STEAM GENERATOR PRIMARY SIDE TUBE CLEANING AT POINT LEPREAU USING THE SIEMENS MECHANICAL CLEANING PROCESS

By

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Presented at 4th Technical Committee Meeting
on the "Exchange of Operational Safety Experience
of Pressurized Heavy Water Reactors",
Kyong-Ju, 21-26 April 1996

SG PRIMARY SIDE TUBE CLEANING AT POINT LEPREAU USING THE SIEMENS MECHANICAL CLEANING PROCESS

Overview:

- **Reasons and objectives of cleaning**
- **Process description**
- **Qualification program**
- **Process application**
- **Cleaning results**

REASONS FOR THE

SG PRIMARY SIDE TUBE CLEANING

After 4214 EFPD of plant operation, thermal performance degradation of SG's has been experienced as shown by a rise in the outlet temperature from 262° to 267.6°C since initial startup. The contributory factors affecting SG thermal performance are considered to be:

- **primary and secondary side tube fouling and**
- **tube bundle flow bypass across the divider plate.**

OBJECTIVES OF THE

SG PRIMARY SIDE TUBE CLEANING

As a consequence of this development, NB Power embarked on a major steam generators maintenance and inspection campaign during the 1995 planned annual outage consisting of:

- **Secondary side chemical cleaning and waterlancing**
- **Primary head divider plate replacement and**
- **Primary side tube bundle cleaning.**

The objective of the primary side tube cleaning was to counteract the contribution of primary side tube deposits to the reduction of the heat transfer efficiency of the steam generators.

SG PRIMARY SIDE TUBE CLEANING

PRE-REQUISITE ACTIVITIES

- **In conjunction with Hydro Quebec, NB Power embarked on a joint plan to request proposals for the primary side tube cleaning.**

- **Following a detailed evaluation of the commercially available cleaning processes, the Siemens Mechanical Tube Cleaning Process was selected as the one fulfilling the selection criteria based on:**

  - **Overall cost,**

  - **Effect on the critical path of the outage,**

  - **Ease of application of the process and**

  - **Ease of handling of the waste generated.**

SIEMENS MECHANICAL TUBE CLEANING

PROCESS

The Siemens Mechanical Tube Cleaning Process uses the VACUBLAST technique in combination with manipulators for SG tube inside surface cleaning:

- **In a closed circuit pressurized air conveys the blasting grit through tubes, thereby removing the surface deposits.**

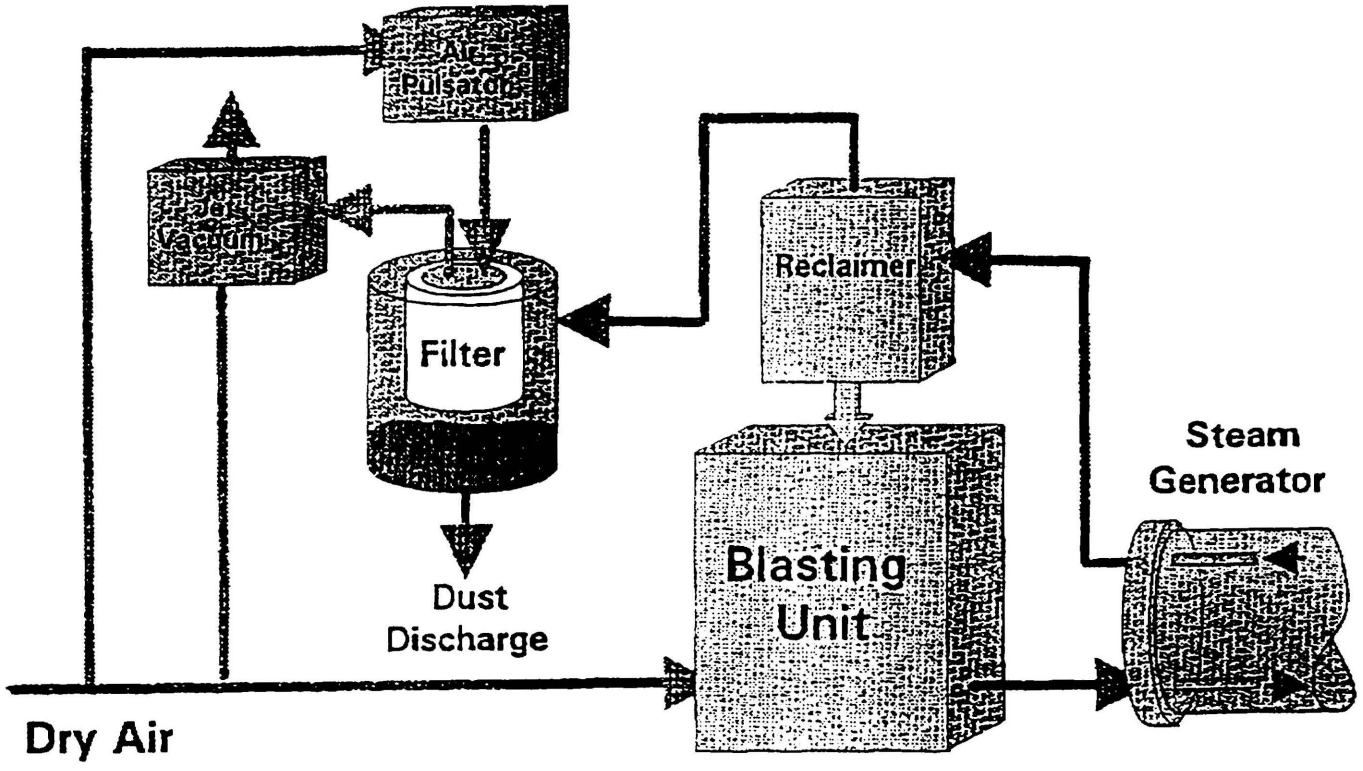
- **Thereafter an underpressure system collects and returns the grit to the blasting unit.**

- **The grit is separated from dust and debris for reuse. This provides less waste generation.**

The closed loop cleaning technique avoids environmental pollution.

