Cold Head Reactor Design for APR1000

Seon Hoe Kim*, Ho Cheol Jang , Byung Ryul Jung, Byung Jin Lee, Se Jin Baik
KEPCO Engineering and Construction Co., Inc. 150 Deokjin-dong Yuseong-gu Daejeon Rep. of Korea 305-353

Keun Bae Yoo, Myung Ki Kim, Dong Hyun Jee
KEPCO Research Institute, 65 Munji-Ro Yuseong-Gu Daejeon Rep. of Korea 305-760

* *Corresponding Author: s06seon@kepco-enc.com*

1. Introduction

'Cold Head' reactor represents a reactor type of which the coolant in the reactor upper head region is as cold as that in the reactor inlet, whereas 'Hot Head' reactor as hot as that in the reactor outlet. Key characteristics of the Cold Head and Hot Head are illustratively compared in Fig. 1.

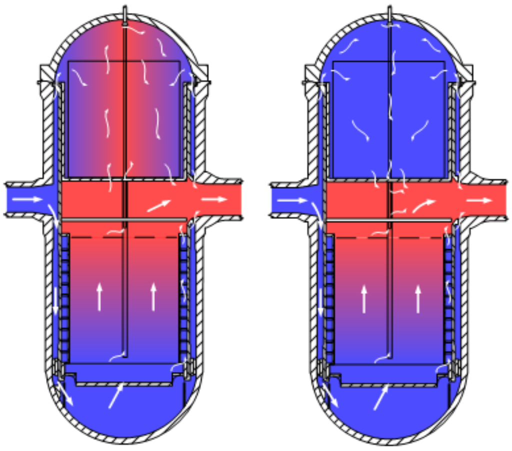
(a) (b)

Fig. 1. Illustrative comparison of two reactor types: (a) Hot Head, (b) Cold Head

EPRI [1] requires that the fluid temperature in the reactor upper head region be as low as that in the cold leg; in other words, it demands the Cold Head for a new reactor. The Cold Head reactor has a couple of advantages: e.g., (1) interfaces between the closure head and reactor vessel, including the internal structure flanges, experience less thermal stress than in the Hot Head reactor since the temperature differences across the interfaces are drastically reduced, and (2) nozzles penetrating the reactor closure head have less chance of PWSCC (Primary Water Stress Corrosion Cracking) which is known sensitive to the level of fluid temperature surrounding the nozzles.

Among nuclear power plants now in operation in Korea, Kori 3&4, YGN 1&2 and UCN 1&2, are Cold Head. Kori 1&2, the oldest, and all of OPR1000 versions are Hot Head [2]. To be more competitive in the market, APR1000, the advanced version of OPR1000 now in development, needs to be Cold Head.

2. Design and Analysis

2.1 Methodology

The main coolant flow in the reactor vessel starts at the inlet nozzles, and goes down the annulus between the reactor vessel and the core support barrel, across the lower plenum, up through the reactor core, and through the reactor outlet nozzles. A portion of the coolant flow leaves the main path not contributing to the convective heat transfer in the core, and thus is called the core bypass flow. Part of the core bypass flow is useful for cooling the reactor internals in the regions not in the main flow path and for cooling the control element assemblies. See Fig. 2 for such leakage flows.

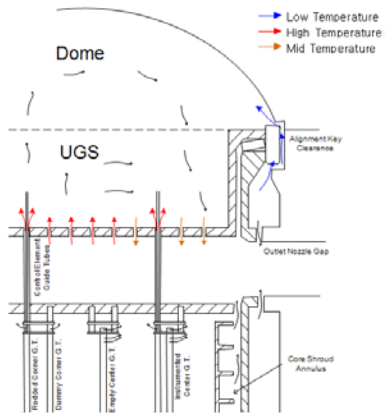

Fig. 2. Leakage flows in and out of the upper head of OPR1000

For the control volume enveloping the upper head region, the coolant flows communicating through the boundary are (1) cold flow into the upper head from the downcomer annulus through the gaps around the Alignment Keys, (2) hot flow into the upper head from the core exit region through the control element assemblies (CEA) guide tubes, (3) hot flow into the upper head from the outlet plenum through the holes distributed in the central area in the upper guide structure (UGS) support plate, (4) down flow from the upper head to the outlet plenum through the holes in the peripheral region in the UGS support plate.

A simple and safe way to make a Cold Head is to control the coolant flows around the upper head region. The basic design approach to keep the upper head region under Cold Head condition is as follows:

1) Coolant in the cold side is allowed to flow into the upper head.
2) Coolant in the hot side is blocked from leaking into the upper head.

3) Leaking paths from the upper head are made to the hot side.

