeding of Th^{232}
  - Actinides from Spent Fuel

<u>CANDU Advanced Fuel Cycles</u>

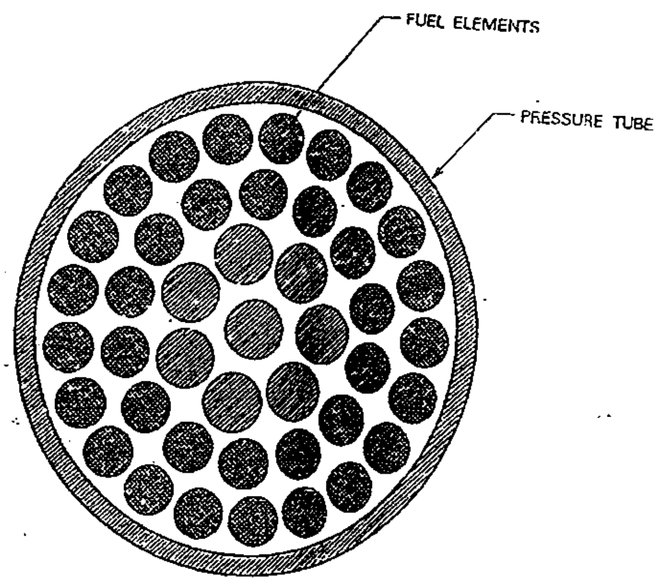
- CANDU reactor dynamics insensitive to fuel type.
- Heavy water is a major determinant of reactor dynamics.
- Flexibility of Fuel Design
  - 37-, 43-, and 61 -element bundle designs.
  - Differential enrichment in each fuel ring.
  - Reduces element power peaking factor from 1.13 (natural) to 1.05 (SEU & MOX).
  - Reduces maximum element ratings from 65 kW/m to 45 kW/m.
  - Allows higher maximum bundle power and higher element burnup.
  - Permits coolant void reactivity reduction.

•



37- Element Fuel Bundle arrangement

Ring#	Number of Elements	Pellet Material
1	1	DU + Dy
2	6	DU + Dy
3	12	SEU
4	18	SEU



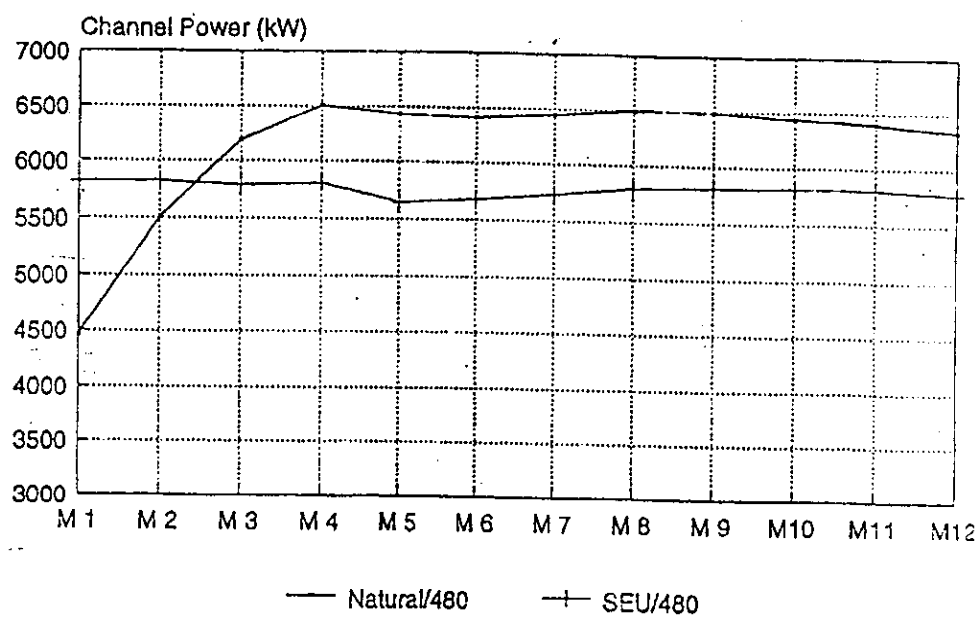
Ring#	Number of Elements	Pellet Material
1	1	DU + Dy
2	7	DU + Dy
3	14	SEU
4	21	SEU

43-Element Fuel Bundle Arrangement

CANDU Advanced Fuel Cycles

- Flexibility of Fuel Management
  - Increases power shaping ability by increasing the differences in regional fuel burnup distributions.
  - Significantly flattens global power distribution by using Global Differential Enrichment.
  - Reduces refuelling power ripple by using 2- or 4-bundle shift fuelling schemes.
  - Increases total reactor power output and/or operating margin.

