ADVANCED PRESSURE TUBE SAMPLING TOOLS

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Abstract

Deuterium concentration is an important parameter that must be assessed to evaluate the fitness for service of CANDU pressure tubes. In-reactor pressure tube sampling allows accurate deuterium concentration assessment to be made without the expenses associated with fuel channel removal. This technology, which AECL has developed over the past fifteen years, has become the standard method for deuterium concentration assessment. AECL is developing a multi-head tool that would reduce in-reactor handling overhead by allowing one tool to sequentially sample at all four axial pressure tube locations before removal from the reactor. Four sets of independent cutting heads, like those on the existing sampling tools, facilitate this incorporating proven technology demonstrated in over 1400 in-reactor samples taken to date. The multi-head tool is delivered by AECL's Advanced Delivery Machine or other similar delivery machines. Further, AECL has developed an automated sample handling system that receives and processes the tool once out of the reactor. This system retrieves samples from the tool, dries, weighs and places them in labelled vials which are then directed into shielded shipping flasks. The multi-head wet sampling tool and the automated sample handling system are based on proven technology and offer continued savings and dose reduction to utilities in a competitive electricity market.

PT Sampling Overview

Deuterium concentration is an important parameter that must be assessed to evaluate the fitness for service of CANDU pressure tubes. Accurately estimating the remaining life of these tubes and ensuring their integrity are major long-term concerns to utility owners. Assessing deuterium content, at one time, meant periodic removal of a pressure tube. This was very costly because of the length of the shutdown required, and yielded information on one reactor lattice location only. A better approach was needed.

In recognition of this need, a method of obtaining a small sample of material from the inside of the pressure tube was developed by AECL Chalk River Laboratories (CRL) and first used at the Nuclear Power Demonstration (NPD) plant in Rolphton, Ontario, in 1987. Soon, a standard method was developed for obtaining a sample of material for deuterium content analysis, after first removing the hydride-rich oxide layer on the inside surface of the pressure tube. The cut made by the leading cutter is nominally 3.8 cm long x 1.3 cm wide x 0.008 cm deep, (1.5 in. x 0.5 in. x 0.003in.), while that made by the second cutter is 3 cm long x 1 cm wide x 0.001 cm deep (1.2 in. x 0.38in. x 0.004 in.). The cut profile is chosen to maintain fuel channel (FC) integrity, with smooth changes in geometry in all axes and careful control on total depth.

The sample obtained is in the form of a single curl, or "chip", and weighs about 120 mg (Figure 1). Deuterium content is determined at CRL using Hot Vacuum Extraction Mass Spectrometry (HVEMS). Total isotopic hydrogen content is estimated by determining the hydride solvus temperature using Differential Scanning Calorimetry (DSC), and along with baseline hydrogen content of tube off-cuts, provides a check for the HVEMS results. Testing of post-irradiated pressure tubes has shown good agreement of deuterium content measurements from samples and through-wall punch pellets taken from removed pressure tubes. Sampling is performed at four standard axial locations— 2, 4, 5 and 5.6 meters from the inlet end— which allow adequate modelling of the deuterium concentration profile.

Damp Sampling

The method of removing the material samples was based on "damp" [1] sampling tools by 1989.

[1] "Damp"— The pressure tubes are defuelled and drained, but may contain some residual heavy water.

These tools comprise a cylindrical tool head, slightly smaller than the pressure tube inside diameter. The tool head contains two cutter assemblies mounted in tandem in a common carriage. The carriage is driven over a cam that causes the two cutters to rise in turn and contact the pressure tube. The first cutter removes the oxide layer and then the second cutter removes the sample of pressure tube material for analysis.

Use of damp tools requires prior isolating of the fuel channel, typically by feeder freezing. Actuation is by hydraulic or pneumatics, and can operate with residual water present in the pressure tube. Heavy water droplets and vapour are isolated from the cut area by a purge gas system to prevent deuterium pick-up by the sample during initial oxidization of the freshly cut material.

Loading of damp tools into the reactor is performed manually from a platform adjacent to the face. Once actuated, a step that requires about 30 seconds, the tool is recovered from the reactor, and the oxide and sample chips are removed. Handling of the chips includes placing them in small plastic vials, capping the vials and then placing them in a shipping flask. Auxiliary equipment supplied by AECL facilitate this transfer, paying heed to the radiation fields of the chips and reduced operator dexterity due to personal protective gear.

