行政院及所屬各機關出國報告

（出國類別：實習）

研習聲波測漏技術在核能電廠蒸汽產生器之應用
並參加第十二屆太平洋盆地核能會議

服務機關：台灣電力公司

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出國地區：美國，韓國

出國日期：89.10.28-89.11.17

報告日期：90.01.15

【一】國外公務之內容與過程

一、10/29-11/5第十二屆太平洋盆地核能會議

太平洋盆地核能會議系列第一屆開始於1976年檀香山,1992年臺北舉辦過第八屆，每屆更增加廣度及深度,本屆(第十二屆)在漢城舉行.贊助機構包括美國核能協會、日本核能協會、韓國核能協會、北京核能協會，臺北核能協會、印尼核能協會、墨西哥核能協會、澳洲核能協會、加拿大核能協會及拉丁美洲核能協會。

國內參與會議代表計有原能會三位、核研所五位及本公司三位,核研所所長為團長,本公司代表皆發表論文。第十三屆預定於2002年九月於深圳召開。

本居研討會在韓國漢城市新完成之會議及展示中心召開,會議主題為核能在廿一世紀之持續發展。

大會討論議題一：

國際合作及核能非衍生之KEDO計畫

大會討論議題二：

核能技術之遠程發展計畫

研討會主題分為十二項詳附表一，本所論文題目："The Windows-bases PC Simulator for Taipower's Nuclear Emergency Experises"發表於T-3C : Nuclear Safety and Regulation

二、11/5-14: 聲波測漏技術在核能電廠蒸汽產生器之應用
全程研究內容分兩階段，第一階段為理論研究及實驗室的規劃，重點工作是

A. 理論上研究聲波在核能電廠蒸汽產生器U型管測漏技術之可行性,
B. 發展數學模式及分析軟體
C. 進行初期系統驗證及實驗室的規畫

第二階段為實驗室及現場雜訊的研究及電廠的應用。

目前進度:十月底已完成期末報告初稿:

1. 洩漏定型訊號
2. 定位
3. 雜訊干擾
4. 早期預警(定性)
5. 趨勢預測(定量)
6. 期末報告

<u>Leak event detection (low frequency signal)</u>

低頻
定型訊號
快, 線上及時定位
短, 低頻
三維異點定位

Operational effect leak detection (High frequency signal)

高頻

短波干擾定位無法用短波達到預測

特定高頻

高頻強度遞減定位

免線上

免及時

多重偵測器

空氣槽洩漏試驗-

試驗 1: Tank w/Plates(圖 1)

試驗 2: Plain Tank w/Single Sensors(圖 2)

試驗 3: Plain Tank w/ Dual Sensors(圖 3)

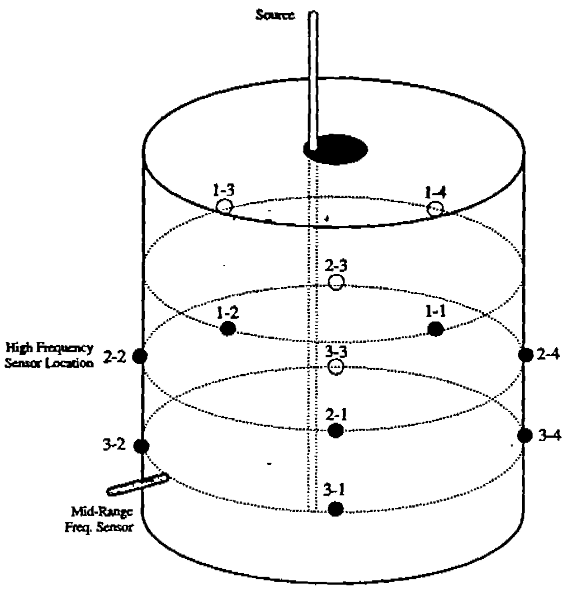
試驗 4:早期預警(定性)

試驗 5:趨勢預測(定量)

試驗 6:熱水流及多重物體環境下洩漏試驗設計(圖 4)

图1

LEAK DETECTION TEST 1 (TANK W/ PLATES):



A 36 inches diameter and 36 inches height stainless steel tank with five perforated plates at 10", 14" 18", 22", and 26" elevations is used for this series of tests. Data acquisition system was set to 50,000 scans/sec for mid-range frequency sensor and 200,000 scan/sec for high frequency sensor. The tank was filled with water up to 24 inches above the mid-range frequency sensor. The following tests were conducted using the mid-range frequency sensor by moving the leak source from the sensor level stage-wise up to a level 34 inches above the sensor:

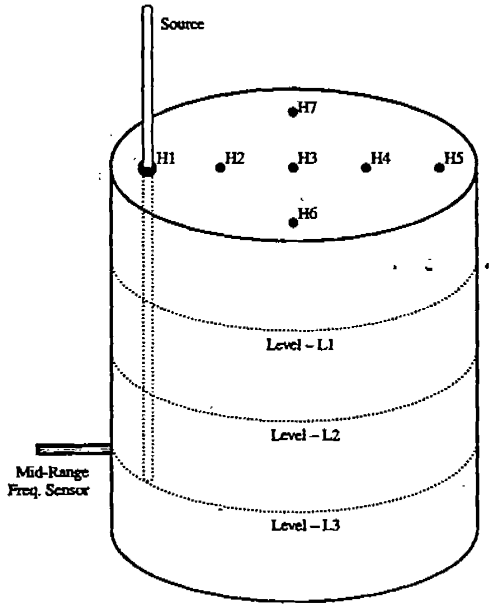
1. Source at 0" above sensor level (Baseline: with source turned off)
2. Source at 0" above sensor level
3. Source at 5" above sensor level
4. Source at 10" above sensor level
5. Source at 20" above sensor level
6. Source at 24" above sensor level (water level)
7. Source at 31" above sensor level (in the air)

The following tests are conducted using the high frequency sensor by anchoring the source at 31" above the mid-range frequency sensor level:

8. The Hi-Freq sensor attached at location 1-1 (Baseline with source turned off)
9. The Hi-Freq sensor attached at location 1-1
10. The Hi-Freq sensor attached at location 2-3
11. The Hi-Freq sensor attached at location 3-3
12. The Hi-Freq sensor attached at location 3-2
13. The Hi-Freq sensor attached at location 3-1
14. The Hi-Freq sensor attached at location 1-1 (Repeat 7)