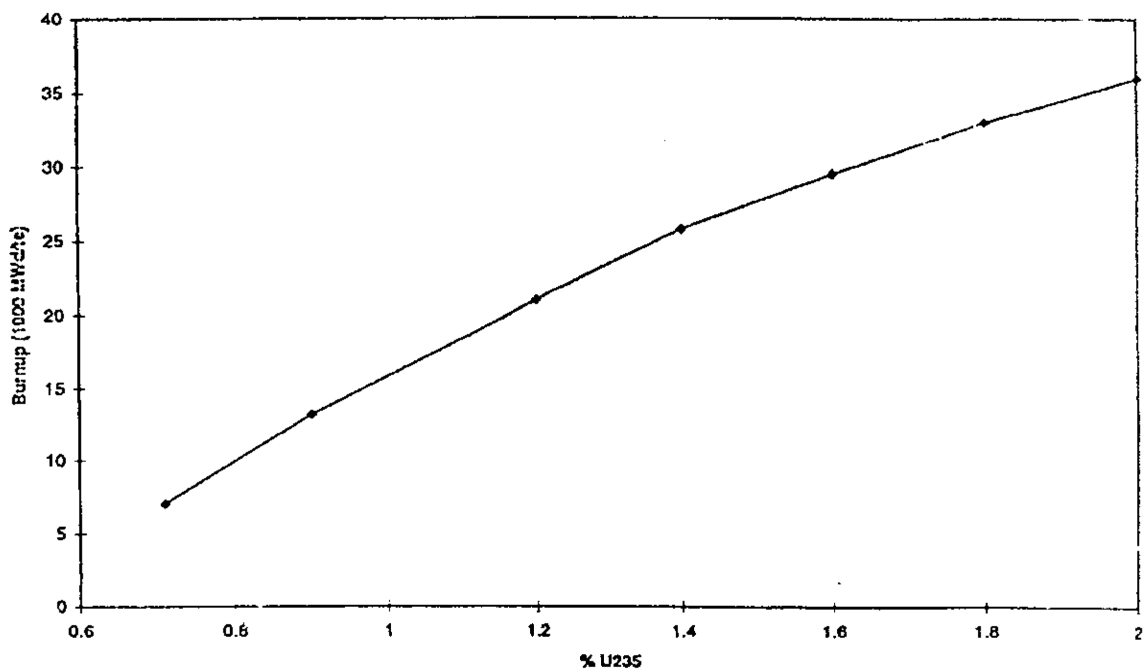
Channel Power Distributions in Natural/480 and SEU/480 Cores