Damp sampling requires substantial effort for a modest production rate. Feeder freezing alone for one channel typically requires at least one shift of a four-person crew (40 person-hours). This is followed by removal of the closure plug, shield plug and fuel by the fuelling machine. Then positioning the tool in the channel using push rods, actuating the tool, recovering it and retrieving the chips requires about 1 hour total (or about 20, 5, 15 and 20 minutes respectively) using a crew of about three. Given the general fields and contamination in the work area, dose accumulation can be a concern.

Wet Sampling

Wet pressure tube sampling increases production rate and decreases accumulated dose by avoiding feeder freezing and, in fact, any work on the reactor face. This is accomplished by fuelling machine (FM) delivery into flooded FCs at maintenance flow conditions. The tools are picked up by one FM from a fuel handling (FH) port (e.g., ancillary port in CANDU 6 plants, or the transfer mechanism 'T-port" at Pickering Nuclear Generating Station (NGS)), delivered to the desired channel and axial location, actuated by advancing a plunger integral to the tool by the opposing FM, and then recovered by the delivering FM. Once deposited into the FH port, the tools are manually withdrawn, the chips removed and the tool reset, before being loaded into the port for another delivery by the FM. The tool plunger is advanced via a string of fuel bundles or custom spacers.

The wet sampling tool (Figure 1) consists of a carriage, cam and cartridge assemblies, similar to the damp tools. The carriage is moved by the FM via a plunger and shaft arrangement. The FMs at CANDU 6 plants and at Pickering NGS are not capable of rotary control, and so the tool must provide this. Typically, samples are taken at the top of the pressure tube (i.e., the 12 o'clock position) when first sampled then at the 11 or 1 o'clock position. The CANDU 6/Pickering wet sampling tool uses a counter-balance arrangement to tilt the carriage-containing segment of the tool to the desired clock position. This segment is mounted on rotary bearings at either end. When the plunger is pushed by the FM, the initial travel of the shaft extends pads that lift the tool segment clear of the bearing supports to hold the tool in the correct radial orientation. A smaller counter-balance arrangement mounted on an independent radial bearing records the radial position of the cut; it is free to move until a pin locks it at the start of plunger travel.

Further plunger movement displaces light water from an onboard reservoir via a piston. The displaced light water flows through a conduit system to the cutter region. This provides flushing to clear heavy water and eliminate unwanted deuterium pick-up by the sample, like the purge gas system of the damp tools. By using internal valves that open as the cutters lift, less than 400 ml of light water is introduced per sample, an amount acceptable to reactor operators.

The wet sampling tools must be compatible with fuel handling equipment. Their length is that of two fuel bundles (fuel bundles are typically handled in pairs), their outboard end is that of the FH ram grapple adaptor to facilitate FM delivery, and their plunger plate is compatible with fuel bundle end geometry. Wet tools for Bruce NGS take advantage of the rotary positioning capability of the FMs there and interface with the FM via a dedicated spacer.

Wet sampling tools are tested and qualified prior to each campaign in a test facility at CRL that simulates the maintenance flow conditions expected. Heavy water is circulated at up to 465 kPa and 70 litre/min during the cutting process. Samples taken are routinely analyzed on site for deuterium content to ensure the flushing system is eliminating deuterium pick-up. Tool actuation and transferred forces, and actuation speed are monitored. Chip weights, and oxide and sample cut depths are also measured to ensure repeatability.

Typical wet sampling campaigns use four tools and production rates are as high as 5 channels per day (24 hour shift coverage) depending on FH practices. Tool reliability is very high. Ten to twenty channel campaigns typically do not require tool change-out. However, a spare tool is qualified to remain in abeyance.

Prior to a wet sampling campaign, FM software must be prepared and tested, and FM operators must be trained. At the beginning of the campaign, FM load and speed settings must be adjusted from that of normal operations and then tested. Electrical jumpers must be installed for control room monitoring of ram force. Commissioning runs, either in the reactor (without cutters) or in a FH test port, are then performed.

FH effort during a wet sampling campaign is summarized in Figure 2. Because each tool samples at only one of the four axial locations, substantial effort is required to shuffle fuel/spacers and deliver the tools. This overhead can limit production rate despite the fact that tool actuation requires only 10 seconds.

