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Blowdown Analysis of the STS Target Assembly

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Second Target Station Project

BLOWDOWN ANALYSIS OF THE STS TARGET ASSEMBLY

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1. INTRODUCTION

During normal operation of the STS Target Assembly, cooling water removes the heat deposited in the tungsten target segments by the proton beam. Because the cooling water flows through the target region where spallation reactions occur, it becomes activated.

When a target segment is replaced during scheduled maintenance or following a component failure, disconnecting the cooling jumper between the target segment and the target drive could allow activated cooling water to leak or spill if water remains above the connection elevation.

To minimize this risk, compressed air is introduced into the cooling circuit to displace a portion of the activated water before disconnecting the jumper. The objective of this analysis is to determine the amount of water that must be removed so that, after the remaining water redistributes under gravity, the final water level remains below the jumper connection.

2. OBJECTIVE

The objective of this analysis is to:

- determine the remaining volume of water after air blowdown;
- predict the equilibrium water level after gravitational redistribution; and
- verify that the final water level is below the jumper connection, thereby preventing leakage of activated cooling water during target segment removal.

3. PHYSICAL BASIS

Immediately after air blowdown, the remaining water is not in hydrostatic equilibrium because portions of the cooling channels may contain trapped water and air.

Once the blowdown process stops, gravity causes the remaining water to redistribute until hydrostatic equilibrium is established. At equilibrium, the free surface of the water becomes horizontal, and the final water level depends only on:

- the remaining water volume, and
- the internal geometry of the cooling passages.

Since no additional water enters or leaves the system after blowdown, conservation of volume applies. Therefore, prediction of the final equilibrium water level requires only the remaining water volume and the internal geometry of the cooling passages. Because the engineering objective is to determine the final hydrostatic equilibrium rather than the transient air–water flow during blowdown, a transient multiphase CFD simulation is not required to determine the final equilibrium water level.

4. ANALYSIS METHOLOGY

The original cooling water volume was divided into two regions:

- Supply volume
    - occupied by compressed air during blowdown;
    - water contained within this volume is assumed to be completely displaced.
- Return volume
    - contains the remaining water after blowdown;
    - this water subsequently redistributes under gravity.

To determine the equilibrium water level:

1. The three-dimensional water domain was intersected by a series of horizontal planes located at different vertical (Y) coordinates.
2. For each Y-coordinate, the volume of the fluid domain below the plane was calculated.
3. The calculated volume was compared with the remaining water volume after blowdown.
4. The Y-coordinate where these two volumes became equal was identified as the equilibrium water level.

Mathematically,

$$\mathrm{V(Y)} = V_{remaining}$$

where

- V(Y) is the volume below elevation Y,
- $V_{remaining}$ is the remaining water volume after blowdown.

This procedure was implemented using the three-dimensional CAD geometry of the cooling passages. Fluid volumes corresponding to different horizontal elevations were measured directly from the CAD model using SpaceClaim 2024 R2.

5. ACCEPTANCE CRITERION

The blowdown is considered acceptable if

$$Y_{equilibrium} < Y_{jumper}$$

where

- $Y_{\text{equilibrium}}$ is the calculated equilibrium water level;
- Y_{jumper} is the elevation of the cooling jumper connection.

If this criterion is satisfied, gravity alone cannot cause water to reach the connection after the jumper is disconnected.

The objective is not to completely dry the target segment. Rather, the objective is to ensure that any remaining activated water remains below the jumper elevation so that it cannot leak when the connection is opened.

6. ANALYSIS CASES

Two air blowdown scenarios were evaluated to support maintenance activities involving the STS Target Assembly. During target operation, the cooling water becomes activated as it removes heat from the target segments exposed to the proton beam. Prior to disconnecting cooling jumpers during maintenance, a portion of the activated cooling water must be removed to minimize the potential for leakage or spillage.

The following two analyses were performed to evaluate different maintenance scenarios. The calculated equilibrium water level is then compared with the elevations of the cooling jumper connections to verify that the remaining activated water is retained below the connection interfaces.

6.1 CASE 1 – AIR PURGE OF WATER IN A SINGLE TARGET SEGMENT

The first case evaluates the removal of activated cooling water from a single target segment prior to segment replacement. Compressed air is introduced into the cooling passages of the target segment to displace a portion of the cooling water. After the blowdown process is complete, the remaining water redistributes under gravity until hydrostatic equilibrium is established.