图 2

LEAK-DETECTION TEST 2 (PLAIN TANK):

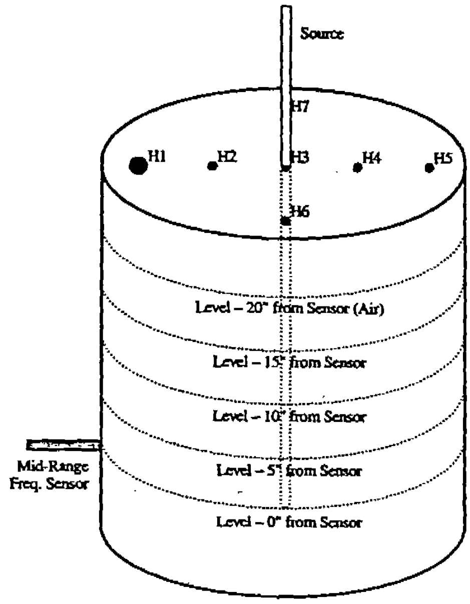


In this series of experiments, in order to eliminate any potential signal distortion, tests were conducted in a 23 inches diameter with 34 inches height tank without any plate. The Mid-range Frequency Sensor was used and the data acquisition system was set at scan rate of 50,000 scans/sec. All experiments were carried out with the leak source submerge in water. Since only one sensor was available, tests were conducted by moving the source to the following location and gathering data in a sequential order:

1. Source at Level L3 and in Hole H1
2. Source at Level L3 and in Hole H2
3. Source at Level L3 and in Hole H3
4. Source at Level L3 and in Hole H4
5. Source at Level L3 and in Hole H5
6. Source at Level L3 and in Hole H6
7. Source at Level L3 and in Hole H7
8. Source at Level L3 and in Hole H1 (Repeat
9. Source at Level L2 and in Hole H3

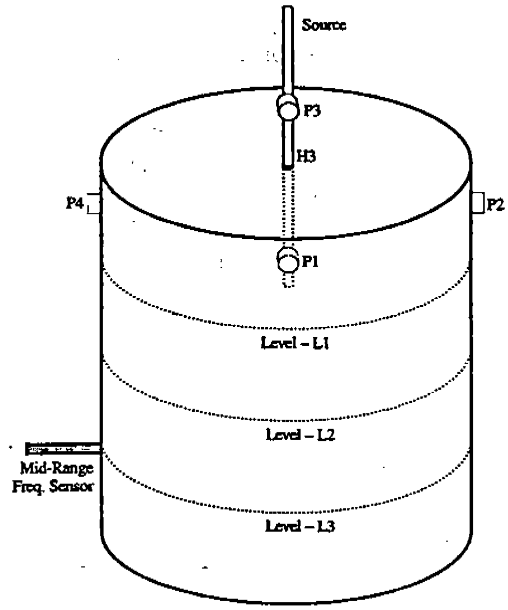
图 3

LEAK DETECTION TEST 3 (PLAIN TANK):



In this series of tests, the same tank as in test series 2 was used. The Mid-range Frequency Sensor was used and the data acquisition system was set at scan rate of 50,000 scans/sec. The water level of the tank was above the sensor. The experiment was started by placing the leak source in Hole H3 and at the same level as the sensors. The source was then moved up 5" at a time until it is completely out of the water (20" above the sensor level).

1. Source at 0" above the sensor and in Hole H3
2. Source at 5" above the sensor and in Hole H3
3. Source at 10" above the sensor and in Hole H3
4. Source at 15" above the sensor and in Hole H3
5. Source at 20" above the sensor and in Hole H3



The High Frequency Sensor with a magnetic base was used for this series of tests. The data acquisition system scan rate was set at 500,000 scans/sec. The source was anchored in Hole H3 and above water level. The experiments were conducted by placing the sensor at different levels and positions as illustrated in the above figure.

6. Sensor place at Level L3 and Position P1
7. Sensor place at Level L3 and Position P2
8. Sensor place at Level L3 and Position P3
9. Sensor place at Level L3 and Position P4
10. Sensor place at Level L3 and Position P1 (Repeat 6).
11. Sensor place at Level L1 and Position P1