Multi-Head Tool

AECL is developing a multi-head tool that would reduce this effort by allowing one tool to sequentially sample at all four axial pressure tube locations before removal from the reactor. After the first actuation, the tool would be positioned for subsequent ones rather than be removed. Four sets of independent cutting heads, like those on the existing damp or wet tools, facilitate this. In this way, the approach incorporates proven technology demonstrated in over 1400 in-reactor samples taken to date.

The multi-head tool is delivered by AECL's Advanced Delivery Machine (ADM) or other similar delivery machines. ADM-delivery essentially eliminates any fuelling machine modifications (hardware and software) allowing much simpler preparations to be made off-line. This eliminates calibration of FM loads and speeds specific to sampling, as well as any specific FH staff training. The overall burden on FH staff is greatly reduced, freeing up this critical plant resource. Figure 3 shows FH and ADM steps required with the multi-head tool. Production rate is expected to exceed 6 channels per day.

An added benefit is that actuation forces are transmitted directly through the delivery machine ram and not through fuel or spacers. This eliminates concerns regarding loading of fuel. Further, spacers are not required, saving considerable effort in handling, inspecting and maintaining the spacers. The ADM provides clock position control, eliminating the need for this provision in the tool.

Chip recovery and tool resetting is simplified as well since only one tool is used during the campaign. Compared to wet sampling, only one-quarter of the entries are required by personnel for chip recovery and tool resetting. As Figure 3 shows, the overall length of the campaign is reduced, further reducing staff requirements. Table 1 shows expected accumulated dose compared to that of typical damp and wet campaigns.

Tool General Arrangement

The tool is compromised of a carriage, cam and cartridge assemblies, like its predecessors. The carriage in this case, contains four sets of independently actuated cartridges. To accommodate channel sag, a flexible joint resides between the tool segment housing the carriage and that housing the actuator and ADM coupling. Overall carriage housing length is kept to an acceptable amount by a novel approach whereby the carriage moves forward and then reverse one carriage module length for each cut, and the cam travels to the next carriage module on the reverse stroke. Figure 4 shows the overall tool arrangement.

The cam or "ramp" mechanism must lock in place to resist the forces of the followers traversing it, then release and travel with the carriage in the reverse direction, and finally lock in place for repeating the cycle. Outside of the reactor, the ramp mechanism must be brought forward by a similar sequence. Testing at CRL has shown this mechanism to be reliable and robust.

Actuation for carriage motion is provided by an electric motor/ball screw arrangement or by a hydraulic cylinder. This motion is simplified since the carriage always travels its full stroke. Both ramp and carriage position are monitored. Motor power signal provides a measure of actuation force. The connection for these power and signal lines is via a connecting module at the end of the tool. This connects to the ADM Advanced Fuel Channel Inspection System (AFCIS) umbilical, which connects to the appropriate power supply and signal conditioners outside the reactor.

In addition to these lines, light water flushing water is supplied to the tool via the umbilical. The water is directed to the appropriate cutting head by valves similar to those of the wet tools. This minimizes the light water introduced into the primary heat transport (PHT) system, keeping the total to that of a typical wet sampling campaign.

Automated Sample Handling System

Discussion in the preceding sections have highlighted how pressure tube sampling technology has advanced significantly in the past few years with the introduction of remotely delivered and actuated wet sampling tools. Elimination of reactor face work has resulted in not only a dramatic schedule decrease, but also in a substantial reduction of radiation dose accumulated by operators. The second phase of the overall sampling process involves transferring the sample chips from the tools to shielded shipping flasks, and then checking and resetting the tools for further in-reactor use. A large majority of the remaining dose is accumulated during this sample retrieval and tool handling. During a typical sampling campaign of 10 channels using CANDU 6 style wet tools, the total absorbed dose is in the order of 1.5 Rem. While the in-reactor tools have changed, much of the out-reactor sampling equipment is still similar to when sampling was first introduced. With this in mind, AECL has developed a system to automate sample retrieval and tool resetting. It is expected that the use of this system will reduce the radiation exposure to one-third of current levels.