Figure 1 shows the initial blowdown configuration for a single target segment. The region shown in blue represents the supply air volume, corresponding to the volume of water displaced from the target segment during the blowdown process, while the region shown in red represents the remaining water volume.

As presented in Figure 2, the total fluid volume, supply air volume (displaced water), and remaining water volume in the single target segment are **7,150,851 mm³**, **2,470,982 mm³**, and **4,679,868 mm³**, respectively. The remaining water volume is larger because it corresponds primarily to the return-side cooling volume. In the STS target cooling design, the return-side volume is intentionally larger than the supply-side volume to increase the dwell time of the activated coolant, allowing short-lived radionuclides to decay before the coolant returns to the target drive and thereby reducing the gamma dose rate in the target drive room.

To determine the equilibrium water level, the total fluid volume was intersected by a series of horizontal planes at different vertical (Y) elevations. The volume below each plane was calculated and compared with the remaining water volume. It was found that the volume below Y = 3,718.04 mm is equal to the remaining water volume of 4,679,868 mm³. Therefore, **Y = 3,718 mm** represents the predicted equilibrium water level after 2,470,982 mm³ of water has been displaced from the **single target segment**. The corresponding water height for this case is 3754.04 mm, as shown in Figure 3.

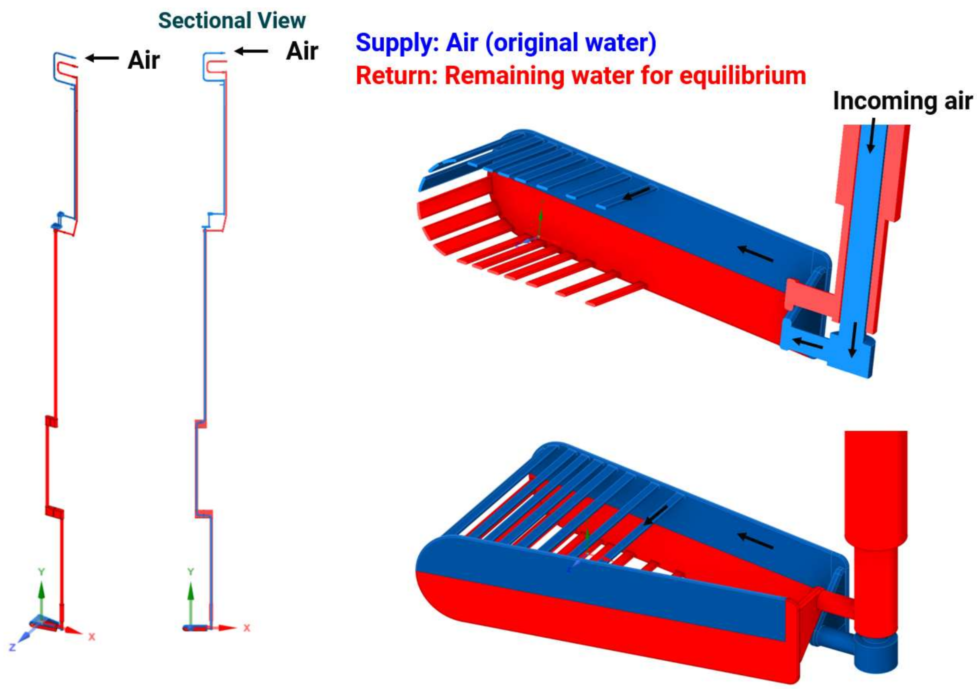

Figure 1. ***Initial blowdown configuration*** *for Case 1: air purge of water from a single target segment. Blue indicates the supply air volume, and red indicates the remaining water volume.*