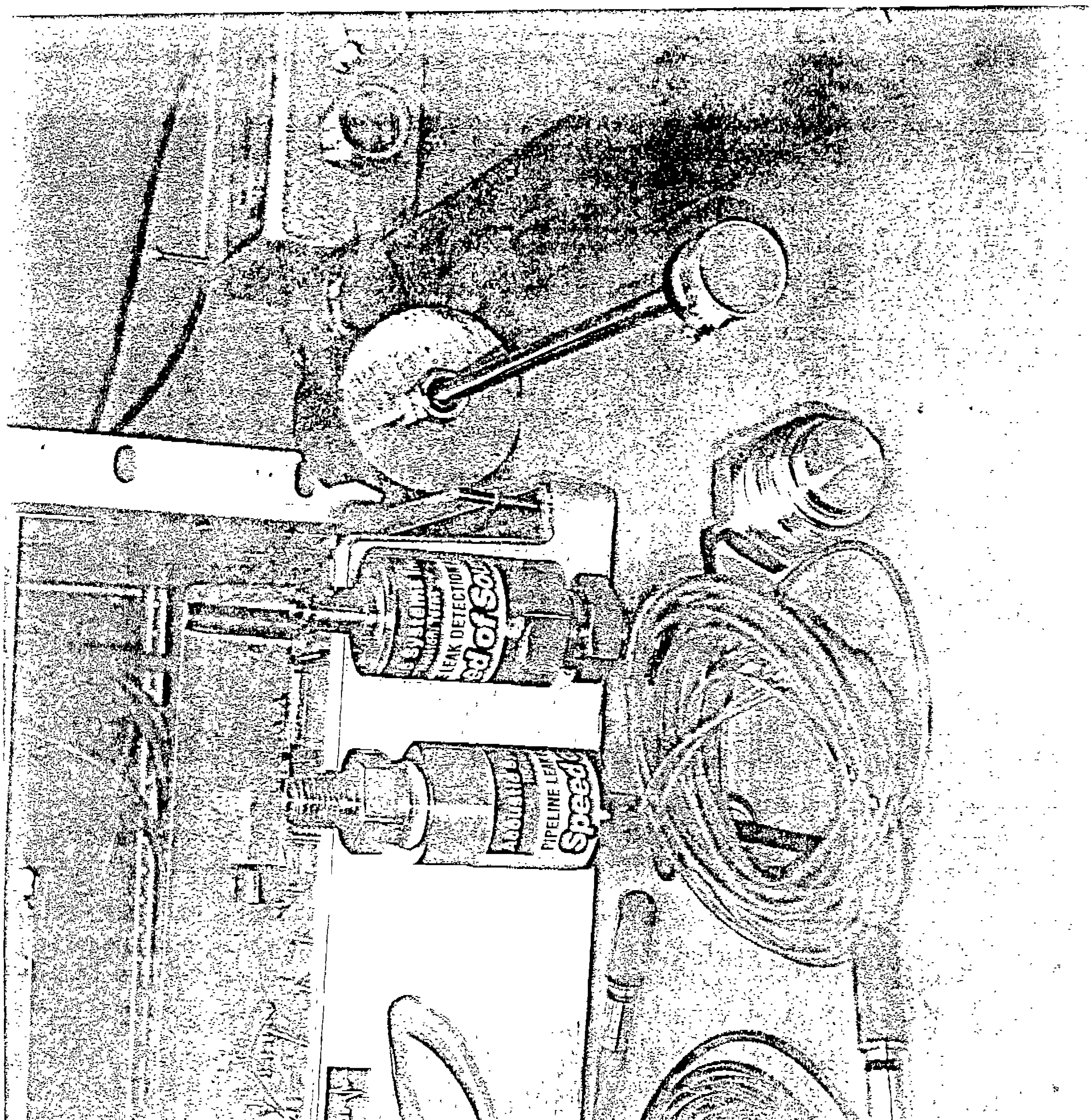
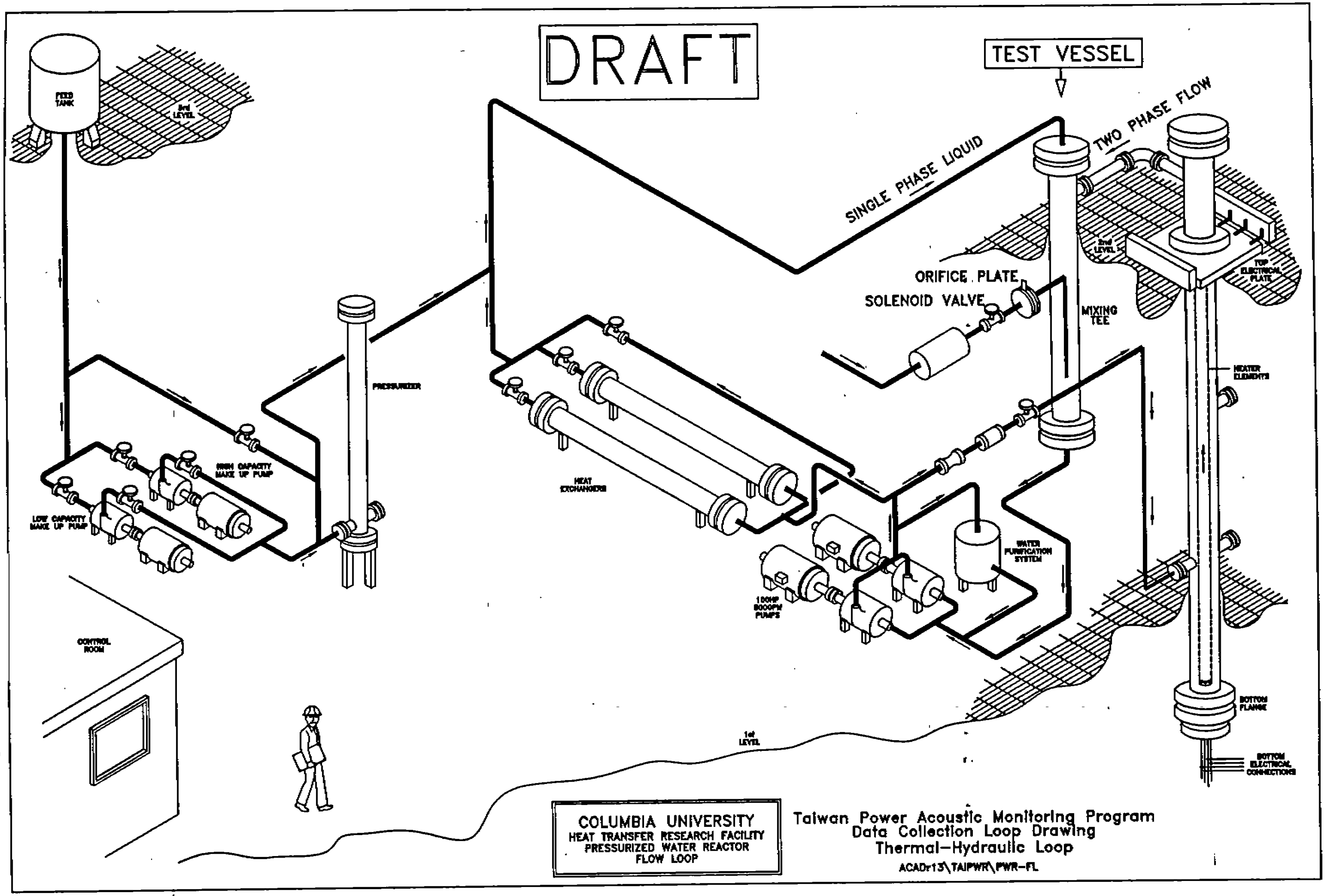

LEAK DETECTION
PIPELINE LEAK

图4


DRAFT
TEST VESSEL
TWO PHASE FLOW
SINGLE PHASE LIQUID
ORIFICE PLATE
SOLENOID VALVE
MIXING TEE
FEED TANK
3rd LEVEL
2nd LEVEL
1st LEVEL
TOP ELECTRICAL PLATE
HEATER ELEMENTS
BOTTOM FLANGE
BOTTOM ELECTRICAL CONNECTIONS
PRESSURIZER
HIGH CAPACITY MAKE UP PUMP
LOW CAPACITY MAKE UP PUMP
HEAT EXCHANGERS
WATER PURIFICATION SYSTEM
CONTROL ROOM
COLUMBIA UNIVERSITY
HEAT TRANSFER RESEARCH FACILITY
PRESSURIZED WATER REACTOR
FLOW LOOP
Taiwan Power Acoustic Monitoring Program
Data Collection Loop Drawing
Thermal-Hydraulic Loop
ACADr13\TAIPWR\PWR-FL

Leak event detection (low frequency signal)

低頻 -The low frequency signal be used to detect the leak event (the occurrence of leak).

