

AN ABSTRACT OF THE THESIS OF

Warren Kermit TenBrook for the degree of Master of Science in
General Science presented on May 23, 1986

Title: Research Reactor Coolant Monitoring Using Automated Gamma
Ray Spectrometry

Redacted for Privacy

Abstract approved: _____
Stephen E. Binney

An integrated sampling and gamma ray spectrometry system has been developed for analysis of TRIGA reactor primary cooling water. A microcomputer controls pumps and valves using BASIC and assembly language programs to pump 300 ml liquid samples into a reference geometry surrounding a Ge(Li) detector. Gamma ray spectra are acquired by a multichannel buffer and are analyzed by a software sequence executed on an IBM PC XT. After analysis the sample can be routed to holding containers or a waste container, depending on a user-selected option. The system is also configured as an on-line coolant monitor, using a NaI(Tl) detector to measure the gross gamma ray activity in the primary line in conjunction with a binary counting chip read under software control. When the gross count rate exceeds a user-selected threshold, a sample is automatically tapped from the primary line, its gamma ray spectrum is analyzed, and an analysis report is printed.

The sampling system was used to remove sequential samples of coolant from the TRIGA primary system at hourly intervals during one megawatt operation. Neutron activation production terms for ^{41}Ar , ^{56}Mn and ^{24}Na were determined. An overnight analysis of the

^{41}Ar , ^{56}Mn and ^{24}Na were determined. An overnight analysis of the primary coolant was also performed to determine the analytical sensitivity of the system using long spectral acquisition times. Finally, the autoanalysis software was used to automatically obtain and analyze a coolant sample, while storing a second sample in a holding container. The holding container sample was analyzed using a separate detector system to independently verify the activity reported during the autoanalysis.

Research Reactor Coolant Monitoring
Using Automated Gamma Ray Spectrometry

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of the requirements
for the degree of

Master of Science

Completed May 23, 1986

Commencement June 1987

APPROVED:

Redacted for Privacy

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Date thesis is presented May 23, 1986

Typed by Warren K. TenBrook

Acknowledgement

The author wishes to thank all those who contributed to the successful completion of this research. Special thanks to Dr. Stephen Binney, who allowed me the freedom to pursue my goals for this project. His generous technical support, guidance and friendship will always be remembered and appreciated. I extend my appreciation to Dr. David L. Willis and Dr. Roman A. Schmitt for their review of this manuscript. I extend special appreciation to Dr. John Ringle for his service as Graduate Council Representative. Thanks to Dr. James Ingle and Dr. Michael Schyler of the Department of Chemistry for their technical assistance and for the use of the apparatus on which this research was based. A special mention of appreciation and thanks to Radiation Center Chemist Michael Conrady. His technical advice and assistance was indispensable in the completion of this research.

Finally, my thanks and love to my wife Patti for her support and assistance throughout my studies.

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RESEARCH REACTOR COOLANT MONITORING USING AUTOMATED GAMMA RAY SPECTROMETRY

INTRODUCTION

Radiological monitoring of the effluents and environs of a nuclear reactor facility is one of the most critical areas of concern for the health physicist. Most exposure to ionizing radiation in reactor facilities results from work involving activation and fission product contaminants from process streams such as the primary coolant, rather than radiation directly from the reactor core. For example, steam generators in pressurized water reactor (PWR) systems are notorious for large accumulations of activation products due to trace contaminants in the coolant. These contaminants are present in all water cooled reactors to some degree, but pose a serious health physics problem for PWR maintenance operations involving heavily contaminated primary coolant system components. This contamination, popularly known as 'crud', is primarily activated metal ions released to the coolant water from corrosion. The control of coolant water chemistry and purity has a direct bearing on the type and quantity of coolant contamination that results. Therefore, to keep personnel radiation dose as low as reasonably achievable (ALARA), the health physics monitoring program must assure that process stream equipment is not excessively contaminated, and must also assure that liquid and gaseous process streams are adequately monitored and controlled so as to prevent any unnecessary contamination from occurring.

Many analytic and radioanalytic methods are employed to determine the nature and concentrations of fission and activation products in effluents. The broadest range of analytic techniques can be used for samples removed from the reactor system and brought to a separate laboratory, a technique known as grab sample analysis. Grab sample analysis allows great simplicity, flexibility and control of analytic procedure, yielding excellent results for routine and emergency monitoring applications involving a wide variety of sample matrices.¹ Nevertheless, there are disadvantages to grab sample analysis as a sole means of obtaining sample data. Foremost among these is timeliness of analysis. Grab sampling of process streams and effluents is typically done according to a scheduled routine, or at such time that other instrumentation or information indicates the need for sample data. The results of a grab sample analysis are additionally delayed by the manual sampling and removal procedure. By the time the sample is obtained, it is less certain that the data will be representative of the chemical and radiological state of the sample matrix when it was in the reactor system. Also, power reactor personnel must contend with the possibility of high dose rates in the vicinity of the sampling point during emergency conditions, when the need for sample data may be greatest.

When more timely and representative sample data are required than grab sampling techniques can provide, analytic instrumentation installed in the effluent or process stream is called upon to provide real-time data. On-line monitoring instruments can provide

constant and immediate data, but are severely limited in flexibility of analysis since they are built into the reactor system. Also, complex on-line instrumentation can be difficult to calibrate and maintain since it is likely to be remote, and may be exposed to intense radiation.

The suitability of grab sample or on-line techniques for a given analysis is dependent upon the sample matrix in question, the reactor system from which it was obtained, the state of the system and the facility as a whole, and the particular analytic data needed. To maintain the flexibility of analysis gained by grab sampling and the rapidity and specificity gained through on-line monitoring, it is useful to invoke the power of digital computers to control analytic instrumentation and sampling equipment. Using software protocols tailored to the needs of specific analyses, a remote, computer controlled analytic apparatus can make flexible decisions based upon instrumental data, making possible an on-line instrument that can bring a variety of analytic techniques to bear on a sample matrix, without intervention or delay. Given reliable instrumentation and data processing capability, this type of system combines the advantages of on-line and grab sample monitoring techniques, with greater reproducibility than manual analysis.

An Automated Liquid Analysis System (ATLAS) has been developed to demonstrate the capabilities and applications of microcomputer control to the radiological analysis of research reactor primary coolant. This system is essentially a compact, robotic laboratory designed to obtain primary coolant samples directly from the

coolant loop upon detection of excessive gross gamma ray count rate in the primary water pipe. The specific activities of sample contaminants are quantified using gamma ray spectral analysis. All of these functions are accomplished without operator intervention. The operator may also interact with the microcomputer to manipulate and analyze any liquid sample by means of a series of user selected options.