Time-average channel Power

The Very Slightly Enriched Fuel Cycle in CANDU

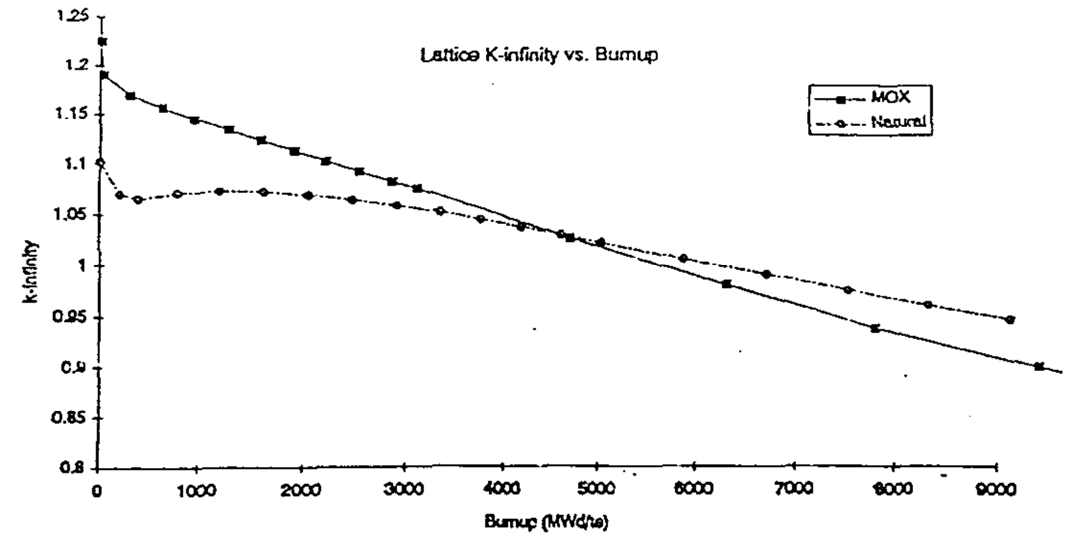
- **Purpose:** **To increase power output with current CANDU plant designs.**
- **Enrichment: 0.8 to 0.9 wt% U235 (cf 0.71wt% in NU fuel).**
- **Main Features**
  - **Uses current (well proven) 37-element fuel design.**
  - **Operates within current (natural uranium) exit burnup envelope.**
  - **Operates within current (natural uranium) power envelope.**
  - **Operates within current channel power limits.**
- **Main Advantages:**
  - **Raises power output by up to 17% (1033 MW(e) from 480 channels).**
  - **No hardware change in existing core design.**



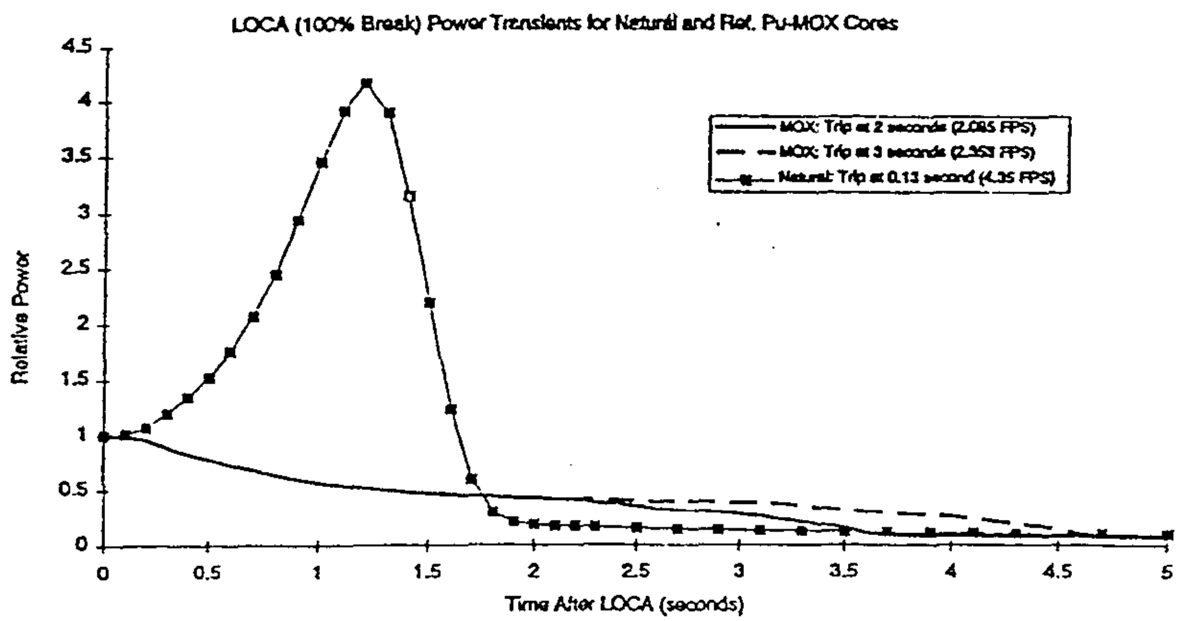
Discharge Burnup vs. Initial Fissile Content

The MOX Fuel Cycle in CANDU

- Purpose: To dispose of weapons grade plutonium in a CANDU plant.
- Enrichment: 1.2 wt% Pu + 0.2 wt% U235 (cf 0.71wt% in NU fuel).
- Main Features
- Uses current (well proven) 37-element fuel design.
  - Operates within current (natural uranium) exit burnup envelope.
  - Operates within current (natural uranium) power envelope.
  - Operates within current channel power limits.
  - Inherent negative void reactivity.
- Main Advantages:
  - Fast disposal rate (1 tone Pu per reactor-year).
  - No hardware change in existing core design.