SIEMENS MECHANICAL TUBE CLEANING

PROCESS SCHEMATIC



SIEMENS MECHANICAL TUBE CLEANING

BLASTING EQUIPMENT

The process blasting equipment consists of a:

- **Generator**

  Incorporates a pressure vessel, furnished with a feed valve, from which blasting grit is fed to the cleaning loop.

- **Reclaimer**

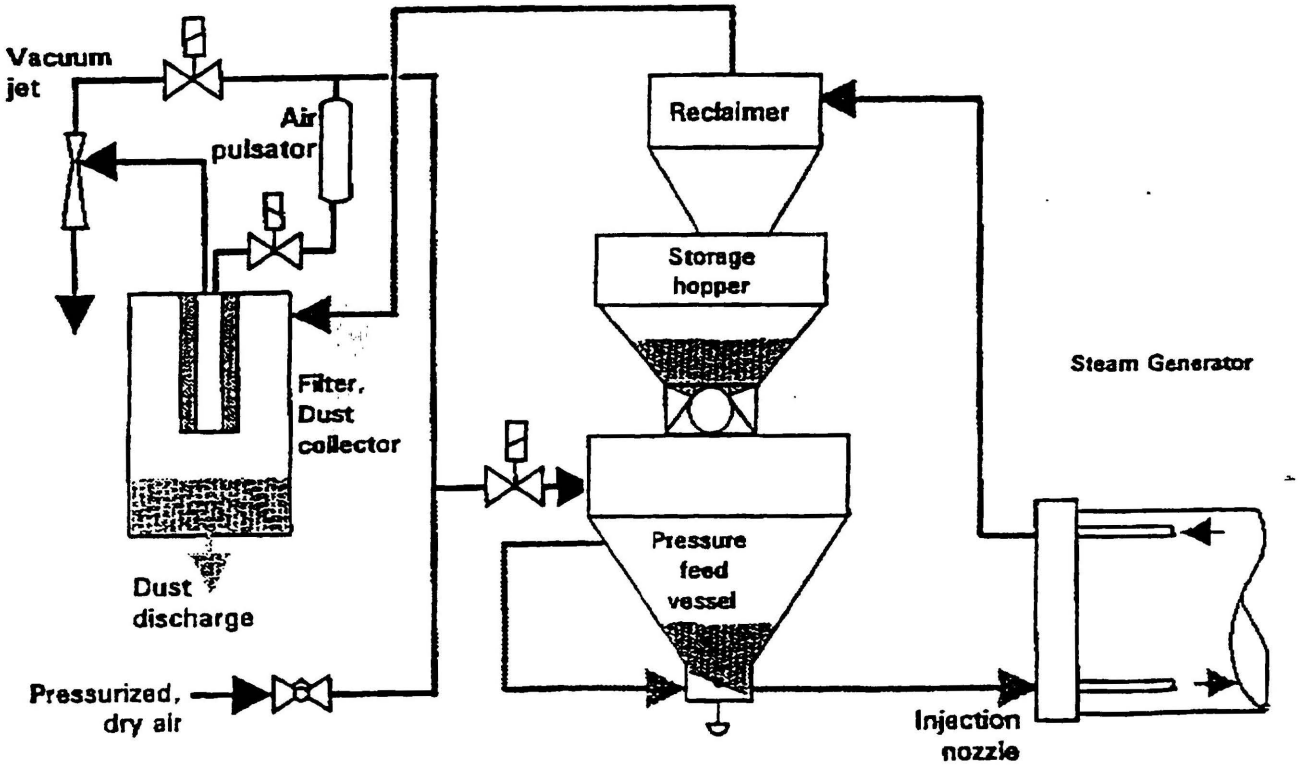
  Recovers the used grit, separates it from dust and debris by air washing and transports it to the storage hopper for reuse.

- **Dust collector**

  Consists of a filter cartridge and a waste container, where dust and debris are collected.

SIEMENS MECHANICAL TUBE LEANING

BLASTING EQUIPMENT



SIEMENS MECHANICAL TUBE CLEANING

QUALIFICATION PROGRAM

Objective:

The objective of the qualification program was to:

- **Tailor the Siemens mechanical surface cleaning process to the CANDU 600 Steam Generator Primary Side Tube Cleaning.**

- **Establish optimum cleaning parameters without exceeding the acceptance criteria.**

Scope:

The Qualification Program consisted of:

- **Material Compatibility Tests**
  Virgin CANDU SG Incoloy 800 tubes were used.

- **Cleaning Efficiency Tests**
  Bruce A SG Inconel 600 pulled tubes were used.

SIEMENS MECHANICAL TUBE CLEANING

QUALIFICATION PROGRAM

The whole process qualification program was designed to ensure the following NBP/HQ acceptance criteria was fulfilled:

- **No nominal wall loss is allowed.**
- **Surface damage (plastic deformation) up to a max. depth of 75 μm is acceptable.**
- **Surface damage, which has resulted in removal of material is not acceptable.**
- **Particles embedded in the surface which has any dimension > 75 μm are not acceptable.**
- **Surface roughness > 1.6 μm, (R.M.S) is not acceptable.**
- **No changes in residual stresses on OD surface of tubes shall be allowed.**

SIEMENS MECHANICAL TUBE CLEANING

MATERIAL COMPATIBILITY TESTS

All tests were performed using a mock-up of the CANDU 600 SG tube arrangement with original length, tube material and the smallest U-bend radius (121 mm).