The operation of the system was demonstrated in three experiments. First, the system was used interactively to obtain TRIGA reactor coolant samples at specific time intervals during one megawatt steady-power operation to observe the specific activity variation for several radionuclide contaminants. The data were compared with a hypothetical model for production of activation product contaminants in the primary coolant. In the second experiment, the system was used to obtain a coolant sample and a gamma spectrum was acquired overnight to identify radionuclides under conditions of reduced ambient background. In the last experiment, the system was operated in an automated analysis mode. An 800 ml primary coolant water sample was tapped when the primary coolant loop gross gamma count rate exceeded a user selected threshold. Approximately 500 ml of the sample was routed to a hold-up container. The remaining 300 ml was left in the sample flow loop reference geometry for gamma ray spectral analysis. The sample in the flow loop was analyzed immediately. The sample remaining in the hold-up container was later removed to a separate counting system to assess the reproducibility of the spectral data.

BACKGROUND

Gamma Ray Spectrometry

Gamma ray detection for quantitative analysis is superficially similar to other forms of spectrometry. Emission spectrometry is the determination of the intensity and energy of photons resulting from transitions between differing electronic energy levels. Since each chemical element possesses a different set of electronic quantum transitions, excited atoms may be identified and quantified by their emission spectra.² Likewise, some nuclear energy level transitions during radioactive decay result in the emission of gamma photons of specific energies and intensities. Gamma ray spectroscopy identifies the radionuclides present in a given sample matrix by determining the energies of the characteristic gamma photons emitted. The radionuclides are then quantified by determining the rate of gamma photon emission at the prominent characteristic gamma energies of each identified nuclide.

To determine gamma ray energy, the detector system responds to a gamma ray interaction by producing a voltage pulse proportional to the energy of the incident radiation. The pulses are amplified, and shaped if necessary, and are then routed to a pulse height analyzer. Single channel analyzers possess two discriminator circuits. The first circuit is adjusted to block pulses below a particular voltage. The second circuit is adjusted to allow a small range of pulse heights, called an energy window, to pass to a

scaler. A differential pulse height distribution is obtained by adjusting the energy window over the required pulse height range and noting the count rate at each setting.

Multichannel pulse height analyzers divide the pulse height range into 256 to 8192 energy windows. Each window is assigned a solid-state memory location, or channel, that acts as a scaler. An analog-to-digital converter determines a digital value proportional to the detection system pulse strength. The count is stored in the channel whose energy window encompasses the pulse height. The pulse height distribution is obtained by graphic presentation of the total counts per channel versus the channel number. Since all pulses are analyzed upon acquisition, multichannel analysis determines the detector pulse height distribution in real-time.

A schematic multichannel pulse height distribution for a monoenergetic gamma ray source is shown in Figure 1. The most prominent feature of the pulse height distribution is the full energy peak, or photopeak. The centroid channel indicates the average pulse height of the photopeak counts, and therefore corresponds to the energy of the incident gamma ray. The multichannel analyzer is energy calibrated by comparing the known gamma energies emitted by a radioactive standard to the centroid channel positions of the resulting photopeaks. Radionuclides in an unknown sample matrix are then identified by the channel locations of the photopeak centroids for that sample.

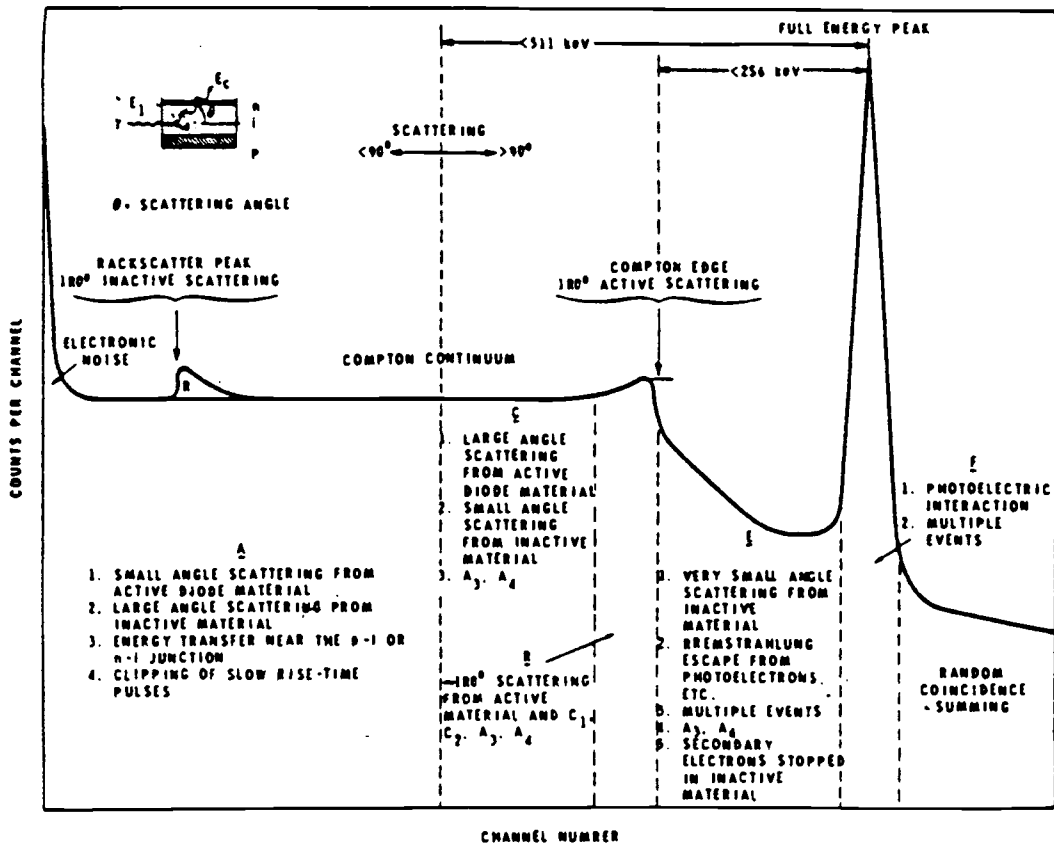


Figure 1. Schematic representation of a Ge(Li) detector pulse height distribution for a 700 keV monoenergetic gamma ray.⁴⁸

The emission rate of a particular gamma ray is determined by dividing the net rate of count accumulation in its corresponding photopeak by the detector efficiency, an energy dependent function. The efficiency function is calculated by dividing the phototpeak net count rate by known gamma ray emission rates from a radioactive standard emitting several gamma rays in the detector's operational energy range. Once the gamma emission rates are determined, the activities of the radionuclides in the sample are calculated by dividing the emission rates by their corresponding gamma intensities per disintegration.