定型訊號-The advantage of the signature signal is unique and the frequency is low (or wavelength is long) which is much less prone to interference (or high penetration capability).

快線上及時定位-can be used for very quick, true on-line, real-time leak detection as well as location determination by differential time of flight to different sensor locations.

短,低頻-the basic problem is to detect a signal of relatively short duration and low frequency (around 1 Hz) in a noisy environment. This requires an on-line real time continuous monitoring and processing of the detector signal to ascertain the existence of a leak.

定型訊號由實驗取得-The general shape of the signal can be obtained from field collected data, literature available data, and laboratory measurement of leaks in a relatively low noise environment.

三維異點定位-the differential time of arrival among different sensors (situated at different axial and azimuthal locations) will allow us to derive the signal source (or leak location) based on time of flight calculation. For a three dimensional component such as steam generator, a topography type re-mapping technique is proposed to calculate the leak location.

Operational effect leak detection (High frequency signal)

高頻-high frequency signals (from a few kilo-Hz to hundreds of kilo-Hz) are usually associated with the existence of leaks.

短波干擾定位無法-the wavelength is relatively short and maybe within the order of magnitude of the characteristic length of many structures, components, and particles in the vessel, the potential of interference caused by various deflection, reflection,.. from the tube bundle, vessel wall, steam bubbles, as well as other structures and components inside the system will make it impossible to determine the time of arrival for this type of signals.

特定高頻-with proper data processing techniques, the special high frequency acoustic signals generated by the release of high pressure fluid to the low pressure system will allow us to identify the leak from other type of noises.
高頻強度遞減定位-due to the high attenuation rate associated with the high frequency signal, it is possible to determine the leak location (or signal source) by differential degree of attenuation (or signal strength) among different sensor locations.

免線上-this type of high frequency signal is associated with the existence of the leak (different from the background noise without leak), the signals exist as long as leak is present. Therefore, there is no need for an extremely high speed data processing.
免及時-The data collected over a certain representative time period (window) will be processed on a continuous basis (a moving window). There is no need for continuously recording all the data (only the current window plus several previous windows maybe needed) because there should be no change on the leak associated signature signals unless the type (e.g. size) of leak changes or disappears.
多重偵測器-In order to confirm the existence of the event as well as to estimate its location in the tube bundle, multiple detectors should be used, at least three coplanar detectors in each section bounded by tube support sheets. These multiple signals serve to confirm the existence of the leak.

Early warning detection:

早期預警- Efforts will be made to search and collect available data for signature signal or similar acoustic signal resulting from flow induced vibration (flow-structure interaction) taking place in a system with similar thermal-hydraulic conditions.

Literature Survey, Data Search & Collection:

長管數據-The preliminary investigation results showed that there are limited amount of related data available in the area of acoustic leak detection for Steam Generator. A few data base sets were obtained from leak detection tests performed in a long pipe.

Hydraulic Tests:

振波傳遞試驗設備-The current shock wave propagation test facility at CU-HTRF will be modified slightly to conduct a simple leak test to obtain some initial information on the leak signature data in a confined environment with different obstructions as well as the pressure effect on the signal pattern. there will be no heating applied to this test.

Leak tests in a thermal-hydraulic environment:

熱水流環境之洩漏試驗-A second set of tests are being designed in order to obtain acoustic data under similar thermal hydraulic conditions as in the steam generator or other heat exchangers.

Early leak warning detection in a thermal-hydraulic environment:

熱水流環境之早期洩漏預警偵測-a test will be design to simulate flow induced tube-plate interaction under thermal-hydraulic conditions. This test will be also performed in the mixing tee in the CHF test facility with conjunction with other CHF test program.

Sensor, instrumentation, data acquisition and processing:

HTRF 數據擷取系統-Special low frequency acoustic sensors and very fast response piezoelectric pressure sensors will be used to detect the event and operating effect leak signals respectively. Both types of data will be collected through the HTRF data acquisition systems (Opto-22 and HP) and recorded for data analysis and processing later.

for the event related low frequency signals,

- -to filter out background noises,
- -to recognize the signature signals,
- -to locate the source (leak location),
- -to process the data efficiently,
- -to perform all these functions on-line on a real time basis.

【二】國外公務之心得與感想

1.「第十二屆太平洋盆地核能會議」：

(1) 取得太平洋盆地各國對核能發展之最新趨勢及瞭解核能廿一世紀之展望，對往後規劃本公司核能研發工作助益甚大。

(2) 廿一世紀核燃料的後端處置將為研發重點，終端處置掩埋研究將更積極處置，此趨勢可供本公司規劃“核燃料的後端處置政策”參考。

2.「聲波測漏技術在核能電廠蒸汽產生器之應用」：

(1).聲波測漏技術已進行研發在熱水流及多重物體環境下可行性研究，測漏技術能否突破雜訊將是成功關鍵。

【三】出國期間所遭遇之困難與特殊事項

無

【四】對本公司具体建議

1.「第十二屆太平洋盆地核能會議」:

第十三屆太平洋盆地核能會議在大陸，會議主題為核燃料的後端處置方法，屆時我國之核燃料後端處置政策將愈明朗，相關研究人員愈將增加，建議應派員參與取得最新趨勢資訊及吸取其他研究者之經驗，對往後核燃料的後端處置研究較有效率。