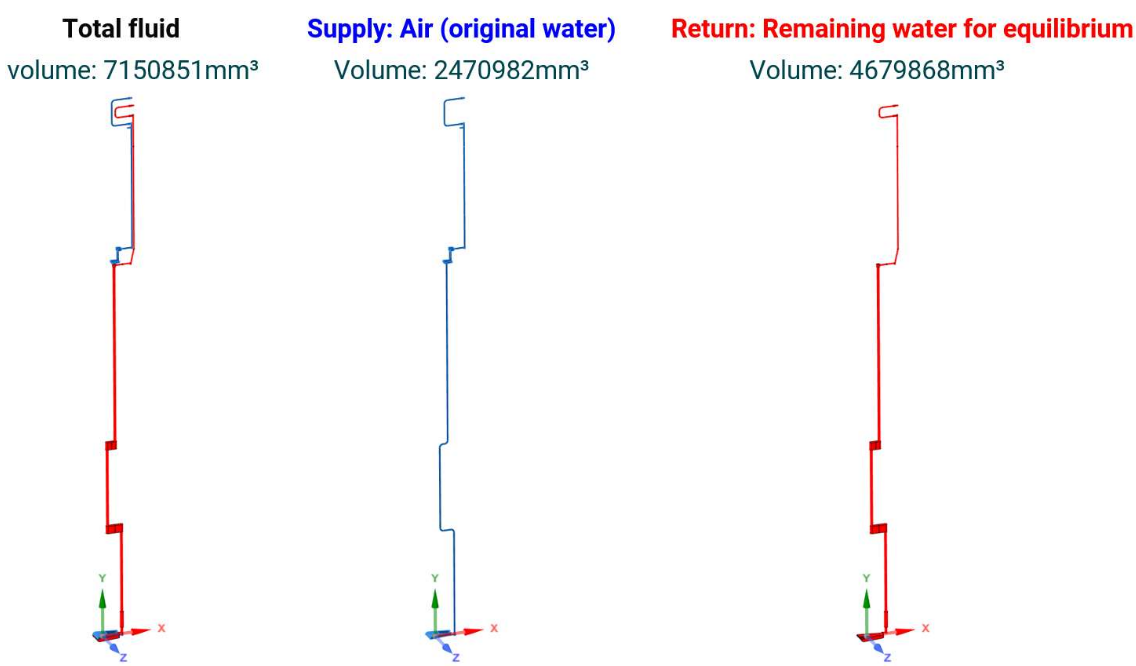

Figure 2. ***Separation of the fluid volume*** *into the supply air volume and the remaining water volume in a single target segment.*

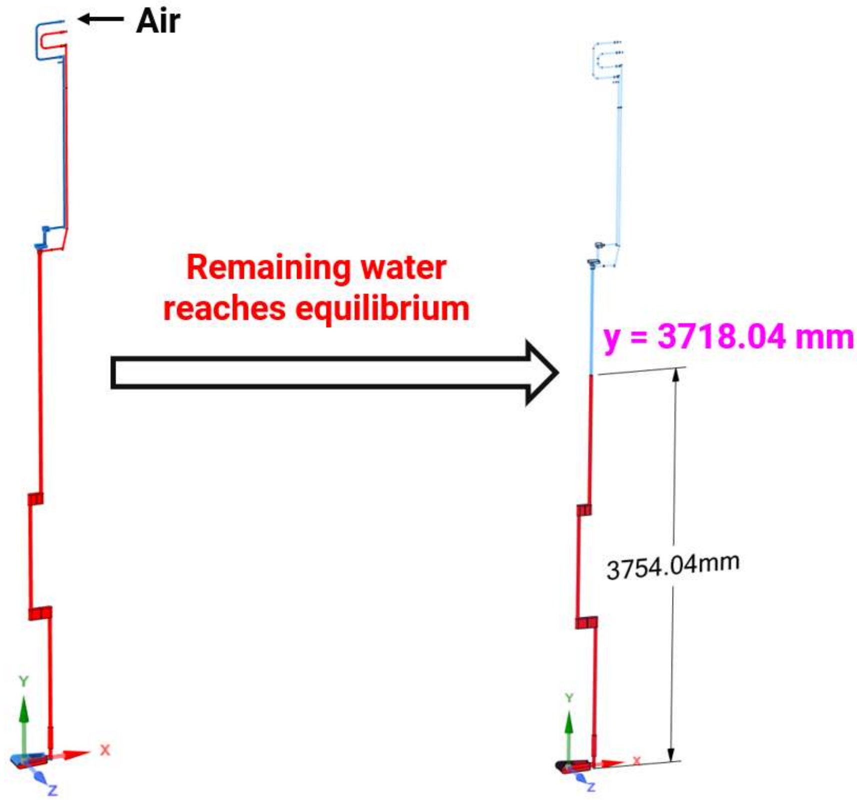

Figure 3. ***Predicted equilibrium water level*** *after air purge of a single target segment.*

6.2 CASE 2 – AIR PURGE OF WATER IN THE WHOLE TARGET ASSEMBLY

The second case evaluates the blowdown of the Target Assembly, including the target drive, target shaft, and all twenty target segments. This scenario represents maintenance activities in which the entire cooling circuit is subjected to air blowdown prior to the major maintenance or removal of the Target Assembly.