The development of detectors for gamma ray spectroscopy using pulse height analysis can be traced from early work involving scintillation detectors and gas proportional counters to modern semiconductor detectors. Early uses of scintillators for charged particle detection required microscopy to observe scintillation photons produced by incident alpha radiation. Curran and Baker³ reported the first use of a photomultiplier tube to convert scintillation photons to electrical current, thus providing an efficient means for measuring the number of scintillation photons produced by incident alpha particles. Kallman⁴ showed that the scintillator naphthalene was transparent to its own scintillation photons, allowing larger crystals to be used to detect beta particles. Hofstadter⁵ largely culminated mid-century scintillation detector development by applying sodium-iodide, thallium-activated crystals to gamma ray detection. NaI(Tl) crystals were used

extensively as detectors for gamma spectrometry in activation analysis, and are still used in many monitoring applications because of their efficiency and simplicity, but their ability to resolve complex gamma ray spectra is limited. Interferences occur in many samples, requiring chemical separations or spectrum stripping to simplify the spectra for quantitative analysis.

Since the late 1940s, proportional counters have supplemented scintillation detectors for the spectrometry of gamma rays in the characteristic X-ray energy region.^{6,8} Proportional counters also have been extensively used as X-ray spectrometers. However, gamma ray spectroscopy using proportional counters alone is severely limited by the low probability of direct interaction between the fill gas and incident gamma rays of energies exceeding 100 keV.⁷

The first use of semiconductors for radiation detection was reported by Van Heerden⁹, who applied voltage across a silver chloride crystal cooled with liquid air and counted the current pulses caused by incident alpha particles. Various crystalline materials were tested in similar crystal conduction detectors. At room temperature, Stetter¹⁰ and Champion¹¹ tested diamond and Frerichs¹² tested cadmium sulfide. Hofstadter¹³ studied silver and thallium halogenides at low temperature. These studies revealed that crystal conduction detector pulse charge collection was difficult because of charge carrier trapping in crystal impurities and defects. Electron losses from the conduction band to holes also led to loss of pulse charge.

To avoid carrier trapping and improve charge collection, p-n semiconductor junctions in germanium crystals were used by MacKay¹⁴ and Orman *et al.*¹⁵ to detect alpha particles. Mayer and Gossick¹⁶ showed that germanium detector output pulses were proportional to the energy of the incident alpha particle. MacKay observed that the energy required to create an electron-hole pair in a germanium crystal was only 3 eV, as opposed to more than 30 eV for ion pair production in an ion chamber detector. These studies indicated that semiconductor detectors could potentially yield far better energy resolution for charged particle spectroscopy than previous radiation detection methods.

Junction detectors contain too little active detector volume in which penetrating gamma radiation can efficiently interact. To create a larger detector volume, Pell¹⁷ applied lithium to a p-type silicon crystal and used heat to diffuse the lithium into the silicon, forming an n-type layer. Heat and bias voltage were applied to the crystal to drift the lithium ions from the n-type layer into the p-type region. An intrinsic semiconductor layer of considerable volume was formed between the remaining p-type silicon and the n-type layer near the crystal surface. Later refinements resulted in lithium compensated regions more than 50 millimeters deep in germanium crystals.

Freck and Wakefield¹⁸ reported the first gamma ray spectrum obtained with a lithium-drifted germanium, or Ge(Li), detector. The ratio of photopeak height to Compton edge height resulting from ¹³⁷Cs 662 keV gamma radiation was approximately 0.3. This was a

substantial improvement over lithium-drifted silicon detectors. One year later Webb and Williams¹⁹ refined the use of Ge(Li) crystals for gamma spectroscopy. They observed that the peak to Compton edge ratio was dependent on the intrinsic semiconductor volume in the Ge(Li) crystal. Using a Ge(Li) crystal drifted to 5 mm depletion depth, they were able to obtain a 662 keV peak to Compton ratio of approximately 1.8. Tavendale and Ewan²⁰ demonstrated improved Ge(Li) detector energy resolution using ⁶⁰Co gamma ray spectra.

The excellent energy resolution of Ge(Li) detector systems make them ideal for gamma ray spectroscopy of complex sample matrices. Ge(Li) detectors have been especially useful in neutron activation analysis. DeVoe²¹ provides an excellent overview of many early activation analysis experiments using semiconductor detectors. Gordon *et al.*²² and Banham *et al.*²³ used Ge(Li) spectroscopy to determine the recoil ranges and yields of fission products. Cooper *et al.*²⁴ used direct Ge(Li) spectroscopy to analyze a wide variety of complex biological and environmental samples containing low-level gamma activity. Analysis of Hanford production reactor primary coolant from a once-through cooling system revealed over 15 activation products resulting from neutron bombardment of natural salts and trace elements in Columbia River water.

Reactor Primary Coolant Water Monitoring

Virtually every radiation detection method available has been used to assay radioactivity in reactor coolant water. Early

techniques emphasized the use of Geiger-Mueller counters or ionization chamber instruments. McKay and Walton²⁵ developed a method for testing contaminated water by evaporating a 25 ml effluent water sample and analyzing the residue with a scintillation detector to determine alpha activity. Then a one milliliter sample was evaporated and its beta activity determined using a thin window Geiger-Mueller detector. Finally, gross beta-gamma count rates were obtained from a Geiger-Mueller tube immersed in the effluent stream. Emmons and Lauderdale²⁶ described a Geiger-Mueller on-line monitor which used an ion exchange resin column to preconcentrate low-level fission product activity. The preconcentration step greatly improved the sensitivity of the monitor. Gordon et al.²⁷ developed a reactor coolant monitor that employed detection of Cherenkov radiation from fission product beta particles.