There are other important benefits to the implementation of such a system beyond dose reduction. These include:

- Improved In-Field Monitoring: The automated system is capable of visually inspecting and weighing the pressure tube chips and recording the data for QA purposes. This provides better capability to ensure quality in-reactor samples are taken. Analysis results are affected by both oxide and sample chip weight. Weighing the chips on-site allows the sampling support specialists to more closely track tool performance and enables quicker response if tool adjustments are required, ensuring high quality analysis results. An added benefit of pressure tube chip weighing is that it uniquely identifies the chips at the earliest stage of processing.
- Reduced Staffing: Staffing for the current wet sampling campaigns typically involve four operators to perform sample retrieval, tool preparations and flask loading. This is in addition to Sampling Tool Technical Specialists and any QA and radiation protection personnel. This staffing level is required for each shift, usually two or three depending upon station practice. These personnel must undergo training with the sampling auxiliary equipment prior to the in-

reactor campaign and are then dedicated to the project for its duration. The automated system reduces staffing requirements since all operations are performed by the Sampling Tool Technical Specialist via a remote control panel. Conventional safety hazards due to crowding of the work area are also eliminated. Only one operator is required to perform flask change-outs, freeing up scarce resources during an outage.

Two design configurations have been produced for use with either the wet axial or multi-head sampling tools. The main components of each configuration are the same with different arrangements to meet installation requirements. The design for use with wet-style tools at CANDU 6 stations has the handling system installed at the ancillary port. The configuration for the multi-head tool has the handling system mounted directly onto the ADM frame. This approach allows remote sample retrieval directly on the reactor face to minimize tool and platform movements and save time. The modular design of the system will allow it to be easily adapted for use at other reactor types or with other delivery systems.

The operational steps the system can perform include:

- receiving and positioning of the tool head (in conjunction with the ADM for the multi-head tool),
- opening of the chip retaining clips,
- visual inspection of pressure tube chips and cutters,
- retrieval of the pressure tube chips from the sampling tool head,
- individual weighing of the pressure tube chips,
- packaging in labeled vials and flasking of the chips,
- verification of the sampled clock position (wet axial tool only),
- preparation of the tool for further sampling by returning the carriage to home and recharging the light water reservoir (wet axial tool only),
- re-inspection of cutters, general tool condition, and
- returning the tool to the tool delivery system.

All operations are performed remotely via a touch-screen panel. The computer control system has been set up with an automated module for performing various sequences. The program contains several hold-points for operator verification at critical steps. Both the equipment hardware and control software have been designed to allow for easy manual intervention for any equipment malfunction or non-standard situation.

Summary

Advances in both sampling tool and sample handling equipment offer reductions in dose, cost and schedule. The designs draw upon proven technology to ensure process reliability. The multi-head sampling tool is scheduled for demonstration 2000 December. The Automated Sample Handling System currently exists in a working prototype.

Method	Accumulated Dose (Rem)
Damp (1993)	13
Wet	1-1.5
Multi-Head	<0.5 (est.)

Table 1: Typical Accumulated Dose for 10 Channel PT Sampling Campaigns by Different Methods.