As presented in Figure 4, the total fluid volume, supply air volume (displaced water), and remaining water volume in the Target Assembly are **173,113,619mm³**, **62,162,223mm³**, and **110,951,396mm³**, respectively.

Figure 5 shows the initial blowdown configuration for the target shaft, and Figure 6 shows that the total fluid volume, supply air volume (displaced water), and remaining water volume in the target shaft are **12,042,938mm³, 4,901,149mm³, and 7,141,789mm³,** respectively. Although the supply and return channels of the target shaft and the twenty target segments are connected within the target drive (the upper portion of the Target Assembly), the bottoms of the target shaft and target segments are not hydraulically connected. Consequently, after blowdown and subsequent gravitational redistribution, the equilibrium water levels in the target shaft and the target segments are different. Therefore, the redistribution of water in the target shaft must be evaluated separately from that in the target segments.

After the blowdown of the Target Assembly, the remaining water volume of **9,917,444 mm³** in the target drive (shown in magenta in Figure 7) redistributes to the target shaft and the twenty target segments under the influence of gravity. As discussed in Report **S03020000-DAC10003**, at the same flow rate of 7.5 GPM, the pressure drops through a single target segment and the target shaft are 8.4 psi and 4.9 psi, respectively. This indicates that the flow resistance of the target segment is higher than that of the target shaft. Consequently, the targe shaft would be expected to receive a larger portion of the remaining water volume (9,917,444 mm³) in the target drive after gravitational redistribution.

To provide a conservative estimate of the equilibrium water level in the target segments, this analysis assumes that the remaining water in the target drive is equally distributed among the target shaft and the twenty target segments. Since the target shaft has a lower hydraulic resistance than a target segment, it would be expected to receive a larger share of the redistributed water. Assuming an equal distribution therefore overestimates the amount of water retained in each target segment, resulting in a higher predicted equilibrium water level in the target segments. Under this assumption, each component receives an additional **472,259 mm³** of water (= 9,917,444mm³/21) from the remaining water volume in the target drive.

Accordingly, after blowdown of the complete Target Assembly (displaced water volume = 62,162,223 mm³ as shown in Figure 4), the remaining water volumes in a single target segment and the target shaft become **5,152,128 mm³** (4,679,868 mm³ + 472,259 mm³) and **7,614,048 mm³** (7,141,789 mm³ + 472,259 mm³), respectively.

Using the same methodology described in the previous section, it was determined that, for a single target segment, the fluid volume below Y = 4,283 mm is equal to the remaining water volume of 5,152,128 mm³. Similarly, for the target shaft, the corresponding elevation is Y = 569 mm. Therefore, after blowdown of the complete Target Assembly, the predicted equilibrium water levels are **Y = 4,283 mm** for the target segment and **Y = 569 mm** for the target shaft. The corresponding water heights are 4,347 mm and 633 mm, respectively, as shown in Figure 8.

Figure 9 compares the predicted equilibrium water levels for the two blowdown scenarios: Case 1, air purge of a single target segment, and Case 2, air purge of the complete Target Assembly. As shown in Figure 9, the equilibrium water level in Case 2 is approximately 565 mm higher than that in Case 1. Nevertheless, even after blowdown of the complete Target Assembly, the predicted equilibrium water level remains below the cooling jumper connections, confirming that the residual activated water remains contained during maintenance operations.

