NUCLEAR TRAINING CENTRE

COURSE 133

NUCLEAR TRAINING COURSE

COURSE 133

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*To be written

Reactor, Boiler & Auxiliaries - Course 133

BASIC MODERATOR REQUIREMENTS

The basic nuclear and non-nuclear requirements of the moderator are discussed in this section.

NUCLEAR CONSIDERATIONS

(a) As described in levels 2 and 1, Nuclear Theory, the neutron slowing down and absorbing properties of moderators are combined in a number, the moderating ratio, which is a direct measure of the moderating effectiveness. For a natural U fuelled CANDU reactor with a heterogeneous lattice design we use the best moderator available which is heavy water, having the highest moderating ratio possible.

Use of light water is not feasible without fuel enrichment and the use of graphite would dictate very large core size, such as is used in the UK Magnox reactors.

(b) Further nuclear specifications demand a high chemical purity in the moderator from the neutron absorption point of view.

Of main concern is:

(i) the B concentration must be kept low. Table 1 shows a summary of the moderator chemical analysis at Pickering NGS illustrating this point.

(ii) Moderator isotopic must be maintained high.

The latter causes most concern; B being easily (and deliberately) removable in the IX columns; as upgrading is both expensive and time consuming. Reactor grade D_2O from BHWP is 99.75% D_2O and an idea of the $ value of this isotopic is indicated in Table 2 for the Pickering moderator system.

In practice our stations maintain their moderator system isotopic as follows:

(i) Douglas Point uses a Sulzer Upgrader and AECL.

(ii) Pickering uses a Sulzer Upgrader for on-line upgrading of moderator D_2O and for upgrading of downgraded moderator recovery. (The Upgrading Plant at Pickering (UPP, Lummus), a larger unit, is dedicated entirely to the upgrading of the low tritium heat transport D_2O.)

(iii) Bruce NGS has its own on line moderator system upgrading facility.

These upgraders are capable of achieving higher isotopic than reactor grade of 99.75% and there is great economic incentive to achieve this as seen in Table 1. By 1976, for instance, it is hoped to have the Pickering moderators up to 99.84% isotopic.

(c) Other important nuclear parameters of the moderator are the SLOWING DOWN LENGTH Ls and the DIFFUSION LENGTH L of the neutrons.

The slowing down length Ls, being a measure of the distance travelled during neutron thermalization, physically determines the amount of moderator between the channels, i.e. it determines the reactor lattice pitch. For instance, Table 3 shows the lattice pitches for our reactors and their respective Ls values.

The diffusion length L, being a measure of the distance travelled by the thermalized neutrons before capture occurs physically determines the fraction of neutrons in the core absorbed in the moderator and hence L should be as large as possible. Table 3 compares the core averaged L values in all our stations. After the pressure tubes, the moderator itself is in fact the next largest parasitic neutron absorber in the calandria.

NON-NUCLEAR CONSIDERATIONS

Numerous chemical and physically properties of the moderator must be considered in addition to the nuclear properties described above. The following are some of the important considerations.

(a) Minimum corrosion must be achieved to prevent scale formation, flow restrictions due to corrosion products and contamination due to active corrosion products.

(b) Control of D_2O radiolysis into D_2 and O_2 gases by γ radiation.

The deuterium released into the moderator cover gas system has to be maintained less than an operational limit of 2% D_2 to prevent a possible explosion hazard. Above this limit the reactor must be derated, and shut down at 4% D_2.

Excess O_2 dissolved in the moderator on the other hand must be kept low to prevent increased corrosion. The conductivity data of Table 1 reflects the typical acceptable levels.

(c) Cost of D_2O increases both the capital reactor cost and make up cost. In practice this means that D_2O systems where possible should be of welded construction and leak detection systems will be a requirement.

Recovery systems for D_2O are necessary to D_2O areas where leakages are possible and the ventilation systems for these areas will be closed circulation systems with dryers to remove D_2O vapour from the air.

(d) Activation products of D_2O. Production of tritium in the moderator, see Table 1, is the source of a large manrem dose in our stations and is one of the major disadvantages to the use of D_2O. In addition short lived isotopes N-16 and 0-19 are produced during operation and it is the presence of these isotopes which prevents access to the system during operation.

(e) The boiling point of D_2O is convenient so our moderator can be kept at a temperature of typically 60°C, compatible with calandria thermal stresses, at atmospheric or slightly greater pressure.

The freezing point at 3.8°C should be noted in cases where heat exchanger shell side coolant is service water likely to be cooled at any time less than this temperature.

For future CANDU reactors and possible commercial organic cooled reactors (based on the OCR WRI at Whiteshell) or future boiling light water reactors (such as GI at Gentilly) there is no other alternative to D_2O moderator being considered in the long term.

Table 1 Chemical Analyses for Pickering NGS

(September 26, 1973)

MODERATOR (IX inlet)	Unit 1	Unit 2	Unit 3	Unit 4
pH	7.0	7.0	7.0	7.0
conductivity mS/m	0.023	0.034	0.027	0.047
chlorides mg/kg	< 0.1	< 0.1	< 0.1	< 0.1
boron mg/kg	< 0.1	< 0.1	< 0.1	2.7
D_2O weight %	99.74	99.74	99.73	99.50
tritium Ci/kg	9.2	6.0	6.4	5.18

Table 2 Moderator System Isotopic Data (Pickering)

Change in D_2O Isotopic Δk Change Fuel Cost Penalty*	±0.1% ±3.6 mk ±300,000$ year

* Zero penalty taken for 99.75% D_2O

Table 3

	NPD	DOUGLAS POINT	PICKERING	BRUCE
Lattice Pitch (cm)	26.1	22.86	28.58	28.58
Ls (cm)*	11.8	12.33	12.07	12.07
L (cm)*	15.9	12.25	14.95	14.90

Lattice Pitch, slowing down lengths and diffusion lengths for CANDU stations.

* These are values averaged over the core; for 99.75% D_2O the values are Ls = 11 cm and L = 100 cm which change with temperature and fuel burn up.

ASSIGNMENTS

1. Why is Douglas Point moderator water not upgraded at BHWP?

2. The values of Ls and L for H_2O are 5.6 and 2.8 cm respectively and for graphite are 19 and 64 cm respectively. What can be said about the core sizes then of typical BWR's and graphite reactors in relation to CANDU?

3. What advantages does the large L value for reactor grade D_2O moderator give to the CANDU system compared to other reactor types?

4. Pickering moderator system contains about 290 Mg of D_2O. How much H_2O inleakage, or accidental addition is required to downgrade the system by 0.1%?

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