Two different series of tests were performed:

- **Determination of the Worst Case Location:**

  Three different blasting materials (SS shot, glass beads, corundum) at highest blasting pressure and longest blasting time were used in these tests.

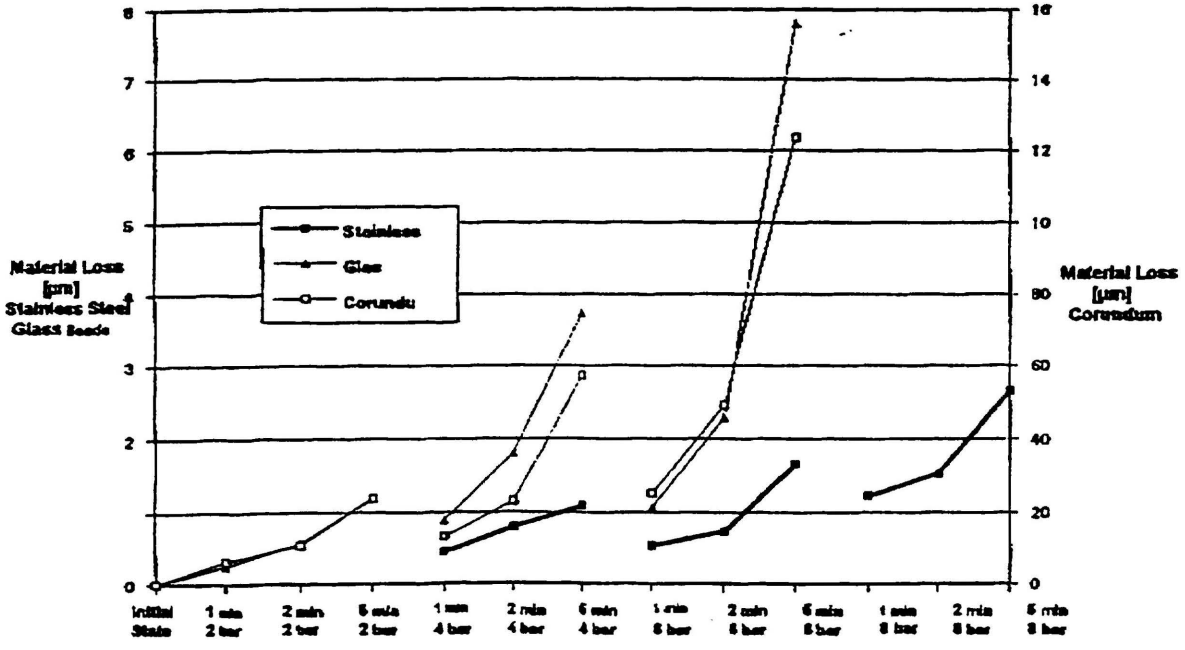
- **Material Compatibility at Worst Case Location:**

  At three different blasting pressures (2-8 bars) and blasting times (1-5 min) for three different blasting materials (SS, glass and corundum) effect on the tube material was established.

SIEMENS MECHANICAL TUBE CLEANING

MATERIAL COMPATIBILITY TEST RESULTS

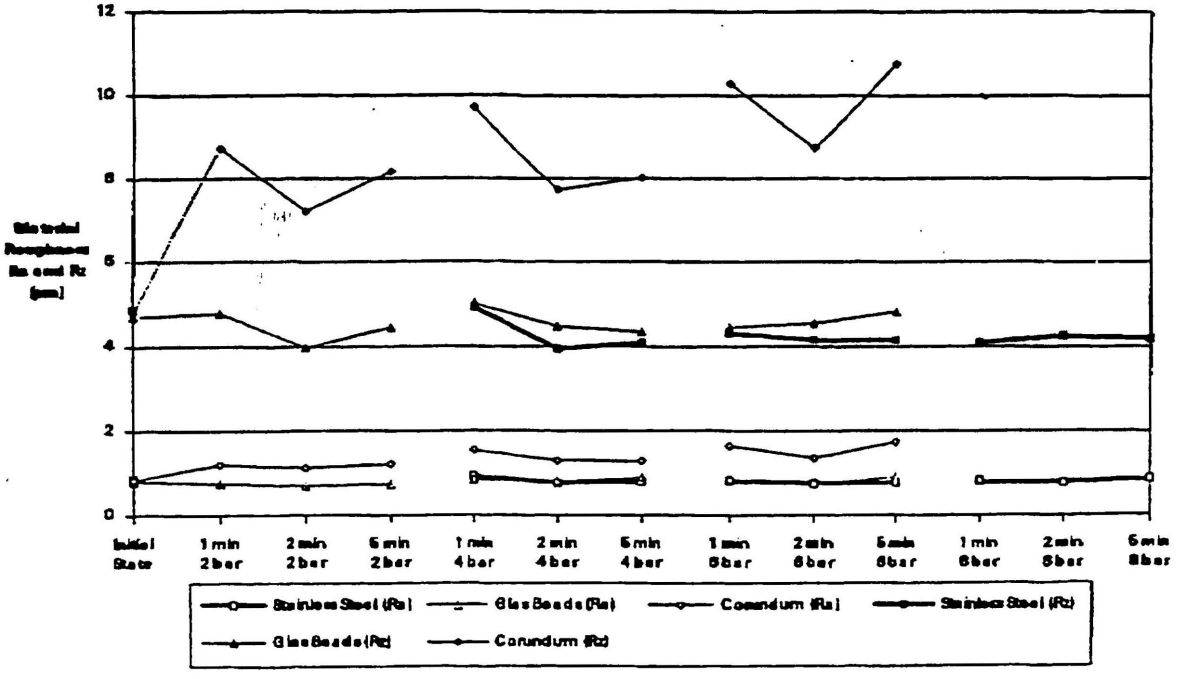
Material Wear: ***< 1 µm under application conditions (SS grit, 1 min. and 6 bar)***