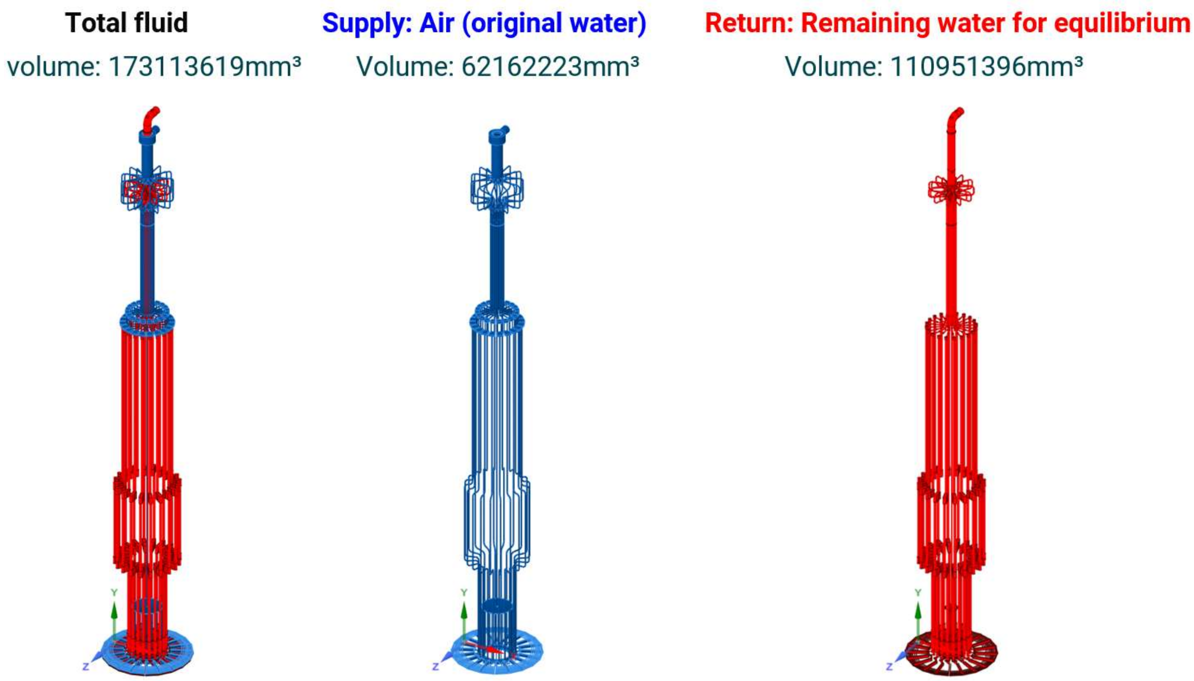

Figure 4. ***Separation of the fluid volume*** *into the supply air volume and the remaining water volume in the target assembly.*

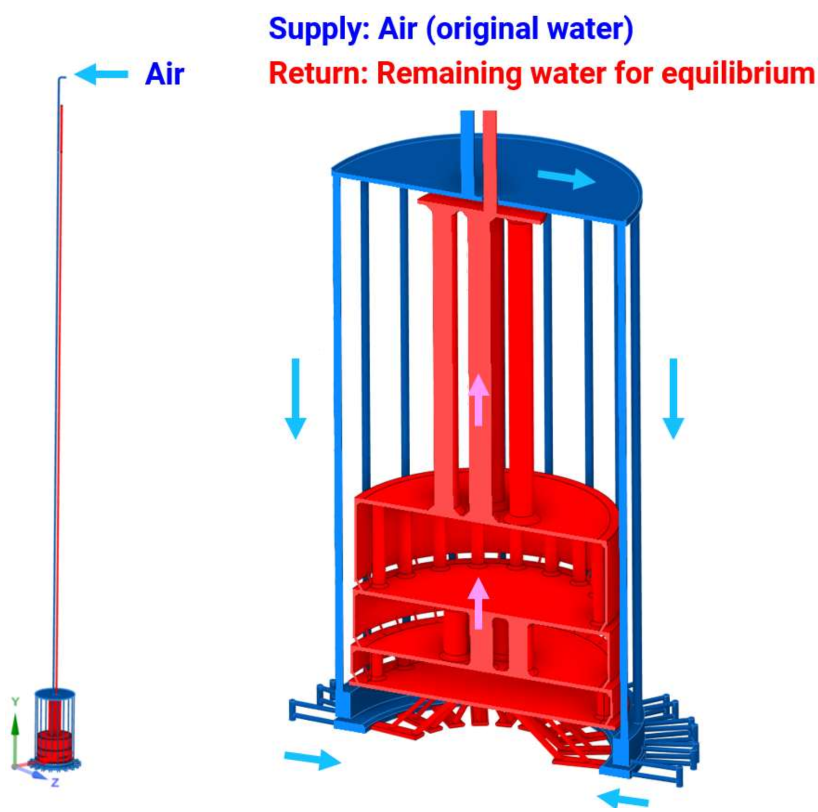

Figure 5. ***Initial blowdown configuration*** *for the target shaft. Blue indicates the supply air volume, and red indicates the remaining water volume.*

