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Analysis of F/M Duty Cycle and O/M Cost for Four-Bundle Shift Refuelling Scheme in CANDU6 NPP

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Abstract

A four-bundle shift refuelling method, a refuelling scheme that can reduces local flux peak compared to the current eight-bundle shift refuelling method used in CANDU6 NPP, is analyzed to see how much Fuel Handling System load and management cost increase are required due to the change. The current eight-bundle shift refuelling method requires to refuel eight fuel bundles from a single fuel channel, and to refuel 14 fuel channels in a week on average assuming that the reactor is in a steady state. The four-bundle shift refuelling method increases Fuelling Machine duty cycle and operator load. The study showed that the refuelling scheme change from the eight- to four-bundle shift increases the operation and maintenance cost about 35% from the current figure by conservative estimate and that the Fuel Handling System has enough flexibility to meet the demand of a more frequent refuelling scheme.

1. Introduction

This paper reviewed and analyzed the implication of four-bundle shift refuelling on CANDU6 NPP. A four-bundle shift refuelling method itself is more benign than the eight-bundle shift refuelling scheme since it causes smaller neutron flux ripple during refuelling. Hence it gives larger safety margin than eight-bundle shift refuelling scheme. The eight-bundle shift refuelling scheme used in CANDU6 NPP is chosen to balance the Fuelling Machine fatigue and plant management. The need for four-bundle shift refuelling arises when fuels fabricated from enriched uranium are to be used. A four-bundle shift refuelling scheme can be used with natural uranium fuel as well to get the benefit of increased safety margin. This study focused on the analysis of fuel handling system capacity and the cost increase due to switching from eight- to four-bundle shift refuelling scheme. A comparative study of ROP (Regional Overpower Protection) margin from changing eight- to four-bundle shift refuelling scheme is not covered in this study.

This study includes the fuelling time, the current operator management scheme, and the maintenance cost, etc., based on the whole core four-bundle shift refuelling scheme. A partial implementation of four-bundle shift refuelling, i.e. combination of the eight-bundle shift refuelling scheme and the four-bundle shift refuelling scheme, is not considered in this study.

2. Description of Current Fuelling Method (eight-bundle shift refuelling scheme)

2.1 Refuelling operation

Current refuelling operation scheme at CANDU6 NPP is eight-bundle shift refuelling method. The upstream machine loads eight new fuel bundles while downstream machine receives eight spent fuel bundles. Table 1 shows typical refuelling operation schedule per week. On average 14 channel refuelling operations are carried out in a week.

Table 2 shows major refuelling operation timing for a channel. Fuelling time can vary depending on the location of channel and refuelling mode either FAF (Flow Assisted Fuelling) mode or FARE (Flow Assist Ram Extension) mode. A FARE mode fuelling takes about 10-15 minutes longer than FAF mode fuelling.

Table 1. Regular refuelling operation schedule.

Day	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
Num. of channels to refuel	3	3	0	3	3	2	0

Table 2. Eight-bundle shift refuelling time for a channel unit : min.

Operation	Refuelling a single channel	Refuelling 2 channels with same flow direction	Refuelling 2 channels with opposite flow direction
system start up	30	30	30
New fuel transfer operation	41	41	82
Reactor face fuelling operation	69	138	138
Spent fuel discharge operation	53	106	106
System shutdown	30	30	30
Total	223	345	386

2.2 Operator management and annual maintenance cost

A typical organization for the operation and maintenance of F/H system of two units CANDU6 NPP is shown in Figure 1. Refuelling Operation Group consists of 2 teams of dedicated operators. The regular work hours in a week are 44 hours. The Mechanical and Electrical Groups are responsible for maintenance of the F/H system. Mechanical and Electrical Group has 6 engineers each and external support ranging from 5 to 10 engineers. Approximate annual maintenance costs for a F/H system is around 0.5 million U.S. dollars.

A regular overhaul period is scheduled after 15 months of normal operation. The overhaul period for CANDU6 NPP built in 80’s is about 2 months and that for recent CANDU6 NPP is about 40 days. The difference is mainly due to SLAR (Spacer Location And Relocation) operation on fuel channels. Recent CANDU6 NPP has fixed type spacers and therefore no SLAR operation is required, while CANDU6 NPP built in 80’s has loose type spacers.