SIEMENS MECHANICAL TUBE CLEANING

MATERIAL COMPATIBILITY TEST RESULTS

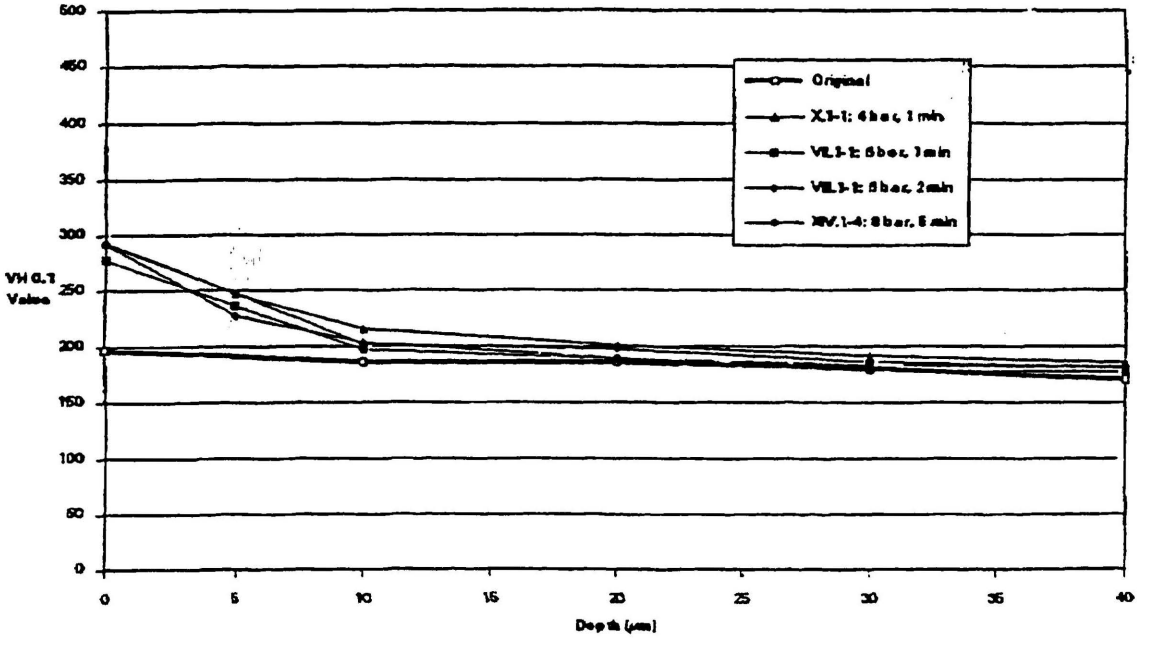
Surface Roughness: ***Almost no changes experienced with SS grit under all test conditions.***



SIEMENS MECHANICAL TUBE CLEANING

MATERIAL COMPATIBILITY TEST RESULTS

Surface Hardness: Increase at ID tube surface (5-15µm)
For all test conditions no changes at OD tube surface



SIEMENS MECHANICAL TUBE CLEANING

MATERIAL COMPATIBILITY TEST RESULTS

Surface Residual Stresses:

Residual stresses were measured on ID and OD surfaces of blasted and not blasted samples by X-ray diffraction with the following results:

- **On OD surface there was no change of surface stresses,**
- **On ID surface a compressive stress of -364 to -422 N/mm^2 was introduced by blasting.**
- **These results were consistent with the hardness measurement results confirming no change on the OD surface; Increase of hardness and compressive stresses on the ID surface.**

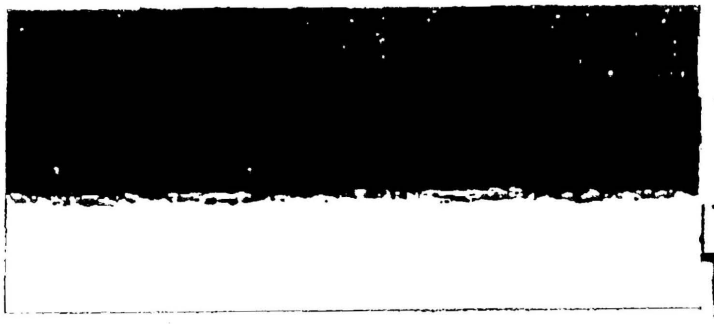
SIEMENS MECHANICAL TUBE CLEANING

CLEANING EFFICIENCY TEST RESULTS

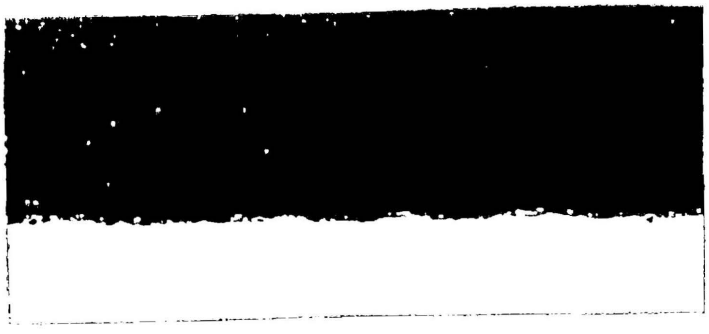
Scale removal:

As received: 60-80 µm

After 0.5 min cleaning: 8-10 µm



After 1 min cleaning: 1-4 µm

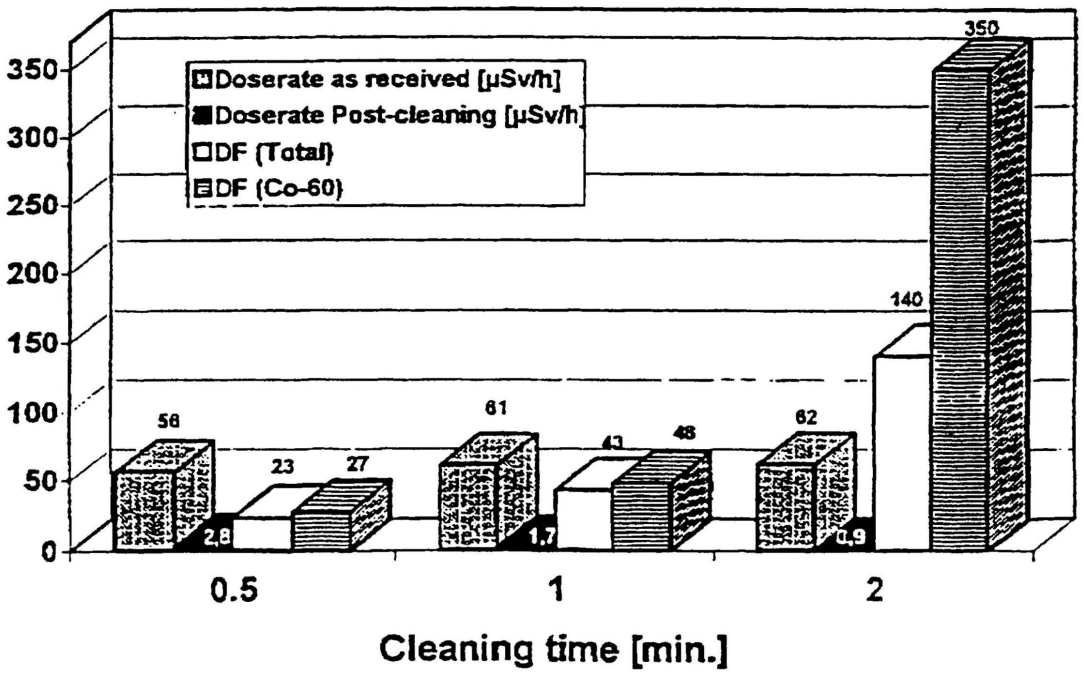


After 2 min cleaning: 0-2 µm

SIEMENS MECHANICAL TUBE CLEANING

CLEANING EFFICIENCY TEST RESULTS

Decontamination Factors:



SIEMENS MECHANICAL TUBE CLEANING

QUALIFICATION TEST RESULTS

- **High material compatibility of the process was confirmed. All acceptance criteria was fulfilled.**

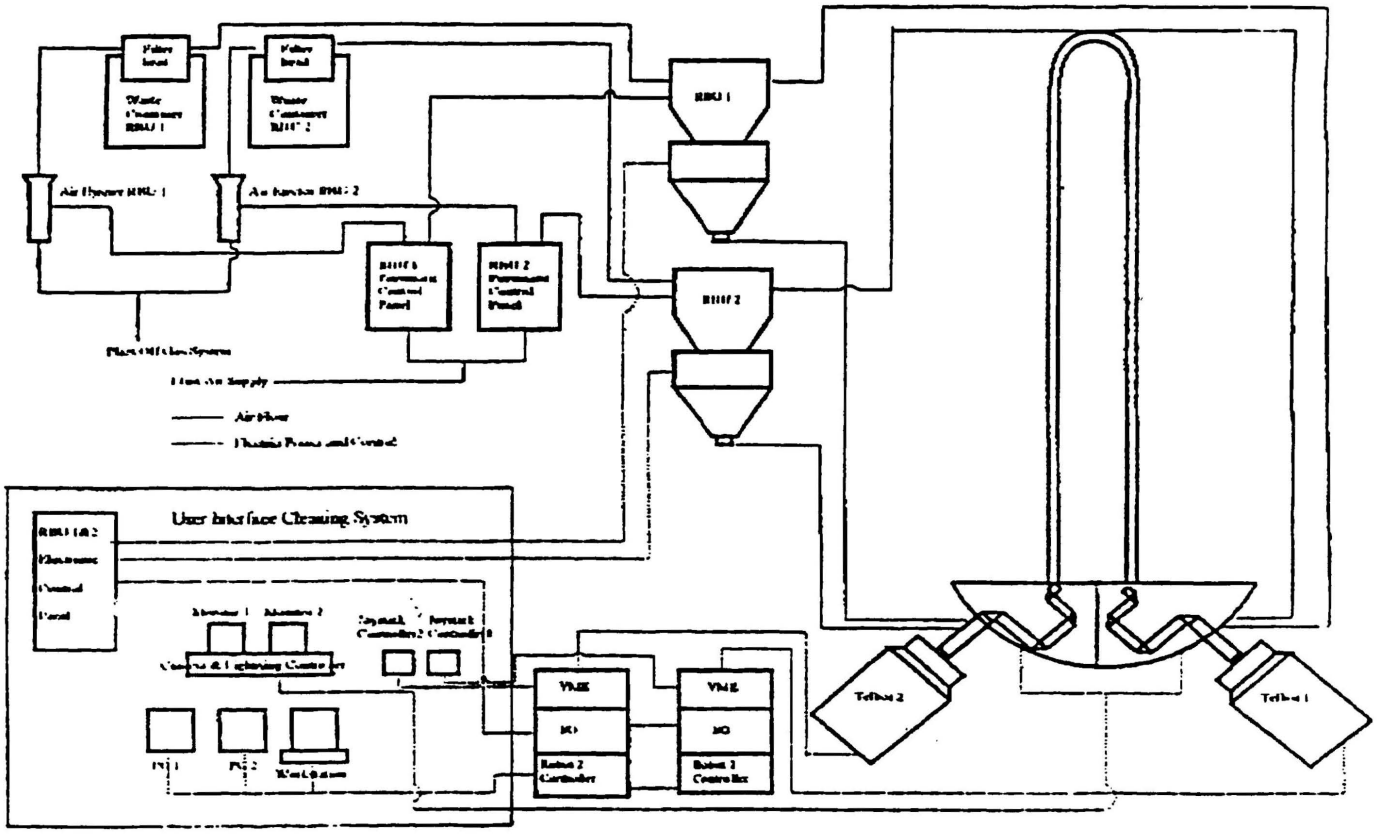
- **The cleaning efficiency tests confirmed that ID tube scale could almost be completely removed using SS grit within a blasting time range of < 1 min.**