Lattice k-infinityvs. Burnup for the reference Mox Fuel and Naturel CANDU Fuel



Comparison of LOCA Power Transients for Reference MOX Fuel and Natural CANDU Fuel

Destruction of Actinides In CANDU

- ACTINIDES ARE RADIOACTIVE HEAVY ELEMENTS THAT ARE PRODUCED BY THE USE OF URANIUM IN NUCLEAR REACTORS.

- MANY ACTINIDES ARE LONG-LIVED; FOR EXAMPLE PLUTONIUM-242 HAS A HALF-LIFE OF 376000 YEARS.

- SOME OF THEM ARE HIGHLY TOXIC AS WELL; FOR EXAMPLE, NEPTUNIUM-237 AND AMERICIUM-241 ARE IMPLICATED IN CANCER.

- SAFE DISPOSAL OF ACTINIDES IS A HIGH PROFILE ISSUE BEING STUDIED JOINTLY BY SEVERAL COUNTRIES. THE SOLUTIONS BEING SUGGESTED INVOLVE CAPITAL INTENSIVE PROJECTS SUCH AS ACCELERATORS AND FAST REACTORS.

- CANDU HAS A REMARKABLE ABILITY TO USE ACTINIDES AS FUEL AND DESTROY THEM. BECAUSE URANIUM IS ABSENT FROM THIS FUEL, NEW ACTINIDES ARE NOT PRODUCED. OUR STUDIES SHOW THAT-.

  - A CANDU 6 REACTOR OF CURRENT DESIGN CAN, IN ONE YEAR, CONSUME THE ACTINIDE PRODUCTION FROM 3 TO 4 LWR's EACH RATED AT 1 GW(e).

  - THE ACTINIDE FUEL BUNDLE IS IDENTICAL TO THE CURREN 37-ELEMENT DESIGN EXCEPT FOR THE ABSENCE OF URANIUM.

  - THE ENERGY PRODUCED FROM THE ACTINIDE DESTRUCTION RESULTS IN THE CONSERVATION OF URANIUM RESOURCE.

  - WHENEVER REQUIRED, THE ACTINIDE FUEL CAN BE REPLACED WITH CONVENTIONAL CANDU FUEL WITHOUT REPERCUSSIONS ON REACTORS OPERATION.

- THE ABOVE FEATURES MAKE CANDU REACTORS PARTICULARLY RELEVANT TO LWR OWNERS THAT INTEND TO REPROCESS THE LW SPENT FUEL.

WHAT HAPPENS TO NEUTRONS IN CANDU

38% PRODUCE FISSION

62% ARE LOST

3% LEAK OUT

6.3%ARE ABSORBED OUTSIDE THE FUEL

(1.5% ARE ABSORBED IN THE MODERATOR)

91% ARE ABSORBED IN THE FUEL

(33% ARE ABSORBED TO PRODUCE FISSIONABLE MATERIAL)

WHAT HAPPENS TO NEUTRONS IN LWR

27% PRODUCE FISSION

73% ARE LOST

1% LEAK OUT

29% ARE ABSORBED OUTSIDE FUEL

(16% ARE ABSORBED IN MODERATOR)

70% ARE ABSORBED IN FUEL

24% ARE ABSORBED TO PRODUCE FISSIONABLE MATERIAL)

What Advanced Fuel Cycles Do for CANDU

- No hardware change to existing CANDU core.
- Permit reactor power increase without adding fuel channels.
- Extend natural resources.
- Reduce waste volume and toxicity.
- Extend pressure tube life.
- Make void reactivity zero or negative.
- Provide the option to use light water as a coolant,