The refinement of solid scintillation detectors in the 1950's provided simple and versatile gamma ray detectors for monitoring applications. Thallium activated sodium iodide crystals and other alkaline halide crystals were used extensively for gamma ray monitoring because their elemental constituents had high atomic numbers and high crystal densities, increasing the probability of gamma interaction per unit detector volume. Upson and Connally²⁸ described the design of a generic on-line NaI(Tl) gamma monitor to measure gamma count rate in a variety of process streams at the Hanford reservation, including reactor effluent. The NaI(Tl) detector and photomultiplier tube were connected to a count rate meter by a 15 meter cable and the resulting count rate was fed to a

strip chart recorder at a remote location as much as 300 meters distant. Heath^{29,30} was the first to apply the spectroscopic capabilities of NaI(Tl) crystals to coolant monitoring. One monitor design employed two NaI(Tl) detectors viewing a coolant flow chamber. The first detector system discriminated against all pulse heights except that of ^{16}N , the major source of background obscuring low-level fission product activity. The second detector responded to radioiodine gamma radiation. By recording the difference between the count rates from the two detector systems, ^{16}N background interference was reduced, improving radioiodine detection sensitivity. Heath also described a coolant monitor that used an anion resin column to capture radioiodine in the coolant and thereby integrate radioiodine activity over the adsorption time. To improve signal-to-background ratio, a discriminator was used to reject all pulses below 800 keV, leaving counts from ^{132}I and ^{134}I and low level contaminants. The preconcentration and pulse height discrimination improved sensitivity by several orders of magnitude over direct gamma measurements of coolant streams. Strindehag³¹ developed a similar technique using a NaI(Tl) detector to selectively measure radiokrypton gamma emissions above 2 MeV.

High-resolution semiconductor detector systems are widely used for both routine and postaccident primary coolant monitoring. Graham et al.³² reported on the development of a monitor using a Ge(Li) detector to view a let-down line from the main primary flow. The let-down flow path was made long enough to allow for ^{16}N and delayed neutron decay. More than 25 significant radionuclides were

identified by the system, which was far more than that obtainable with NaI(Tl) spectrometry. Crotzer and Bestoso³³ described a similar system employing a minicomputer to control spectrum acquisition, perform data analyses and report analytic results. Ikeda et al.³⁴ reported on a radioiodine analysis system employing a Ge(Li) detector. Heath and Cline³⁵ developed an elaborate monitoring network using several remote Ge(Li) detector systems, including remote multichannel analyzers and electronics. Each detector system was coordinated by a central DEC PDP-9 processor which controlled the spectrum acquisition, performed energy calibrations using electronic pulsers of known gain, and reduced the MCA data.

A major goal of coolant monitoring analyses is the detection of fission products released from the reactor fuel to the primary water. Nuclear fuel is thermally stressed and fatigued during its lifetime because of the high power densities in the reactor core. This stress can lead to small defects in the fuel cladding, releasing fission products that have collected in the plenum. Many power plants use primary coolant monitoring to sensitively detect fission products releases from fuel defects during normal operation. Beraha et al.³⁶ discussed the validation of computer models for fission product transport in the primary system using a coolant sipping test during refueling. Kimura and Itoo³⁷ described a similar sipping apparatus to inspect fuel integrity during planned reactor inspection outages. This system employed an automated sample sipping apparatus to reduce work time and personnel radiation

exposure, and used ion-exchange separations to preconcentrate fission products for Ge(Li) detector gamma spectral analysis. Tokoi et al.³⁸ reported on a fully automated sampling system to sensitively monitor coolant radioiodine activity. Coolant was routed to a holding container where a NaI(Tl) detector was used to predetermine the volume that would yield appropriate count rates for Ge(Li) detector analysis. Low-level coolant samples were preconcentrated with ion-exchange resins. This system was able to detect $10E-6$ $\mu\text{Ci/ml}$ of ^{131}I within 10% reproducibility at the one sigma confidence level.

In the wake of the 1979 fuel melt accident at the Three Mile Island nuclear power plant Unit 2, greater industrial and regulatory attention was given to post-accident emergency monitoring systems capable of remote coolant radioactivity measurements. Stoddart³⁹ summarized the regulatory requirements for post-accident sampling of primary coolant and containment building atmosphere. These requirements included the capability to obtain coolant samples and identify and quantify the radionuclides present under extreme radiological conditions without exceeding established personnel radiation exposure limits. Nestel et al.⁴⁰ reported that post-accident sampling systems should be used for routine monitoring applications to condition the equipment for possible emergency monitoring use and to familiarize technicians with the monitoring procedure. Also, field testing of a monitoring system at the reactor facility was recommended, preferably performed by a party other than the manufacturer or purchaser to avoid bias.

Martini⁴¹ assessed Ge(Li) and hyperpure intrinsic germanium (HPGe) detection systems to determine which semiconductor detector characteristics were most desirable for nuclear power plant post-accident monitoring applications. The critical parameters identified were stability under ambient temperature extremes, sensitivity to ambient dust and humidity levels, spectral degradation from system dead time losses, and spectral degradation due to mechanical vibration. The merits of mechanical refrigeration for remote detector cooling as opposed to liquid N₂ cooling were also discussed. Zimmer⁴² reported the relative advantages of Ge(Li) detectors over scintillation detectors for on-line coolant monitoring applications. The advantages included higher sensitivity per unit volume, excellent energy resolution, and spectra that are amenable to corrections for peaked background, random coincidence summing and true coincidence summing. Zimmer also described a method for reducing detector system dead time losses due to high count rates by using remotely controlled collimators to compensate for a rise in gamma emission rate during an excursion or accident situation.

There is significant operational experience with coolant monitoring systems at nuclear power plants. Kan *et al.*⁴³ described a reactor coolant sampling system that removed dissolved gases from the coolant sample before analysis. The sample was monitored with a gross gamma detector to determine count rate. Then the sample was diluted to bring the gamma activity within an appropriate range for spectral analysis using an intrinsic (HPGe) germanium detector.

Hearn and McLain⁴⁴ and Hearn et al.⁴⁵ designed a compact remote automated sampling system for monitoring reactor coolant and containment atmosphere under routine and post-accident conditions. The system used a computer to operate sampling equipment, monitor a sample gross count ratemeter, and position collimators so that the sample count rate was optimized for analysis using a HPGe detector. The computer then performed the gamma spectral analysis and reported the data to the operator. This system was functional in ambient background radiation in excess of 100 R/hr, and possessed a sample specific activity dynamic range of $10E-4$ to $>10E+7$ $\mu\text{Ci/ml}$.