- **Considering the results of the compatibility and cleaning efficiency tests following application conditions were specified:**

  - **Blasting grit:** stainless steel,
  - **Blasting time:** 1 min.
  - **Blasting pressure:** 6 bars

PROCESS APPLICATION

EQUIPMENT SET-UP



SIEMENS MECHANICAL TUBE

CLEANING PROCESS CONTROL

- The complete cleaning process system, blasting units and manipulators were remotely controlled.
- Blasting units and manipulators were interfaced:
  - to ensure that both units communicate to each other,
  - to ensure that no situation occurs which may lead to a system leakage.
- Several logic interlocks were incorporated to the system to ensure system tightness even in case of irregularities on the tubesheet face.
- The complete blasting status display was provided on a local control panel.

SIEMENS MECHANICAL TUBE CLEANING

DELIVERY SYSTEM

- As a delivery system for the blasting and suction heads two AECL Telbot robots were used at the hot and cold legs of the SG's.

- These fully computerized manipulators were inserted through the SG manways to create the closed cleaning loop by connecting the blast and suction hoses of the cleaning equipment with the inlet and outlet of each tube through specially designed nozzles and seals.

- Visual feedback and remote display of the manipulator movements to the operator was provided by cameras mounted on blasting and suction and in each bowl.

SIEMENS MECHANICAL TUBE CLEANING

PROCESS APPLICATION

Following successful completion of the qualification program and the integrated testing at AECL, the cleaning equipment was deployed and set-up at PLGS:

- **The 2 blasting units were located in a ventilated tent in the boiler room.**
- **The 4 shielded vessels containing waste containers were located in another ventilated tent in the boiler room.**
- **Provision was made to weigh the waste containers on an ongoing basis.**
- **The cold leg of each steam generator was also provided with a ventilated tent.**
- **On the basis of the ID deposit distribution information obtained from 2 tubes chemically cleaned during 1994, decision was made to start the cleaning process by blasting at the cold leg and receiving the blasted material at the hot leg end of the tubes being cleaned.**
- **All hoses were inserted into plastic layflat to avoid any leakage.**

SIEMENS MECHANICAL TUBE CLEANING

PROCESS APPLICATION (Cont'd.)

- The process exhaust, even though contamination free, was equipped with a charcoal filter and a HEPA filter and vented to the D_20 Vapour Recovery System.

- The compressors supplying dry air were located outside the R/B.

- Following successful completion of all pre-requisites, including drying of tubes, ID cleaning of tubes in SG #2 was started. The system was designed and set up to clean two tubes simultaneously.

- To demonstrate that the integrity of the tubes is not affected due to primary side cleaning by this technique, a sample of tubes from SG #2 were tested by UT before and after cleaning prior to applying the process on a large scale. As expected, no effect on the tube integrity was detected.

- Due to the outage schedule constraints and the available time to clean all four steam generators, it was decided to clean approximately 2100 tubes in each steam generator.

- Following clearing of various previously unknown interferences with the manipulators, smooth cleaning of the tubes continued for all steam generators.

SIEMENS MECHANICAL TUBE CLEANING

PROCESS APPLICATION (Cont'd.)

Following cleaning of SG#2 tubes, the cleaning equipment was relocated to clean SG#4 tubes in the same manner.

- **Due to access restriction to the east side Steam Generators # 1 & 3 (because of the SLAR activities), close coordination with SLAR was maintained while cleaning tubes in these steam generators.**