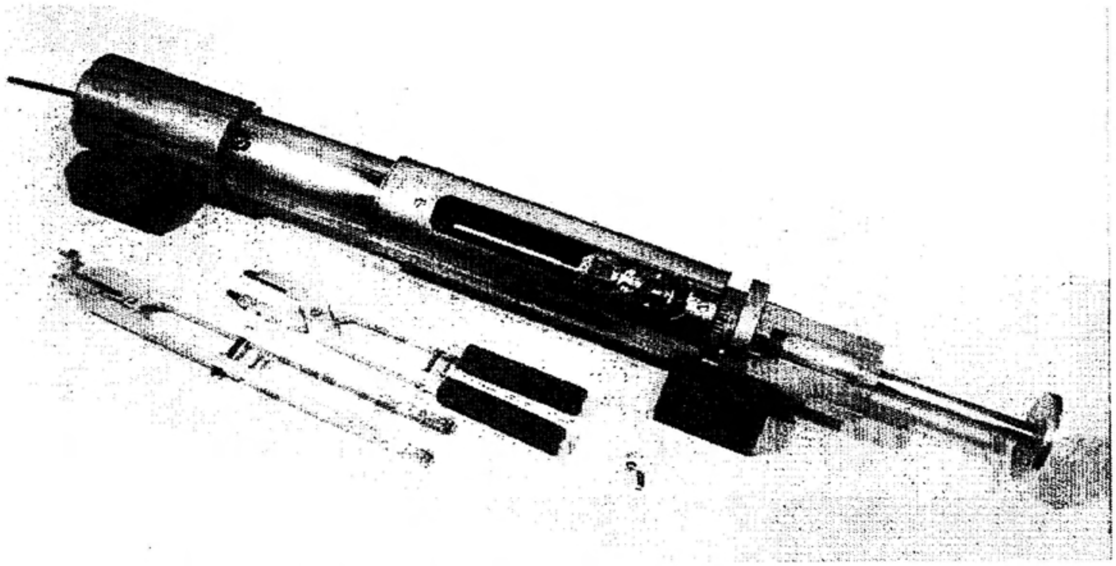

Figure 1: CANDU 6/Pickering Wet Sampling Tool with Hand Tools and Chips (see circular dish).

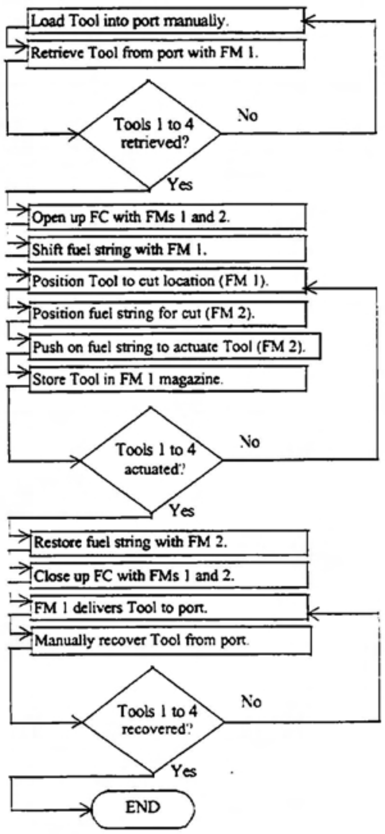

Figure 2: FH Steps for Wet Sampling of One FC.

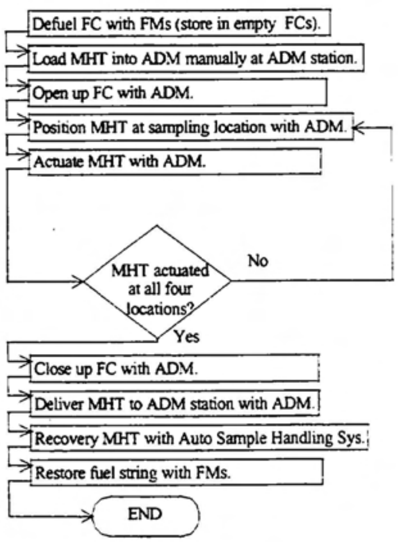

Figure 3: FH Steps for Multi-Head Sampling of One FC.

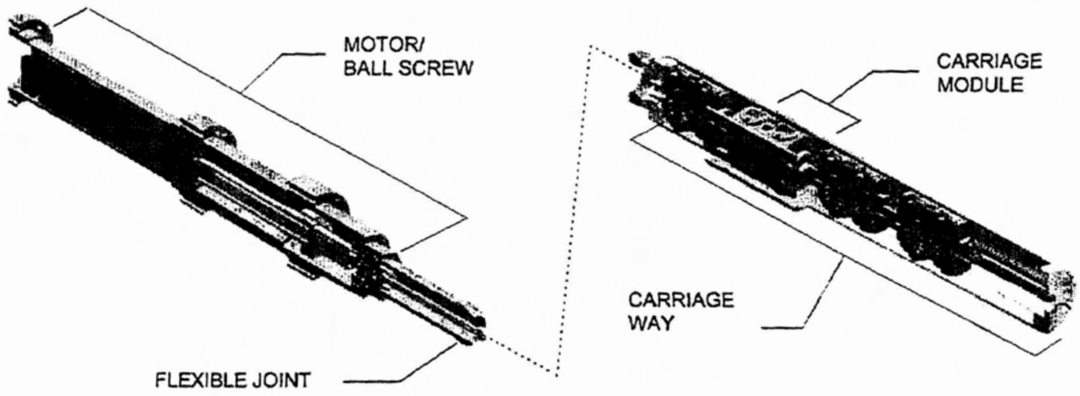

Figure 4: Multi-Head Sampling Tool