2.「聲波測漏技術在核能電廠蒸汽產生器之應用」:

(1).本研究計畫第一階段重點工作在於可行性研究、撰寫分析程式及實驗室規畫，目前已完成，期末報告時將到核三廠與有關人員詳細規劃測漏工作方向及未來應用範圍。核三廠急需線上測漏技術，特別是線上洩漏點及洩漏量之確定攸關機組停機與否，因此本案將朝此方向進行。

(2).第一階段工作大致可行，建議即進行第二階段工作。

(3).配合本研究計畫第二階段工作及哥大其他實驗之時程，將先購置一套油管測漏儀器，進行U型管測漏可行性研究，此油管測漏儀器未來尚可裝置於本公司火力電廠油管測漏系統。

附表一

本所論文題目："The Windows-bases PC Simulator for Taipower's Nuclear Emergency Experises"發表於 T-3C : Nuclear Safety and Regulation

PBNC2000
12th Pacific Basin
Nuclear Conference

Monday, October 30

Opening session
Plenary Session 1
: KEDO Project for International Cooperation and Nonproliferation

Tuesday, October 31

Plenary Session (P-2)
: Longterm Prospects of Nuclear Technologies

Parallel Session
- T-1 New Millennium with Nuclear Energy Public Communications for Confidence Building
- T-2A Operation and Maintenance of Nuclear Power Plants
- T-3A Nuclear Safety and Regulation
- T-4A Nuclear Fuel Management
- T-5A Spent Fuel and Radioactive Waste Management
- T-6A Design, Engineering and Construction of Nuclear Power Plants

Wednesday, November 1

Parallel Session (morning)
- T-2B Operation and Maintenance of Nuclear Power Plants
- T-3B Nuclear Safety and Regulation
- T-4B Nuclear Fuel Management
- T-5B Spent Fuel and Radioactive Waste Management
- T-6B Design, Engineering and Construction of Nuclear Power Plants
- T-7A Promotion of Nuclear Energy Utilization
- T-8A Economic Competitiveness of Nuclear Energy

Parallel Session (afternoon)
- T-2C Operation and Maintenance of Nuclear Power Plants
- T-3C Nuclear Safety and Regulation
- T-5C Spent Fuel and Radioactive Waste Management
- T-6C Design, Engineering and Construction of Nuclear Power Plants
- T-7B Promotion of Nuclear Energy Utilization
- T-8B Economic Competitiveness of Nuclear Energy

Thursday, November 2

Parallel Session (morning)
- T-2D Operation and Maintenance of Nuclear Power Plants
- T-5D Spent Fuel and Radioactive Waste Management
- T-9A Radiation Protection
- T-10A Aging Management and Life Extension of Nuclear Power Plants
- T-11A Medical Applications of Radioisotopes and Radiation
- T-12A Advanced and Future Nuclear Reactors

Parallel Session (afternoon)
- T-5E Spent Fuel and Radioactive Waste Management
- T-10B Aging Management and Life Extension of Nuclear Power Plants
- T-11B Medical Applications of Radioisotopes and Radiation
- T-12B Advanced and Future Nuclear Reactors

Closing Session
· Keynote Address
Mohamed ElBaradei, Director General, International Atomic Energy Agency

★★ NOTICE ★★
YOU MUST INSTALL "korfont" ON THIS CD-ROM
BEFORE LOOKING INTO THE CONTENTS

THE WINDOWS-BASED PC SIMULATOR FOR TAIWAN POWER COMPANY'S NUCLEAR EMERGENCY EXERCISES

Lang-Chen Wang
Taiwan Power Company

Li-Chi C. Po, John M. Link
And Francis Kenny
Micro-Simulation Technology

November 1, 2000

PBNC 2000, Seoul, Korea

TPC to prepare accident scenarios for emergency exercise

- Transient analysis computer codes (RETRAN, RELAP, MAAP etc)
  - A lot of work to prepare input deck
  - Output difficult to present
  - Not interactive (No manual control)
  - Limited severe accident capability
  - Limited source terms (radiological release) for general emergency evacuation

- Training Simulators
  - No severe accident model and source terms
  - Difficult to get simulator time
  - Must be operated by licensed operators

PC-based Simulator for E-Exercise

- Microsoft Windows 95 or NT Operating System, 32-bit processor, Graphic User Interface (GUI)
- Existing PCTRAN (Personal Computer Transient Analyzer) Thermal-Hydraulics and Reactor Physics Code developed by MST of USA
- TPC has experience in early DOS versions for Plant No. 1 (Chingshan) and No. 2 (Kuosheng)
- Reduced Node for Reactor Coolant and Containment System
- Have completed Lungmen (GE ABWR 2x1300 MW in Construction) and Maanshan (Westinghouse 3-loop PWR 2x900 MW) in Windows models
- Extended to include Radiation Monitoring System (RPS) and Release Pathway models
- Designed specifically for emergency exercise
- Also used for safety analysis, training and PRA

Software Structure

- Written in Microsoft Visual Basic 6.0
- Input/output in Microsoft Access Database
- NSSS and Dose mimics with point-and-click control
- Pop-up and Drag-down menu, on-line and post run plotting of transient curves
- Back-track, Restart and Snap a new Initial Condition capabilities
- Output can be achieved in Access for re-plotting
- Compatible to MS Office such as Excel and PowerPoint for documentation and presentation
- Radiological Release in iodine and noble gas (Source Term) in Access format directly transmitted to Dose Dispersion Software for offsite dose projection

Maanshan Plant Model

- Westinghouse 3-loop PWR (2 x 900 MW)
- Single loop with pressurizer at left, two loops lumped at right
- Normal operation controls for the reactor power demand, pressurizer pressure and level, SG pressure and feedwater flow, etc.
- Reactor Protection System, ECCS, Containment Spray and Coolers for safety

Mathematical Models

- Point Kinetics Core with Rod and Boron Reactivity input, Doppler, Moderator Temperature and Void feedback
- Non-equilibrium pressurizer with heater and spray
- Homogeneous Equilibrium Model (HEM) for two-phase RCS and SG secondary
- Reduced-node conservation of mass, momentum and energy equations
- Zaloudek critical flow for sub-cooled and Moody for saturated fluid discharge from breaks
- HEM plus non-condensibles for containment
- Baker-Just for Hydrogen generation after core exposure
- Radiological release uses US Regulatory Guide 1.3 and 1.4 (NUREG 1465 Revised Source Terms are in development)