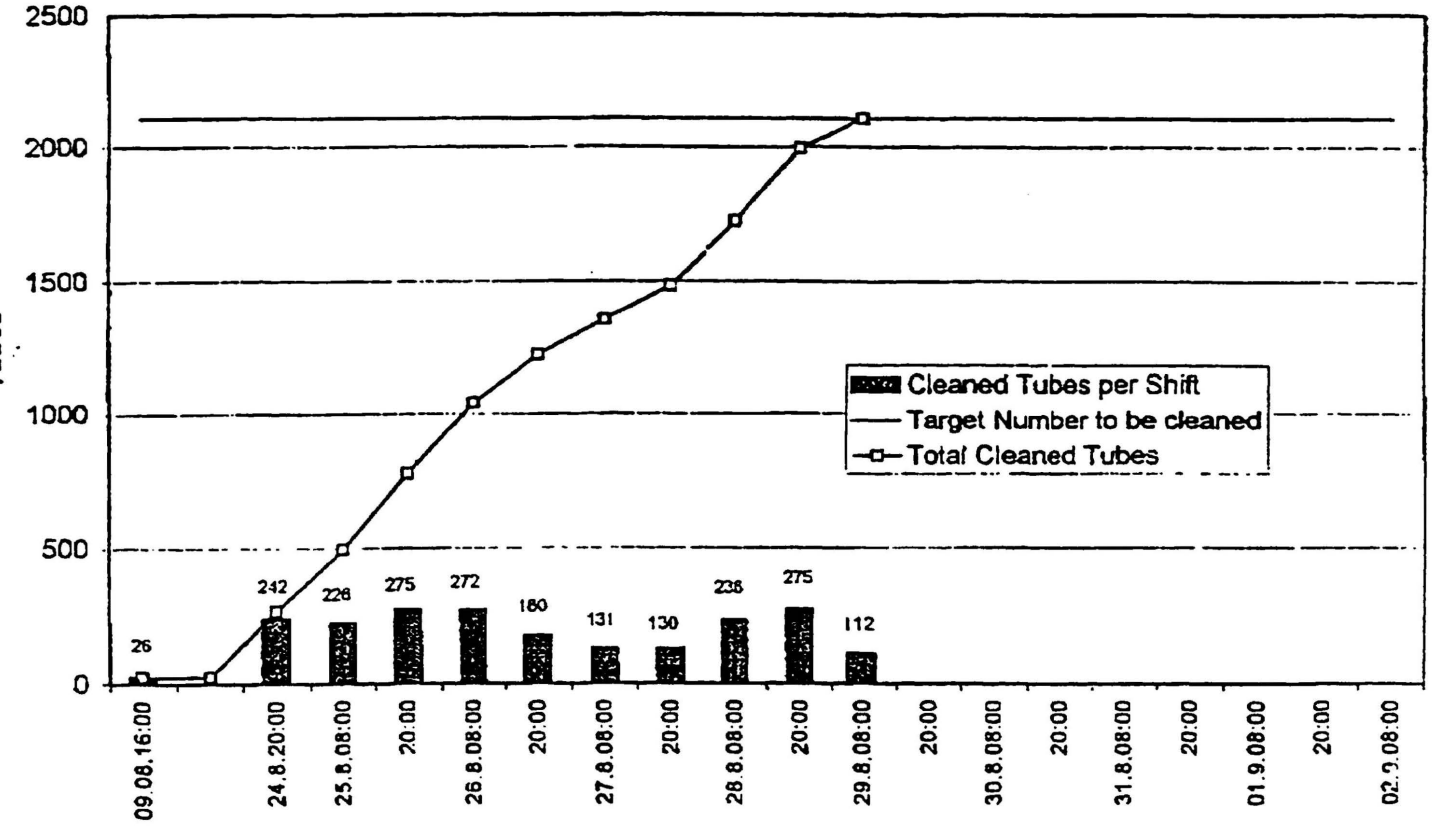
- **During planned SLAR tool change windows, the cleaning equipment was moved to clean SG #3 tubes. Guidelines to coordinate SLAR and SG #3 tube cleaning work were established.**

- **Following cleaning of tubes in SG #3, the equipment was relocated to SG #1.**