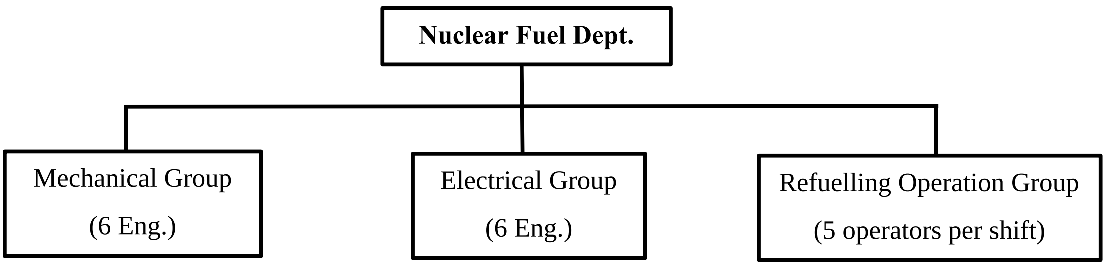

Figure 1. Nuclear Fuel Department organization (typical)

3. Estimation of Fuelling Time and Maintenance Cost of Four-Bundle Shift Refuelling Scheme

3.1 Estimation of refuelling operation time

Based on the timing of eight-bundle shift refuelling operation on channel O11, the four-bundle shift refuelling operation time can be estimated. In order to meet the required amount of fuels to handle, refuelling should take place at least four channels a day on average or 16 fuel bundle replacement a day. The fuelling time depends on the number of channels involved and direction of channel flow in the refuelling job. There are various fuelling job combinations for a four-bundle shift refuelling method depending on the number of fuel channels to visit at a time.

Table 3 enumerates various fuelling jobs depending on different number of channels and channel flow direction. At each refuelling job, a pre-operational check up is done and it takes around 30 min. And after finishing the refuelling job, another check up is done before shutting down the system and it takes around 30 min. A single channel refuelling job will consist of getting new fuel bundles by upstream F/M (35 min.), moving both F/Ms to the designated channel, refuelling on reactor(61 min), and discharging spent fuel bundles by downstream machine (44 min.). A 2 channel refuelling job where both channel flow directions are the same will consists of receiving new fuel bundles by upstream F/M (35 min.), moving both F/Ms to the first designated channel, refuelling on reactor (61 min.), discharging spent fuel bundles by downstream F/M at the same time receiving new fuel bundles by upstream F/M (44 min), moving both F/M back to the second designated fuel channel, refuelling on reactor (61 min), and discharging spent fuel by downstream F/M (44 min). A 2 channel refuelling job where both channel flow directions are opposite will consists of receiving new fuel bundles by upstream F/M (35 min.), moving both F/Ms to the first designated channel, refuelling on reactor (61 min.), discharging spent fuel bundles by downstream F/M (44 min.), switching downstream F/M as upstream F/M, moving upstream F/M to NFP, receiving new fuel bundles by upstream F/M (35 min), moving both F/M back to the second designated fuel channel, refuelling on reactor (61 min), and discharging spent fuel bundles by downstream F/M (44 min). This logic is applied to other type of refuelling job as well.

To carry out similar fuelling load as current schedule for eight-bundle shift refuelling, six channel refuelling operations are required on several days (Mon., Tue., Thu., Fri.), and on these days F/Ms have to operate for around 12 hours and 40 minutes. On Saturday, four channel refuelling operations are required which takes around 9 hours and 10 minutes. Therefore total refuelling operation time in a week is 59 hour 50minutes (3590 min.) based on tables 2 and 3. To get the most conservative result, refuelling operation by a single channel job only will requires 24 separate channel refuelling operations in a week and it will take around 80 hours. Hence total refuelling time will be in between these two figures. It is also note that the timing is on average, it doesn't take into account the parameters such as FARE mode refuelling and channel locations.