Possible Release Pathways

- Radio-nuclide Transport From the Fuel Rods Into the Gap
- Radio-nuclide Transport From the Fuel cladding into the Coolant
- Loss of Coolant Accident Transport from the Coolant to the Containment
- Containment design basis leakage and failed-to-close isolation valves
- Routine Effluent Releases from Condenser
- Letdown line and ECCS Recirculation from the RB sump into the Auxiliary Building
- Auxiliary Building vent
- Steam line Safety Valves and PORV release to the Atmosphere

Emergency Exercise

- For the first time, PCTRAN-developed scenario was used at Maanshan on September 5, 2000
- A full-scale (Atomic Energy Council audited) annual exercise
- Multiple SG tube rupture caused core failure with a stuck open SG relief valve to release radioactivity to the atmoshere
- Maximum Site Boundary Dose in the order of 0.3 mSv/hr whole body – Dose Rate to activate a General Emergency declaration and area evacuation

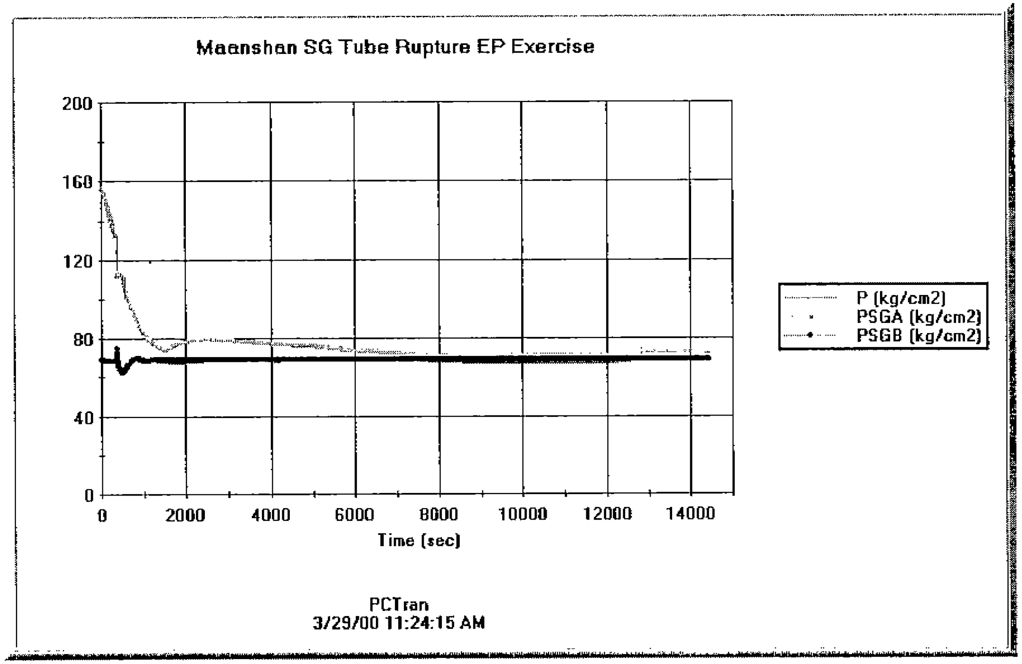


Figure 3 Primary and SG Secondary Pressure for a Tube Rupture Exercise

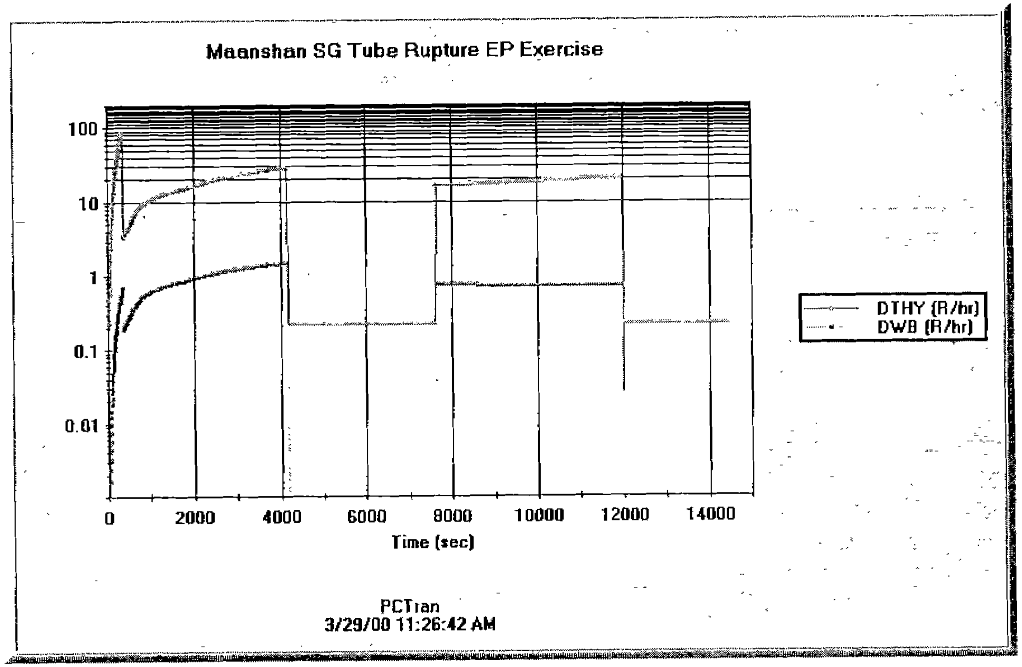


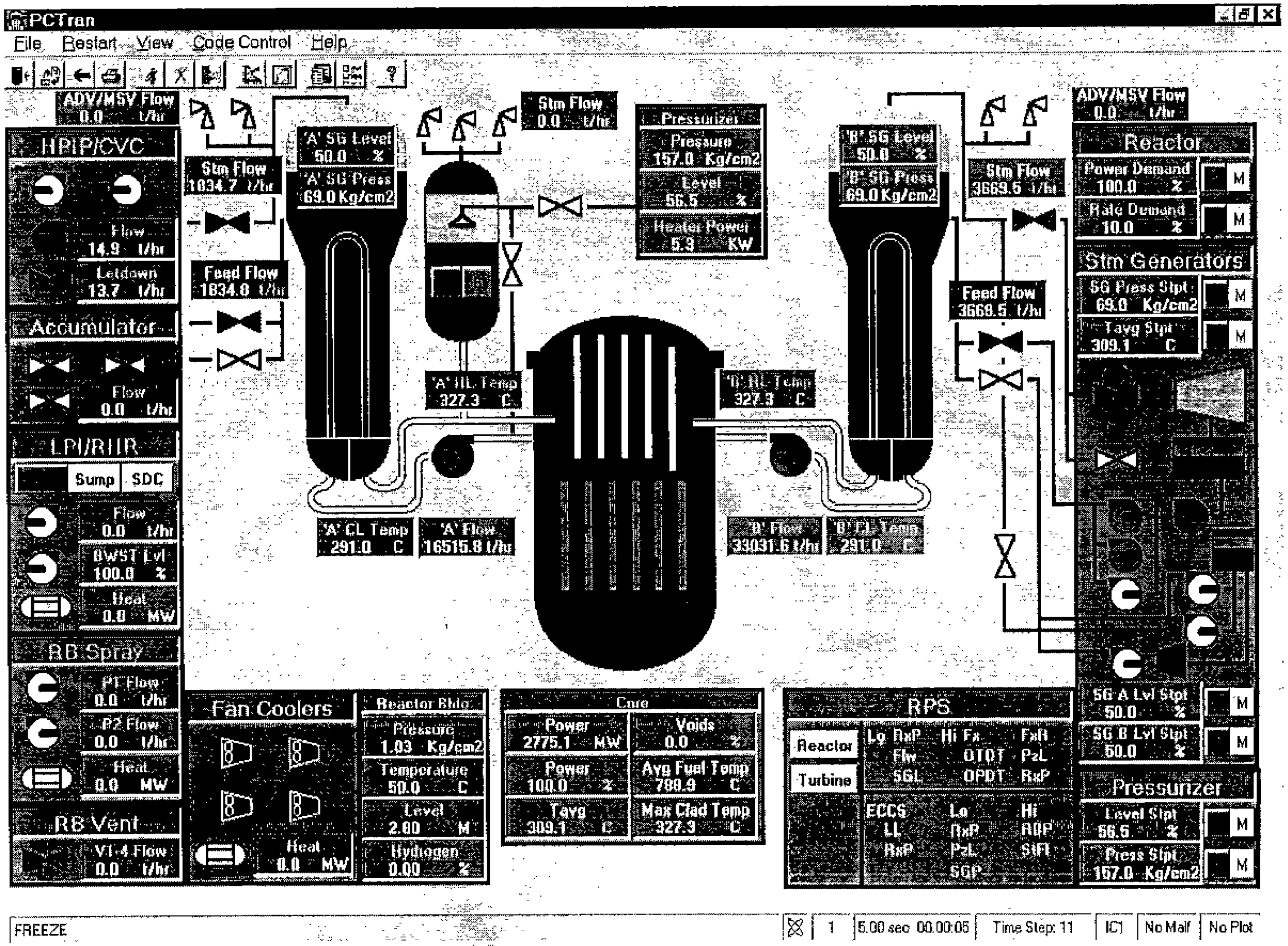
Figure 4 Thyroid and Whole Body Dose Rates at Exclusion Area Boundary

Integration with Offsite Dose Projection Model

- TPC sponsored another project to develop a real-time dose projection system
- Also Window-based software
- Using real-time meteorological condition, 3-D terrain for dose dispersion
- PCTRAN generated release pattern was used as the source term for dose projection