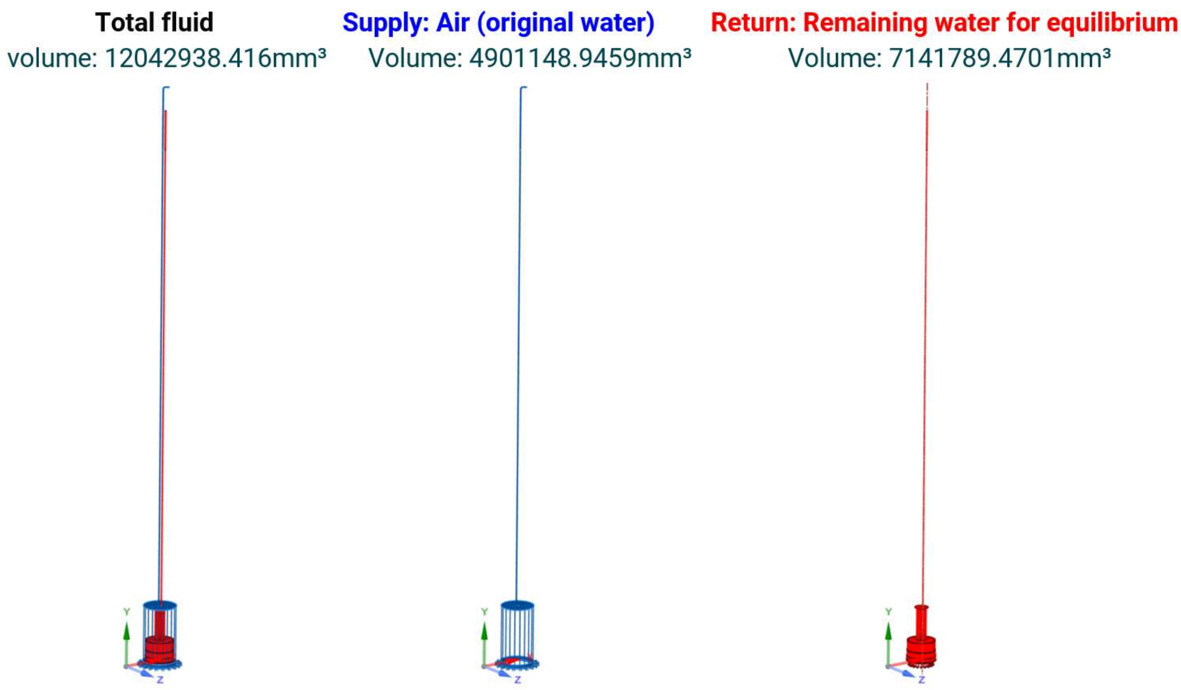

Figure 6. ***Separation of the fluid volume*** *into the supply air volume and the remaining water volume in the target shaft.*

