Innovative Design of a Metal Sampling Tool for Enhanced Safety in Nuclear Pressure Tubes

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Abstract:

Efficient maintenance of nuclear reactors is essential to ensure operational safety and reliability. This document outlines designing a device to extract metal samples from nuclear reactor pressure tubes. The design focuses on minimizing radiation exposure, ensuring operational ease, extracting the sample from 4-inch-wide horizontal tubes and meeting stringent safety and functional requirements. Through client consultations and market benchmarking, the document organizes client needs, prioritizes design criteria, and proposes innovative solutions to address this challenge.

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Introduction:

1.1 Background:

Ensuring the structural integrity of nuclear reactor pressure tubes is important to operational safety of those reactors. Over time, these tubes suffer degradation as hydrogen accumulates from the heavy water in the reactors. To address this challenge, Canadian Nuclear Labratories (CNL) requires a practical and efficient solution to extract metal samples safely from 15 feet in a 4-inch-wide pipe.

1.2 Objectives:

Our objective is to create a sampling device tailored to CNL's operational demands. This includes prioritizing radiation exposure reduction, ensuring dependable tool functionality, and preserving the collected samples, while making it user-friendly and durable.

Analysis and Research

2.1 User Needs:

Understanding the user's needs is central to designing an effective solution for metal sampling in nuclear reactor pressure tubes. CNL's primary and secondary needs highlight critical requirements for the device:

Requirements for the device:

- Ensure the device can reach a sampling depth of 15 feet within the tube.
- Operate effectively in both horizontal and vertical tube orientations.
- Collect precise metal samples with weights ranging between 30 and 80 mg.
- Ensure the device is modular and portable for ease of transportation and assembly.
- Include integrated feedback mechanisms to provide real-time updates to the operator.
- Implement fail-safe systems to allow safe retrieval of the tool in the event of malfunction.
- Emphasize cleanability to facilitate easy maintenance and extended usability.

2.2 Problem Statement

Extracting the sample efficiently allows the system not to have a stress point, ensuring the performance stays the same. However, sampling in nuclear systems poses its own set of issues

Current Challenges:

- Safety Risks: Manual intervention in sampling processes exposes operators to high radiation levels, increasing safety hazards.
- Operational Inefficiency: Current methods are time-consuming and prone to imprecision, affecting the quality and consistency of collected samples.
- Tool Limitations: Existing tools lack the modularity and adaptability needed for varied tube orientations and depths.

Importance of Solution

Developing a purpose-built sampling device will resolve these challenges by providing:

- Enhanced safety through minimized operator exposure.
- Increased operational efficiency with real-time feedback and precise sample collection.
- Reliable and durable equipment that supports long-term use and adaptability to diverse operational scenarios.

Design Solution

3.1 Design Criteria and Prioritization

Criteria	Description	Priority
Sampling Distance	Ensure 15 ft. Reach	5
Tube Orientation	Work in vertical and horizontal positions.	5
Sample Weight Consistency	Collect 30-80 mg samples accurately.	5
Containment	Prevent operator contact with samples.	5
Works in Diameter	Works in the desired diameter of 4 inches	5
Fail-Safe	Enable tool retrieval upon malfunction.	4
Real-Time Feedback	Provide operational updates.	4
Modularity	Ensure portability and easy assembly.	3

Cleanability	Allow for easy cleaning and maintenance.	3
Collection Flexibility	The mechanism of sample collection is adaptable and less critical.	2
Power Independency	Operate without external power sources.	2
Durability	Sustain prolonged use in challenging environments	2

3.2 Potential Solution

When looking into creating a potential solution, we were influenced by a device we found on Amazon that could clean chimneys through a drill system. We believed that even though it is not a requirement for our tests, it would be quite a good solution for the actual system. Additionally, the attachment we would send in would involve using a scraper, whether a pipe cleaner, or a cleaner for a grill that would then be vaccumed up into a safe containment storage that would be easily detachable and can be shipped off for testing. For a fail-safe mechanism, we would have it where the operator has to consistently hold the button down to keep it drilling, and if there would be any issue arising, letting go would stop the whole process.

Additionally, another solution we came up with was taking inspiration from an anime known as “Jujutsu Kaisen”. One of the characters uses these nun chucks that had 3 segments. We did not completely go through the logistics of it as when we stacked up our initial design with this design, it seemed better in almost every metric, while additionally being very feasible to create.

Conclusion

The designs we came up with deal with all the criteria for dealing in nuclear environments. As we thought out one more solution a lot further, we believe that we already have an effective product that can extract a sample efficiently. This system definitely meets our design criteria quite effectively, especially after looking at parts that could work with the system. By adequate

prototyping along with testing, we believe we can make a product that will be really great for acquiring a sample safely.

References

- CNL x uOttawa Design Challenge Presentation
- Consultation with Scott Read, CNL Engineer
- Amazon drill powered chimney sweep.