A New Methodology for Recirculation Pool Debris Transport Evaluation at Sump Clogging Issue

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1. Introduction

One of the most important applicable areas of analytic refinement considered in resolving GSI-191 sump clogging issue is the recirculation pool debris transport. Based on CFD analysis result combined with debris transport experiment, some analytic refinement methodologies have been suggested [1, 2]. However, due to complexity involved in debris transport, there still exists a room for improvement. Therefore, in the present study, previous evaluation methodologies are reviewed critically and a new methodology for the recirculation pool debris transport is suggested.

2. Review on previous recirculation pool debris transport methodologies

In this section, representative recirculation pool debris transport methodologies suggested by NEI and USNRC respectively are critically reviewed first.

2.1 NEI 04-07 methodology

In the NEI 04-07 analytic refinement methodology which is the US utility method [1], followings strategies or features are used.

- Use of minimum flooded containment level
- Specified water sources/sinks locations (figure 1.)
- For conservatism, the break flow is assumed to fall freely by gravity onto the water surface.
- The turbulent kinetic energy and the velocity could be compared to the debris-specific settling and tumbling velocities to determine fraction of debris transport to the sump screen.
- Curbs and trash racks are considered as restrictions.
- CFD mesh was clustered areas of interest where high velocities and gradients are expected.

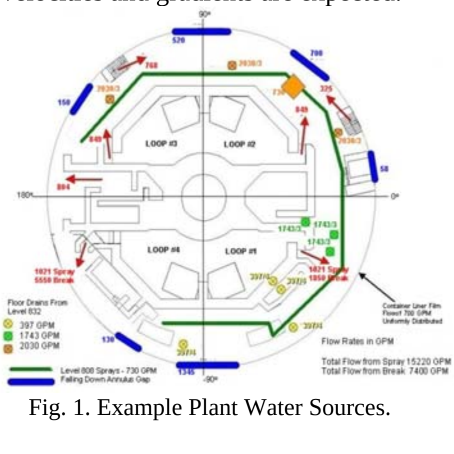

Fig. 1. Example Plant Water Sources.

Based on above strategies and features, CFD result was implemented to quantify the recirculation pool debris transport as below.

- For a given type and size of debris, plot velocity magnitude contours for the minimum bulk transport velocity at a selected elevation. The area within the velocity magnitude contour connected to the recirculation sump is determined, and it may be assumed that debris in this area will be transported to the sump screen.

In spite of detailed guidelines, the NEI 04-07 method has some drawbacks. Major drawbacks identified by USNRC are given as below. [2]

- Neglect of restrictions less than 6 inches in diameter or the equivalent should be verified.
- Using a uniform distribution of debris on the sump floor is not acceptable because the debris entrance into the pool is not uniform.
- A better-defined size distribution of debris should be used.(e.g. four size categories for fibrous debris)
- Suggested values for turbulent kinetic energy required to suspend debris should be verified.

In addition to above, other drawbacks are also identified by peer review. They are given as

- It has been found that debris can move at flow velocity even below the measured threshold tumbling velocity required to move them due to turbulence effect [3]. However, this effect of turbulent kinetic energy on the tumbling velocity of debris is not accounted.
- Although importance of velocity vectors and flow streamlines information was stressed, any plausible methodology to implement the information to determine debris transport can not be suggested at all.

2.2 USNRC SER methodology

In the safety evaluation report on the NEI 04-07, the USNRC suggested an evaluation methodology for the recirculation pool debris transport [2]. Although it has almost the same strategies and features as those of the NEI 04-07, some of them are unique. They are

- Use of velocities and streamlines are made for comprehensive determination of debris transport by using CFD analysis.
- Debris erosion characteristic is considered. That is to say, 90% of small and large fibrous debris are assumed to become fine debris by turbulence effect.
- When CFD analysis performed, RNG k-ε turbulence model is implemented because which can simulate swirling flow within recirculation pool.

Based on these strategies and features, CFD result was implemented to quantify the recirculation debris transport as below.

- The sump pool was subdivided into relatively fine subdivisions with each subdivision having a source term for debris depositing onto the pool floor at that location. Then, the transport of the debris from each specific subdivision was evaluated independently using streamlines generated from that subdivision to the recirculation sumps and contour maps of debris transport threshold tumbling velocity.
- The streamline plots were used to provide a reasonable connecting pathway whereby a piece of debris would likely travel from its original location in the pool to the recirculation sumps.

In spite of more state-of-art technology adopted, the USNRC SER also has some drawbacks. They are identified as below.

- Turbulence effects on debris tumbling and suspension were stressed but not reflected.
- The variation on tumbling velocities depending on size of specific type of debris was not considered.
- Use of streamline information to determine recirculation pool debris transport fraction was not clearly identified.
- Use of velocity at a height of 0.01m in drawing contour was not justified.

3. Suggestion of a new methodology for recirculation pool debris transport

Through peer review, strategies or features were identified. Some of them are given as below.

- Non-uniform debris source distribution into the recirculation pool should be used.
- Use of local velocity with debris tumbling velocity to determine debris transport.
- Use of turbulent kinetic energy with debris settling velocity to determine debris suspension [4].
- Use of turbulent kinetic energy to augment debris floor transport due to debris tumbling.
- Use of streamlines to determine transport fraction.
- Debris erosion characteristic should be considered.
- A proper reference height from the floor bottom should be used in drawing velocity and turbulent kinetic energy contour maps.
- Variation of tumbling or settling velocities depending on size of specific type of debris should be considered.

Based on above strategies and features, a proposed new methodology for the recirculation pool debris transport with CFD analysis is given as

- The sump pool was subdivided into subdivisions with each subdivision having a source term for debris depositing onto the pool floor at that location.
- Velocity contour map for sump floor was drawn by using original velocity from CFD analysis. Later, the map was extended more by reflecting turbulence effect on debris suspension. Finally, the revised map was further extended reflecting turbulence effect on debris tumbling.
- Using CFD post-process, streamlines coming from a debris source was identified (Fig. 2) and area enclosed by streamlines was determined. The area is compared with velocity contour map determined previous step to determine debris transport fraction.

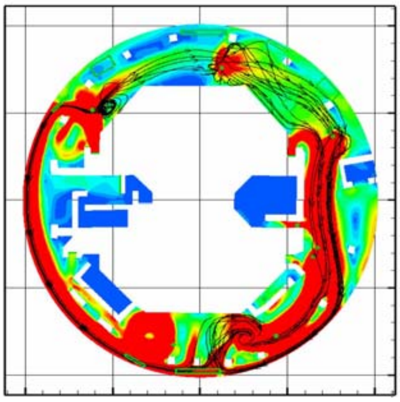

Fig. 2. Example Streamlines Plot.

4. Conclusion

Through peer reviews on available recirculation pool debris transport evaluation methodologies, a new debris pool transport evaluation method was suggested. The proposed method was focused on estimating debris transport fraction by implementing turbulence effect on debris suspension and tumbling along sump floor in addition to streamlines traces.

REFERENCES

[1] Pressurized Water Reactor Sump Performance Evaluation Methodology, NEI 04-07, May 28, 2004.
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[3] GSI-191: Integrated Debris-Transport Tests in Water Using Simulated Containment Floor Geometries, NUREG/CR-6773, December, 2002.
[4] Drywell Debris Transport Study: Computational Work, NUREG/CR-6369, Vol.3, September, 1999.