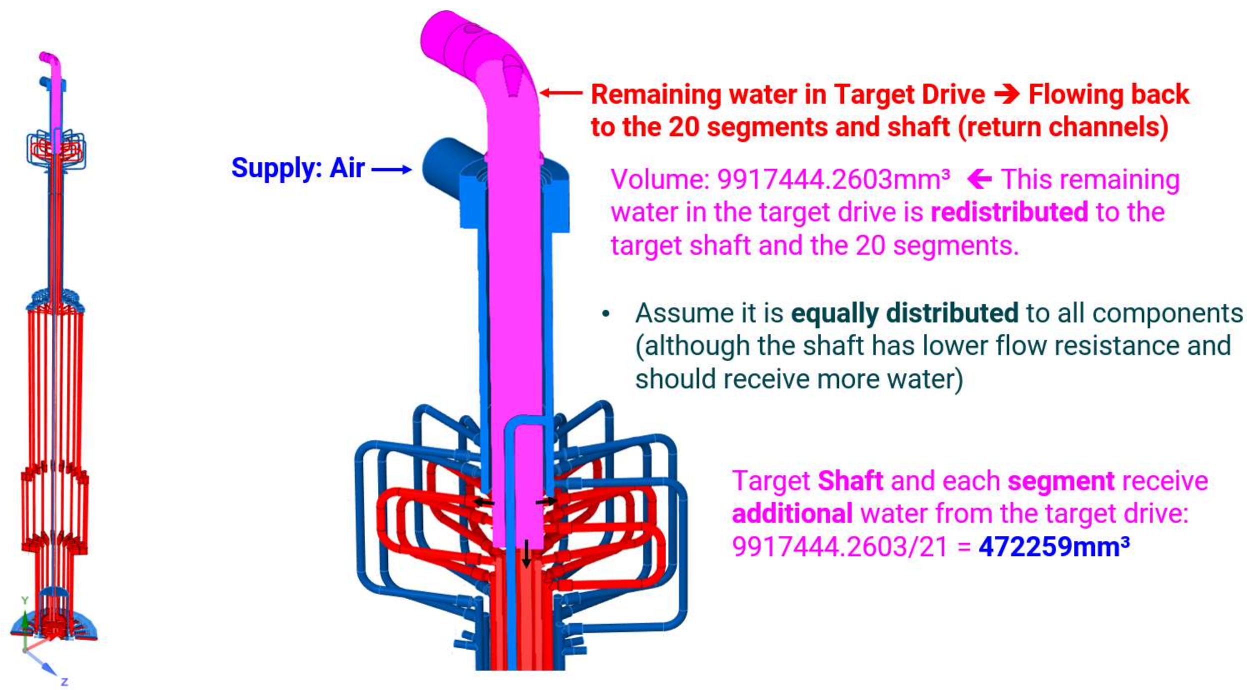

Figure 7. ***Remaining water volume in the target drive*** *after air purge of the target assembly. Blue indicates the supply air volume, red indicates the remaining water in the target shaft and target segments, and magenta indicates the remaining water retained in the target drive.*

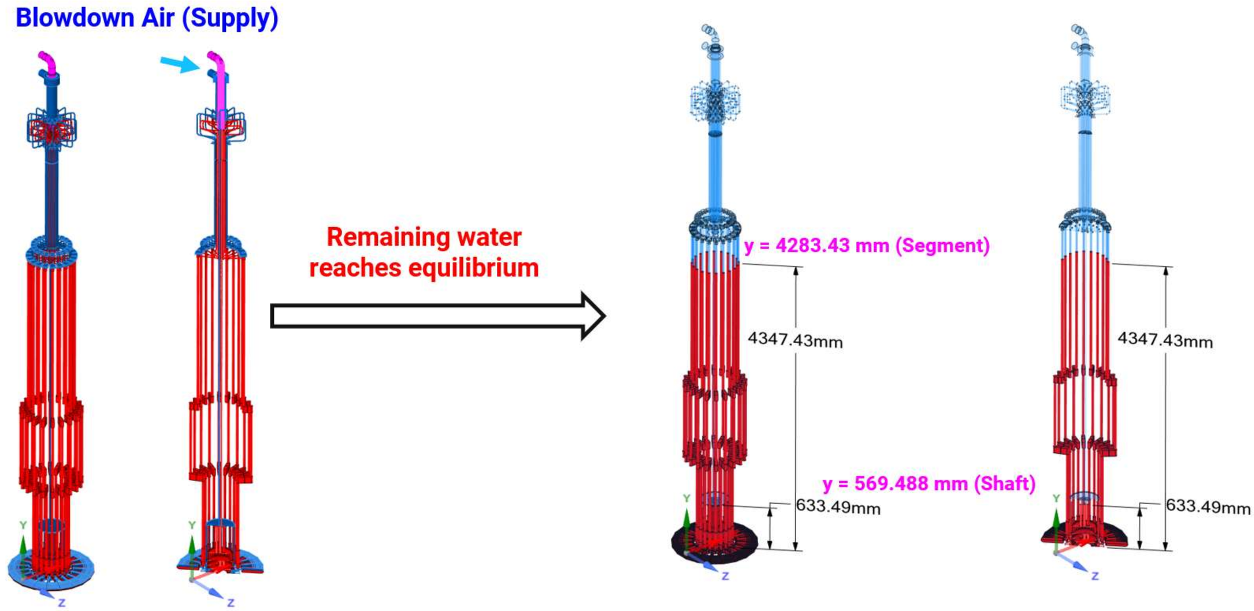

*Figure 8. **Predicted equilibrium water level** after air purge of the complete target assembly.*

