Application of CRDS for Monitoring Gaseous Fission Products in Research Reactors

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ABSTRACT

The safe operation of nuclear research reactors, like the IEA-R1, relies on continuous monitoring to detect fuel element (U3Si2-Al) failures. When cladding degrades, noble gases such as Xenon (Xe) are rapidly released into the cooling water and migrate to the pool surface, serving as early warning indicators of incipient failure. Cavity Ring-Down Spectroscopy (CRDS) is an ultrasensitive optical technique that measures the decay time of a light pulse within a high-finesse cavity [1]. This temporal measurement makes CRDS immune to laser intensity fluctuations, allowing detection limits at the parts-per-billion (ppb) level. This work outlines the implementation of a CRDS setup probing the 631.8 nm Xe transition to enhance structural integrity monitoring.

The setup uses a nanosecond pulsed Optical Parametric Oscillator (OPO) pumped by a Nd:YAG laser, tuned to the 631.8 nm Xenon transition. The beam is coupled into a 50 cm linear cavity formed by high-reflectivity plano-concave mirrors ($R > 99.9\%$), designed to meet optical stability criteria. To evaluate intrinsic cavity losses, the system was connected to a vacuum line (10^{-3} mbar). Initial alignment and signal capture used a 32-channel Licel SP32 spectrometer. Due to its 50 ns resolution limit, the methodology is transitioning to a single-channel Photomultiplier Tube (PMT) and a 2.5 GS/s oscilloscope, improving resolution to 0.4 ns.

Preliminary tests demonstrated effective optical confinement within the cavity. Spatial profiles confirmed the 631.8 nm beam was properly targeted. Ring-down decay curves showed a visibly longer decay tail in the evacuated cavity compared to atmospheric air, reflecting the elimination of molecular absorption losses.

Data analysis revealed that a simple mono-exponential fit does not accurately describe the decay curve due to the simultaneous excitation of multiple transverse cavity modes [2]. Higher-order modes decay faster, requiring a bi-exponential fit to isolate the fundamental mode lifetime. The upcoming high-density PMT acquisitions will allow precise application of this fit.

The initial phase of the CRDS system development successfully demonstrated light confinement and sensitivity to pressure changes. To overcome multimode decay artifacts, future data acquisition will employ a high-speed PMT to accurately measure the baseline decay time. Subsequent steps include calibration with Xenon traces and analysis of actual reactor off-gases.

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