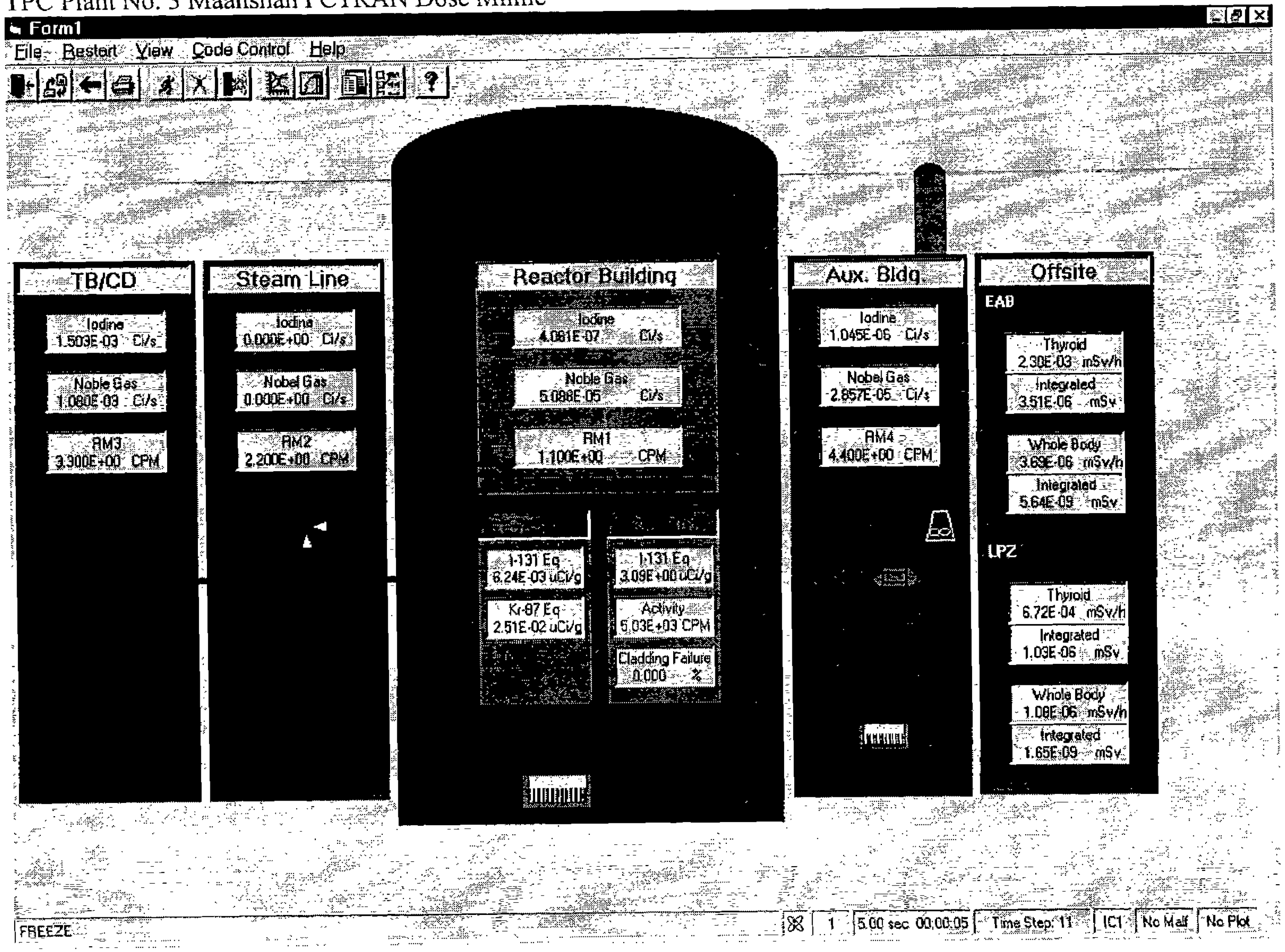
Conclusion and Future Development

- Successful in first use in annual exercise
- Critiques analyzed for further improvement
- Currently in development of TPC's Plant No. 1 (GE BWR4 Mark I) and No. 2 (GE BWR6 Mark III) PCTRAN Windows models
- Eventually a fully computerized network for exercises and actual accident management system

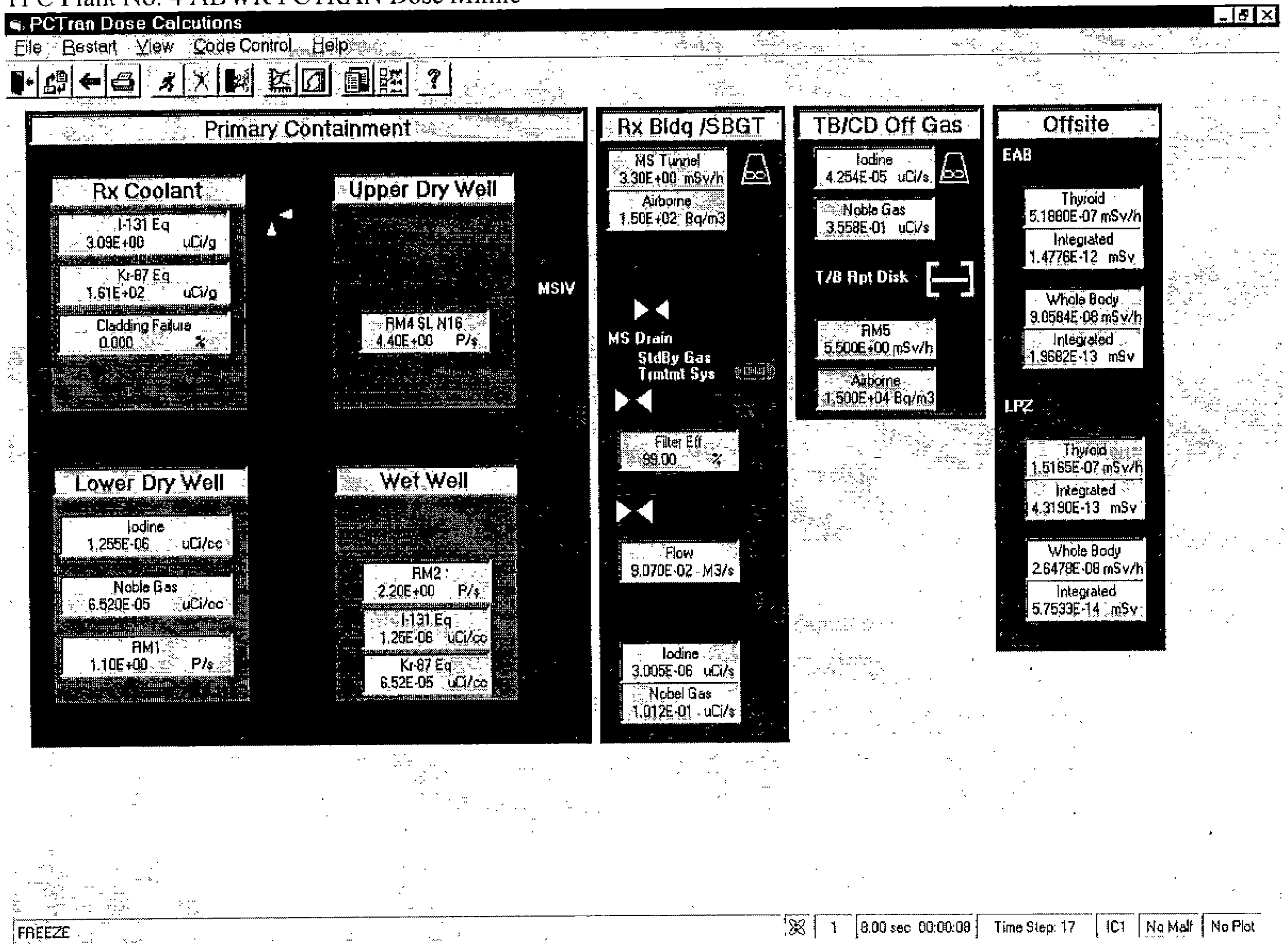


TPC Plant No. 3 Maanshan PCTRAN NSSS Mimic

TPC Plant No. 3 Maanshan PCTRAN Dose Mimic



TPC Plant No. 4 ABWR PCTRAN Dose Mimic



TPC Plant No. 4 ABWR PCTRAN NSSS Mimic