- **Following the same rules, tubes in SG #1 were then cleaned.**

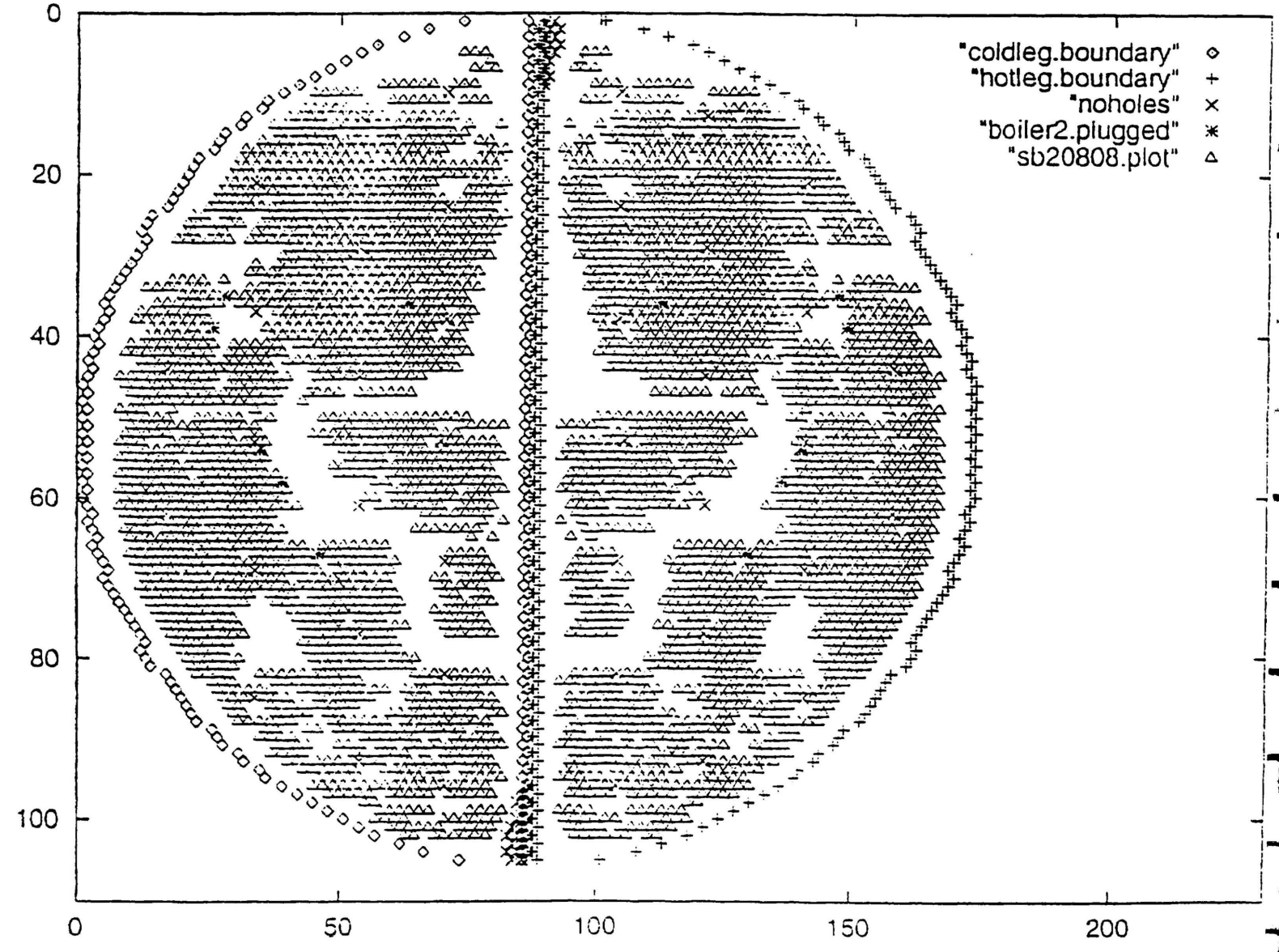
PROCESS APPLICATION

TUBE CLEANING RATE



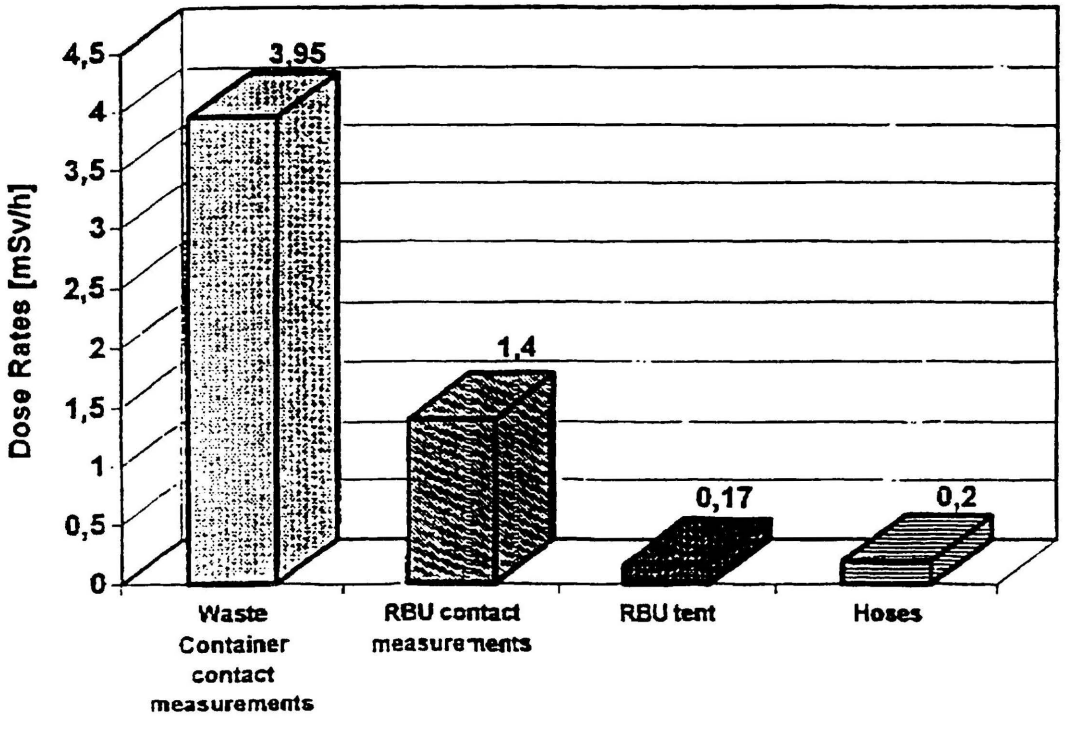
PROCESS APPLICATION

TUBE CLEANING PATTERN



PROCESS APPLICATION

DOSE RATES



SIEMENS MECHANICAL TUBE CLEANING

APPLICATION RESULTS

Removed ID Surface Deposits:

- **Total amount:** **789 kg**
- **Per SG tube:** **96 gr.**

Total Waste Production:

- **Weight:** **2700 kg**
- **Volume:** **3240 l**

Radiation Exposure: **288 mSv**

Time Duration to clean 4 SG's:

- **Cleaning:** **23 days in total**
- **Installation/Removal:** **15 days**

Material compatibility:

No damage to SG tubes confirmed by pre and post cleaning UT measurements of a sample of tubes.

SIEMENS MECHANICAL TUBE CLEANING

WASTE HANDLING

- **To minimize cleaning downtime, two waste containers located in shielded vessels were kept ready for use as the other two were being filled with magnetite being removed from tubes being cleaned.**

- **Number of tubes cleaned and the amount of waste collected were used as a guide to switch over to the standby containers.**

- **The filled containers were then removed from the shielded vessels for transfer to the Solid Radioactive Waste Management Facility (SRWMF). As the dimensions of the waste containers were intentionally kept to be similar to the purification filters, the transfer was handled in the same way as the purification filters.**

- **A total of 14 waste containers were used up.**

SIEMENS MECHANICAL TUBE CLEANING

PROCESS RELIABILITY

- **There was no equipment related failure of either the blasting unit or the manipulators during cleaning of all four SG's. Equipment reliability was excellent.**

- **There was no spread of contamination anywhere as a result of this job in the R/B.**

- **Because of the unexpected interferences inside the SG heads and boiler cabinets with the manipulators, and because of SLAR related interruptions preventing continuous cleaning, the overall cleaning duration was longer than expected.**

- **As demonstrated by ultrasonic testing for thickness checks on a sample of tubes before and after primary side tube cleaning, it was confirmed that the tube integrity was not affected.**

SIEMENS MECHANICAL TUBE CLEANING PROCESS

Conclusions:

- As confirmed by the qualification program testing, the process has demonstrated:
  - High material compatibility and
  - High cleaning efficiency.
- The process has satisfactorily demonstrated during qualification testing that it meets all acceptance criteria.
- The process, which is field proven for cleaning of heat exchangers tubes, could be successfully adapted to the requirements of SG tube cleaning.
- For the SG primary side tube cleaning, the Siemens mechanical tube cleaning process was successfully applied at Point Lepreau as a first time application in any nuclear power plant in the world.