The coolant monitoring needs at research reactor facilities are different in degree from those of power reactors. Research reactor power capacity is three to four orders of magnitude less than that of power reactors, exposing the coolant to somewhat less neutron flux and significantly reducing the thermal stress on the fuel rods. The specific activity found in research reactor coolant is, therefore, much less than that of power reactor coolant. Activation product and fission product activities in the coolant are monitored to keep the reactor operator and the health physicist informed of fuel integrity, abnormalities in cooling water chemistry, and possible contamination from sample leakage or other foreign material. Ionic conductivity measurements of water in the primary coolant line provide a very sensitive indicator of coolant purity. Also, most research reactor facilities employ sensitive gross radioactivity detectors such as Geiger-Mueller counters to monitor the primary coolant. Besar⁴⁶ developed a monitor based upon

a Geiger-Mueller tube placed within a coolant chamber fed by a let-down line. Gross specific activity in the water was estimated from the counter readings by calibrating the detector with water samples of known activity.

To obtain the best analytic data, research reactor coolant samples are removed from the primary system and analyzed with a Ge(Li) detector system in a separate low-level counting laboratory. At the Oregon State University TRIGA reactor (OSTR) a standard procedure is to obtain a 450 ml coolant grab sample in a Marinelli beaker and count the sample overnight, when ambient background radiation is minimal. Bennett⁴⁷ designed an automated radiochemical system for the manipulation and analysis of OSTR cooling water grab samples and other low-level radioactive liquids. Computer control of sample dilution, detector-sample solid angle, sample holdup, ion-exchange separations and preconcentration allowed count rates to be altered for Ge(Li) detector spectral analysis. The coolant analysis time was reduced by a factor of two and the radioanalytic sensitivity was increased using ion-exchange resin preconcentration.

The purpose of this study is to adapt the computer controlled apparatus developed by Bennett to research reactor coolant sampling and analysis, to perform experiments demonstrating its operating characteristics, and to compare the analytical data obtained using the automated system with data obtained using routine research reactor coolant monitoring analyses.

INSTRUMENTATION AND MATERIALS

Overview

The Automated Liquid Analysis System (ATLAS) is composed of several individual systems working together to perform radiological analyses of reactor coolant and other liquid samples. An AIM microcomputer coordinates all the components of the system with a master program. The operator instructs the AIM microcomputer using a series of menu options. The master program prompts for any additional information in order to tailor the menu selection to the operator's particular application. This chapter describes each subsystem of the ATLAS in detail. A simplified diagram of the major ATLAS components is given in Figure 2.

A sampling system manipulates reactor coolant and other liquids using pumps and valves interfaced to the AIM microcomputer. Software options allow samples to be tapped from the primary coolant line or from one of several hold-up containers. The tapped sample is routed into a flow loop reference geometry for gamma spectral analysis, and then may be stored in a hold-up container or routed to a waste container. Any series of pump and valve operations can be defined in software and executed by sending appropriate logic signals from the AIM microcomputer to the sampling system components.

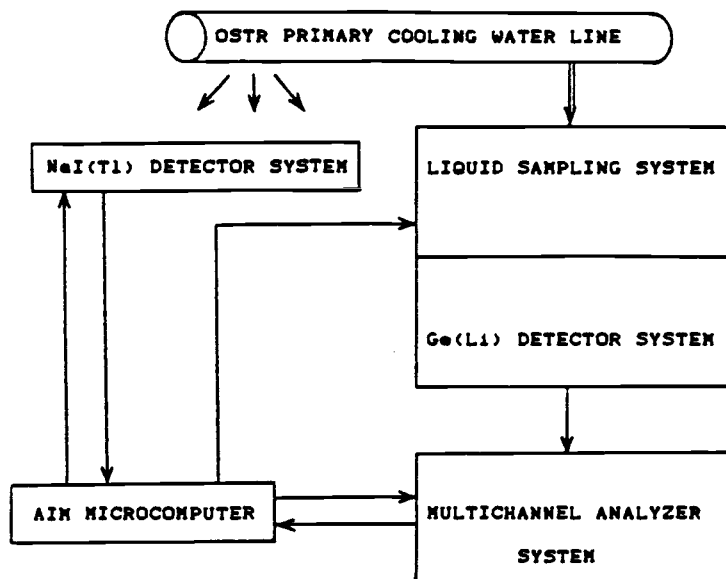


Figure 2. Overview of the Automated Liquid Analysis System (ATLAS).

The Oregon State University TRIGA research reactor (OSTR) is central to the ATLAS's operation. The analysis of the dynamics of radionuclide production, decay and transport in the reactor coolant system provided an excellent proving ground for the ATLAS. The sampling system was connected directly to the OSTR primary coolant system by means of small diameter tubing. The sampling system could then tap a coolant sample by changing a single valve position upon receipt of a logic signal from the AIM microcomputer. The OSTR primary water pump provided the necessary flow pressure in the coolant line. No sampling system pumping was required to obtain a coolant sample.

A gross activity detector system provides the AIM microcomputer with the gross gamma ray count rate of the primary coolant line. While in the autoanalysis mode, the AIM microcomputer continuously displays the gross gamma count rate, and is programmed to execute primary coolant sampling procedures upon observation of count rates greater than a user selected threshold. During the interactive mode the operator can observe the count rate at any time by invoking a software menu option. Statistical software was written to calculate mean count rate, standard deviation and other counting statistics from a series of gross counts accumulated over time. These counting statistics were used to establish nominal values for the autoanalysis gross count rate threshold.

A Ge(Li) detector system is used to detect gamma rays emitted from ATLAS samples. The detector crystal is surrounded by the sampling system liquid counting flow loop, which serves as a

reference counting geometry. The support electronics for the gross gamma detector and Ge(Li) detector systems are housed together near the sampling system and the AIM microcomputer.

A microcomputer-based multichannel analyzer (MCA) system acquires and analyzes the sample gamma spectra. The Ge(Li) detector pulse height distribution is accumulated in a multichannel buffer (MCB) module and is subsequently transferred to an IBM personal computer (IBM PC) for data reduction. To coordinate the sampling procedure with the acquisition of the sample gamma spectrum, a communications link was established between the AIM microcomputer and the IBM PC. Communications software was written to allow the microcomputers to communicate their status to one another by sending and receiving control characters.