Design modifications are made to the existing OPR1000 reactor internal structure; new holes are added in some regions, and existing holes are enlarged or plugged in some regions. As a result of such changes, total amount of the core bypass flow may have to be increased or some flow paths critical to the safety analysis can be modified. To minimize the impacts on the core thermal performance and safety, some design constraints are needed. To find the optimal design option for the Cold Head, a series of parametric analyses are carried, and feasible candidates are sorted out by design constraints.

2.2 Design Constraint

To achieve the Cold Head, more coolant flow from the cold side to the upper head is needed. The core bypass flow may increase and exceed the 3% limit imposed on the OPR1000 design. Based on the design and engineering experiences for OPR1000, APR1400 and some Westinghouse type reactors, the design constraints for the Cold Head reactor development for APR1000 are set as follows:

1) Total amount of the core bypass flow should not be more than 5%.
2) Blowdown flow resistance of the UGS should not be higher than that of OPR1000.

These constraints have been evaluated to be allowable for the core thermal margin and safety analysis.

2.3 A Matrix for Case Study

Coolant flows in and out of the upper head, and the flow distribution and mixing therein are sensitive to the following flow design parameters and can be effectively controlled by them, some of which are newly proposed for APR1000 based on the design experience and some preliminary analysis.

An evaluation matrix of 2,464 cases was organized considering (1) the number of spray flow holes in the reactor vessel flange, (2) size of spray holes in the reactor vessel flange, (3) flow hole size and distribution in the UGS support plate and (4) the number of bleed-off holes in each CEA guide tube wall.

Table 1: Case for parametric study

Description		Variation
No. of Spray Hole		8, 12 … 36 (ea)
Diameter of Spray Hole		0.5, 0.6 … 1.5 (in)
UGS Support Plate Hole Dia.	Outer Region	1.5 (in), plugged
	Inner Region	1.5, 1.75 (in), plugged
No. of Bleed-off Holes / CEA Guide Tube	Outer Region	2, 4, 6 (ea)
	Inner Region	2, 4, 6 (ea)

2.4 Results

323 cases out of 2,464 cases satisfied the design constraints. The sorted cases were evaluated for the feasibility from the view points of mechanical design and structural integrity. The flow paths of the optimal design option are summarized in Fig. 3. The following are the key features of the design option finally chosen:

1) 24 spray flow holes of 1.1" in diameter are added along the reactor vessel flange, through which cold coolant in the downcomer region is sprayed into the upper head.
2) Out of 161 flow holes in the UGS support plate of the existing OPR1000, 72 holes in the inner region are increased in diameter from 1.5" to 1.75", and the other holes in the outer region are plugged up. The 72 holes are the downward flow path from the upper head to the outlet plenum.
3) Two (2) bleed-off holes of 0.5" diameter are made on the wall of each CEA guide tube. These provide bleed-off flow paths to the outlet plenum for the leakage flow through the CEA guide tubes down from the upper head and also for the flow up from below the fuel alignment plate. These holes help prevent the hot flow from rising to the upper head.

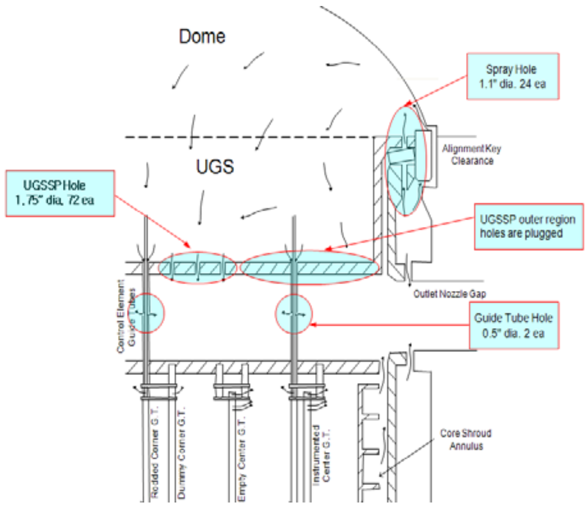

Fig. 3. Leakage flows in and out of the upper head of the Cold Head design option chosen for APR1000

3. Conclusions

As a part of the APR1000 development project, the Cold Head reactor design concept has been established, and an optimal design option has been chosen through a series of parametric analyses and feasibility evaluations. Details of the design will be further evaluated and improved in the next design phases.

REFERENCES

[1] Electric Power Research Institute Utility Requirements Document, Revision 10.
[2] H. C. Jang, 국내원전 원자로 상부헤드 관통관 민감도 분석, Korean Society of Pressure Vessels & Piping, 2007.