Table 3. Four-bundle shift refuelling time unit: min

Refuelling job scheme	Pre. op. time	At NFT	On Reactor	At SFP	Post. op. Time.	Total Time.
Single channel Refuelling	30	35	61	44	30	200
2 ch. refuelling (all same flow dir.)	30	35	122	88	30	305

2 ch. refuelling (opposite flow dir.)	30	70	122	88	30	340
3 ch. refuelling (all same flow dir.)	30	35	183	132	30	410
3 ch. refuelling (opposite flow dir.)	30	70	183	132	30	445
4 ch. refuelling (all same flow dir.)	30	35	244	176	30	515
4 ch. refuelling (opposite flow dir.)	30	70	244	176	30	550
5 ch. refuelling (all same flow dir.)	30	35	305	220	30	620
5 ch. refuelling (opposite flow dir.)	30	70	305	220	30	655
6 ch. refuelling (all same flow dir.)	30	35	366	264	30	725
6 ch. refuelling (opposite flow dir.)	30	70	366	264	30	760

3.2 Manpower requirement and annual maintenance cost

Switching from the eight- to four-bundle shift refuelling scheme requires longer refuelling time as estimated above. In order to follow the current refueling scheme shown in Table 1, at least 6 channel refuelling operation is required on Mon., Tue., Thu., and Fri. Table 4 shows fuelling time and number of channels to refuel. The actual fuelling time will fall between the upper bound and the lower bound of fuelling time.

Table 4. Fuelling schedule for four-bundle shift refuelling scheme

Day	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
Number of channels	6	6	0	6	6	4	0
Multi-channel refuelling time (hour)*	12.7	12.7	0	12.7	12.7	9.2	0
Single-channel refuelling time (hour)**	20	20	0	20	20	13.3	0

* Refuelling time is continuous operation of F/M and is based on conservative estimation given in Table 3. This is the lower bound based on average fuelling time.

** Refuelling time is multiple of single-channel refuelling time given in Table 3. This is the upper bound based on average fuelling time.

The current operator management scheme can support up to 16 hours for a weekday and only 8 hours on Saturday. Wednesday off of fuelling operation is necessary for F/M maintenance and office work of operators. Comparing this and fuelling time given in Table 4, current manpower is barely enough for the four-bundle shift refuelling scheme. Hence adding a team of 4 operators is recommended in case of emergency situation.

The maintenance material cost is estimated to increase by as much as 20 % from the current figure. The figure for a unit reactor is roughly estimated to be 0.6 million US dollars based on the current maintenance cost of the eight-bundle shift of 0.5 million US dollars.

4. Conclusions

Changing refuelling method from the eight-bundle shift scheme to the four-bundle shift scheme increases the number of refuelling operations. With the eight-bundle shift refuelling scheme 14 channel refuelling a week is required on average, while with the four-bundle shift refuelling scheme 28 channel refuelling a week is required. This increased refuelling activity may require a team of additional 4 operators and additional maintenance cost as shown in Table 5. The maintenance cost for the four-bundle shift refuelling scheme is based on 20% increase to the current maintenance cost. The total management and maintenance cost increase due to switching from the eight- to four-bundle shift refuelling scheme would be around 0.5 million US dollars per unit annually. This is roughly a 35% increase from current annual operation and maintenance cost.

A further study on ROP margin increase will be required to see the actual benefit from the four-bundle shift refuelling scheme. This study can also be used for the cost benefit analysis of other type of fuel cycle that may include fuels fabricated from enriched uranium or recovered uranium.

Table 5. Annual Cost Comparison per Unit Reactor (CANDU6 NPP)

	Manpower cost	Maintenance cost	Remarks
8-bundle shift refuelling	9 operators	0.5 million US dollars	
4-bundle shift refuelling	13 operators	0.6 million US dollars	
Increased cost by switching 8- to 4-bundle shift refuelling	4 operators (0.4 million US dollars) annually	0.1 million US dollars annually	Total of 0.5 million US dollars

5. References

1. Design Manual for CANDU6 NPP Fuel Transfer and Storage, 86-35000-DM-001