Oregon State University TRIGA Research Reactor

The OSTR is a TRIGA (Testing, Research and Isotope production, General Atomic) Mark II reactor. It generates one thermal megawatt maximum steady-state power and is capable of generating approximately 3000 thermal megawatts peak power over a ten millisecond time span during pulsed operation. The OSTR consists of a right cylindrical reactor core mounted near the bottom of an aluminum reactor tank filled with water. An above-grade concrete shielding structure houses the reactor tank. Four radial neutron beam ports and a graphite thermal column penetrate the concrete reactor wall. Two pneumatic transfer terminals and an annular rotating rack provide regions of known neutron flux for

neutron activation experiments and isotope production. Two diagrams of the OSTR are shown in Figure 3.

The reactor tank water serves as a radiation shield, neutron moderator and core primary coolant. The water is circulated into the lower region of the pool and rises through channels in the core to the upper region of the pool, following a natural convection pattern. The water is then removed from the upper region of the tank, sent to a heat exchanger for cooling, and returned to the tank lower region. Water on the secondary side of the heat exchanger is pumped to a forced-air convection cooling tower on the reactor building roof. The OSTR also incorporates a demineralizer system to remove ionic impurities from the reactor water. Demineralization reduces the ionic conductivity of the water, thereby decreasing the rate of corrosion of reactor components. Demineralization also reduces radionuclide contamination from neutron activation of water impurities. The demineralizer system water flow pattern parallels that of the primary cooling system, but also includes a single pass through an ion-exchange resin tank and a particulate filter. The OSTR on-line water monitoring instruments include two conductivity cells to measure ionic purity, a Geiger tube to measure gross radiation count rate, and several temperature probes. Most of these instruments are enclosed in a water flow chamber incorporated into the demineralizer system. A diagram of the OSTR water system is shown in Figure 4.

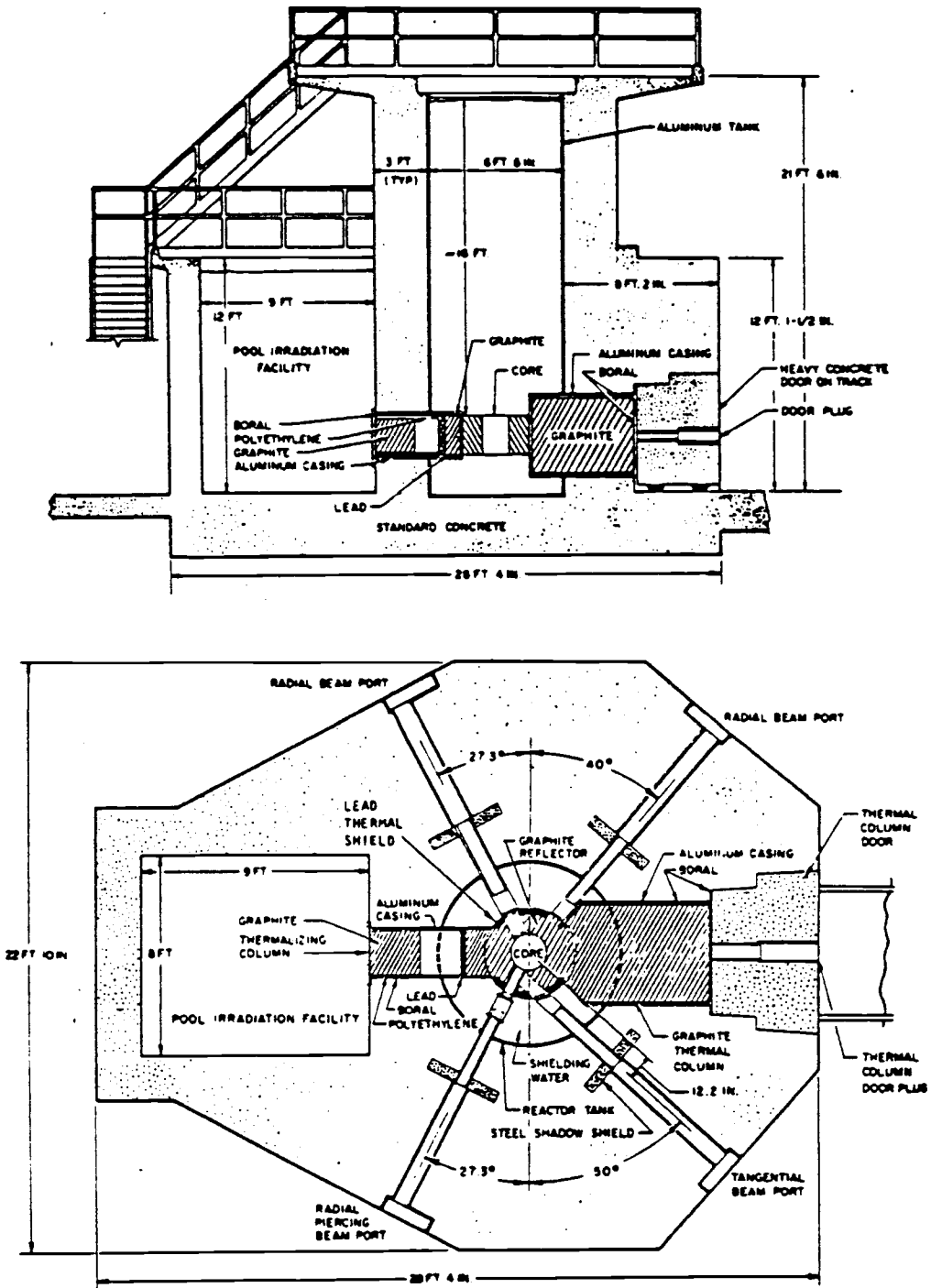


Figure 3. Vertical and horizontal sections of the Oregon State University TRIGA reactor (OSTR).49