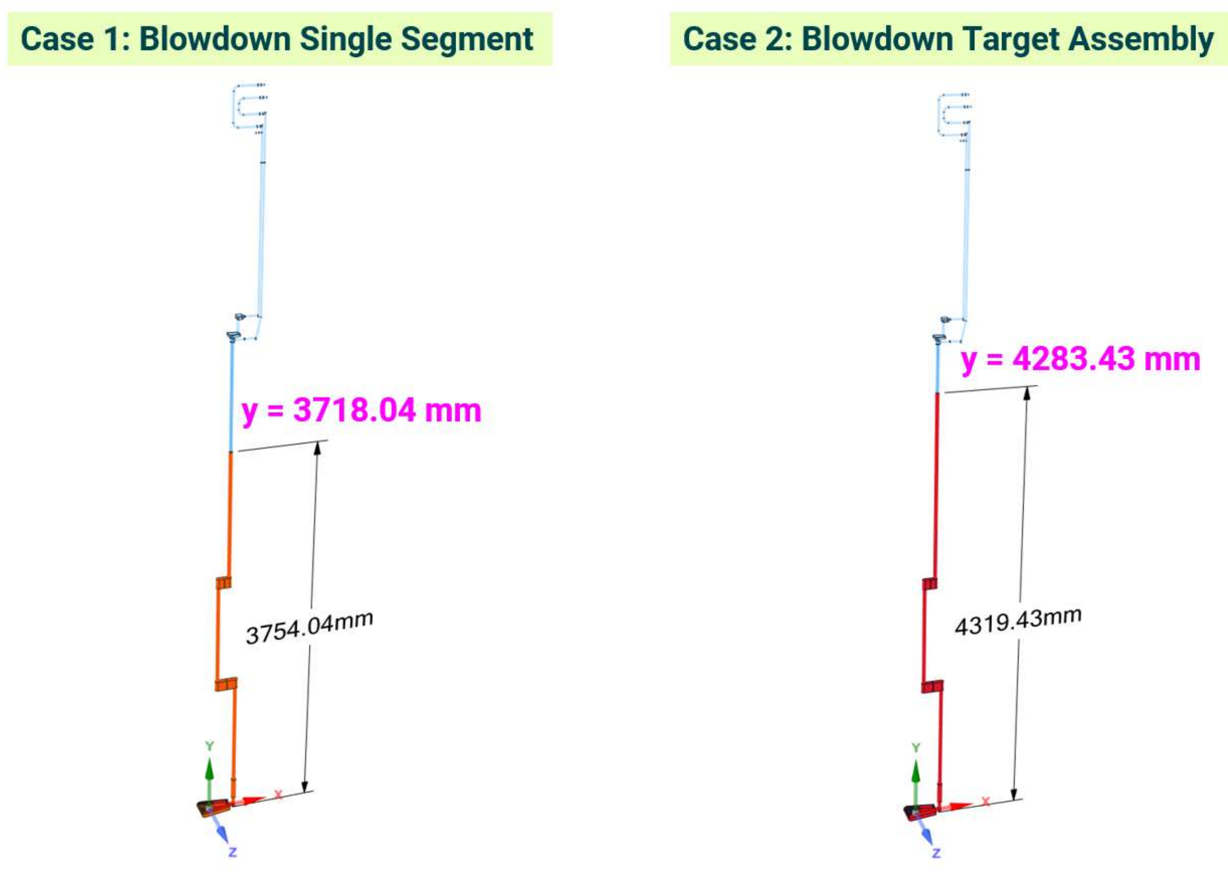

*Figure 9. **Comparison of the predicted equilibrium water levels** for Case 1 (single target segment) and Case 2 (whole target assembly).*