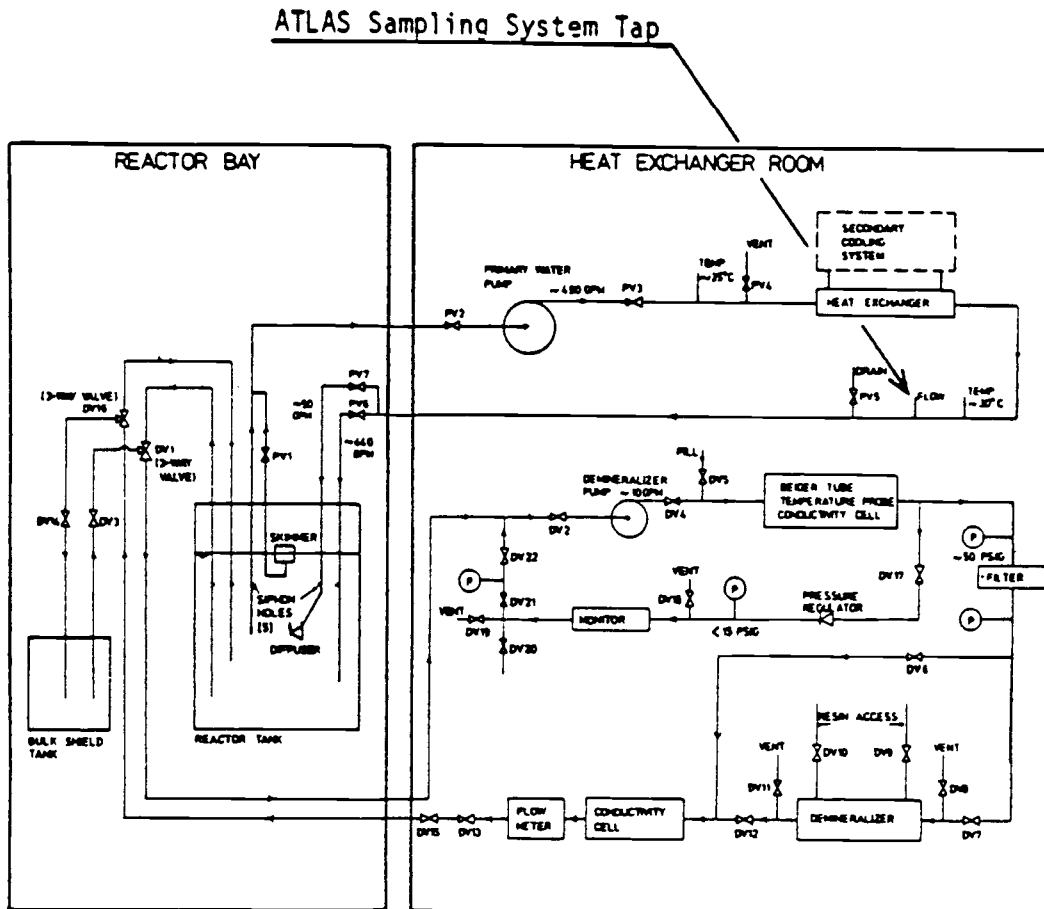


Figure 4. Schematic diagram of the OSTR water cooling and purification system.

Liquid Sampling System

The ATLAS liquid sampling system is a small-scale laboratory system designed to obtain samples of reactor cooling water from the primary coolant system and bring them into a flow loop reference geometry for gamma ray spectrometric analysis. An AIM microcomputer controls several valves and a transport pump to route the analytes to a counting loop, a waste container, or one of several holding containers. The sampling system rests in a plastic tray lined with absorbent paper to contain any leaked liquid. This tray was placed on a desk in the OSTR bay near the heat exchanger room door. The configuration of the sampling system components is illustrated in Figure 5. A list of the sampling system components is provided in Table 1.

The sampling system valves are pneumatically activated by 40 psi air pressure obtained from the reactor building self-contained breathing apparatus compressed air supply. The three-way valves are kept in a designated zero position by a spring loaded mechanism. To switch the valve to position one, a 5 V logic signal from the AIM microcomputer interface is sent to a relay, which in turn activates a solenoid. The solenoid allows air pressure to be applied to the valve slider causing the valve to switch to position one. The spring returns the valve to the zero position in the absence of the 5 V signal.

The six-way valves are operated by a rotor connected to an air driven piston arm. A 5 V logic signal activates a solenoid, allowing air pressure to drive the piston. This rotates the

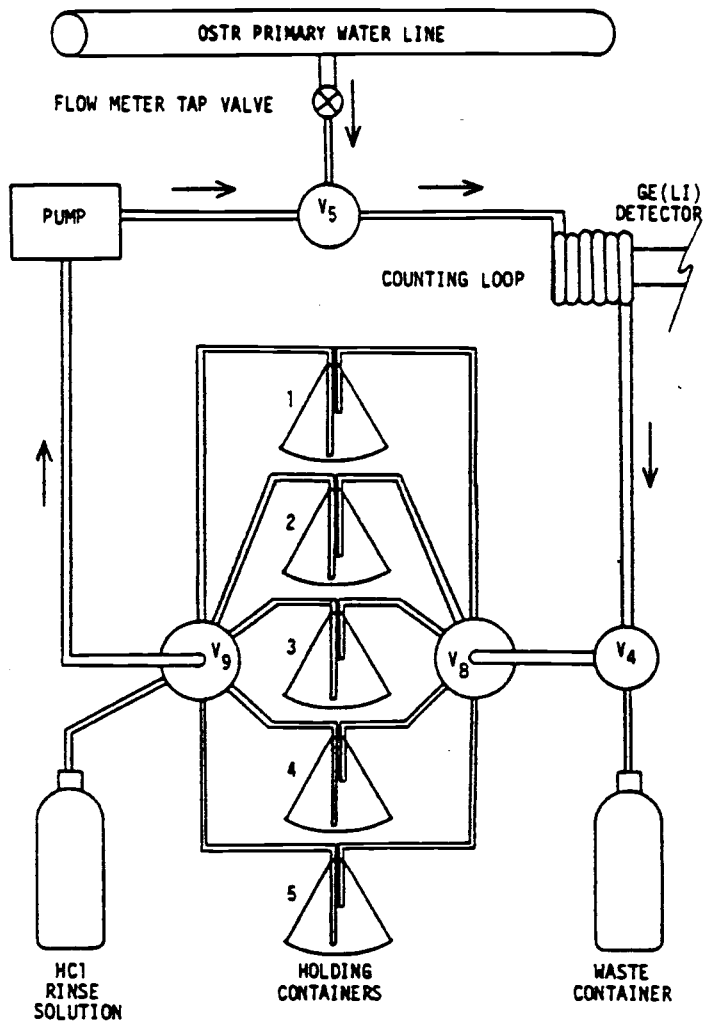


Figure 5. Configuration of the sampling system components.

Table 1. Sampling system components.

<u>Component</u>	<u>Model/Size</u>	<u>Manufacturer</u>
Liquid pump	Lab Junior	Fluid Metering Co. Oyster Bay, NY
3-way valve actuators	5300	Rheodyne, Inc. Cotati, CA
3-way slider valves	5302, 1.5 mm bore	Rheodyne, Inc. Cotati, CA
6-way valve actuators	5003	Rheodyne, Inc. Cotati, CA
6-way Teflon valves	5012, 1.5 mm bore	Rheodyne, Inc. Cotati, CA
3-way solenoid air valves	903-00	Skinner Electric Co. New Britain, CT
Solid state relays	+5 V actuated	Grayhill Electric Co. LaGrange, IL
Teflon tubing and connectors	1.0 mm I. D.	Rainin Instrument Co. Woburn, MA
Plastic tubing	64 mm I. D.	VWR Scientific Co. Seattle, WA
Plastic catch pan	55 x 80 cm	Homemade
Holding containers	500 ml Erlenmeyer flask	Corning Glass Co. Corning, NY
Liquid Containers	4 liter	Nalge Co. Rochester, NY
Marinelli Beaker	450 ml	Control Molding Co. Staten Island, NY
Tube connectors	10 mm O. D.	Dynalab Co. Rochester, NY
Air pressure gauge	0-30 psi	Powers Regulator Co. Skokie, IL

valve orifice to the next valve position. A second logic signal activates a second solenoid to apply pressure to the opposite side of the piston, returning the arm to the initial position. A delay is timed between the two microcomputer logic signals to operate the valves properly. The cycle is repeated to move the valve through several consecutive positions.

An electric powered rotary piston pump is used to pump liquids through the sampling system when primary cooling system pressure is unavailable. The pump flow rate is manually adjustable to a 40 ml/min maximum. The pump is activated by a 5 V logic signal and deactivated in the signal's absence.

OSTR primary cooling water is tapped by the sampling system from a primary cooling system flow meter tap valve located near the heat exchanger outlet. Two threaded Teflon connectors provide a step down from the flow meter valve pipe thread to the 1 mm inner diameter Teflon tubing used in the sampling system. A four meter length of tubing routes the coolant sample from the tap valve in the heat exchanger room to the sampling system in the reactor bay.

The coolant tap line terminates at a three-way pneumatic valve designated as valve number 5. Valve 5 determines the liquid that is routed to a reference geometry counting loop. When set to the zero position, valve 5 accepts flows pumped from the hold-up containers or from the rinse solution container. When set to position one, valve 5 allows primary coolant to flow into the counting loop under primary water system back pressure.

The counting loop reference geometry is composed of 9 meters of 6 mm inner diameter all-purpose plastic tubing, yielding a total volume of approximately 290 ml. The tubing is coiled within a standard 450 ml capacity Marinelli beaker, with an additional winding about the beaker exterior. The tubing ends are terminated with threaded polypropylene tube connectors mated to teflon tubing threaded connectors. The sample loop Marinelli beaker is placed over the detector crystal to achieve a large detector-to-sample solid angle and a small detector-to-sample distance for high counting efficiency. The loop is enclosed within a 20 000 cubic centimeter lead shielding cave.

Liquids exiting the counting loop are routed to a second three-way valve designated as valve number 4. When valve 4 is in the zero position, flow is sent directly to a four liter plastic waste container. When valve 4 is set to position one, liquids are sent to a hold-up container by way of a six-way valve. This six-way valve is designated as valve number 8.

Five 500 ml glass Erlenmeyer flasks serve as hold-up containers. Each flask is provided with a one-hole rubber stopper to contain the flask contents. The single hole provides an entrance and exit for flow tubing. Valve number 8 receives a single liquid flow, and then deposits the liquid in the hold-up container corresponding to the valve position.

A second six-way valve, designated as valve number 9, removes flow from the hold-up container corresponding to the valve position. The removal of liquid is accomplished using the electric

pump, which routes flow to valve 5, completing the sampling system cycle.

NaI(Tl) Detector System

A 76 mm x 76 mm thallium activated sodium iodide scintillation detector is used to detect gamma ray emissions from the OSTR primary water system flow. The detector is located in the gap between the ingoing and outgoing 100 mm inner diameter primary water pipes in the OSTR piping service trench. A NIM (Nuclear Instrumentation Module) bin houses the detector system electronics on a table adjoining the AIM microcomputer. The NaI(Tl) detector system electronics include a high voltage power supply, an amplifier, and a NIM module containing a 32 bit latched binary counting chip. A preamplifier is positioned midway between the detector and amplifier. After the preamplifier and amplifier have increased the detector signal gain, the detector pulses are accumulated on the 32 bit counter chip. The chip is connected to an AIM microcomputer interface so that the counter may be started, stopped, read and reset under computer control. The AIM microcomputer may then relay the count rate to the operator and use the accumulated count information to make operating decisions. The configuration of the NaI(Tl) detector system components is illustrated in Figure 6 and a list of the components is included in Table 2.

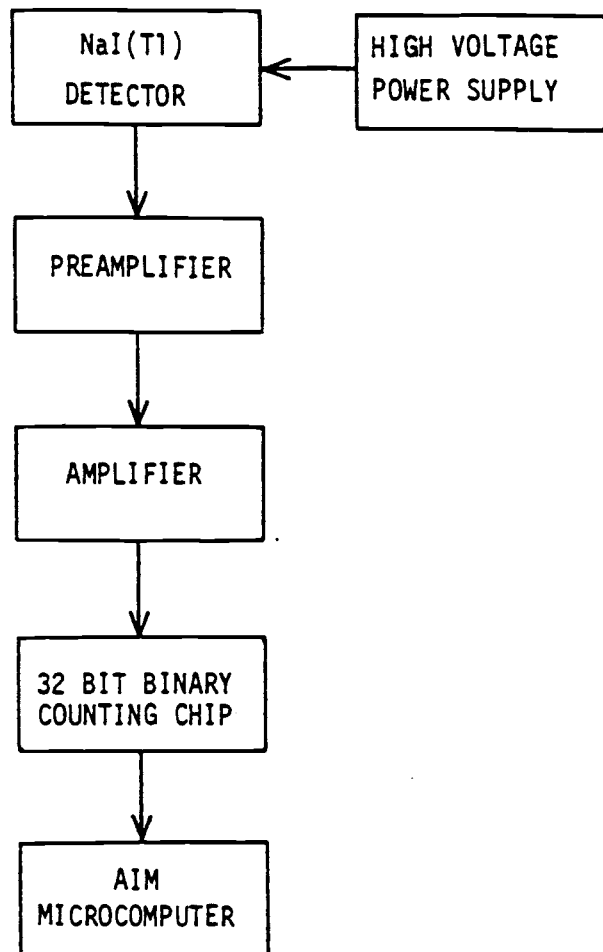


Figure 6. Configuration of NaI(Tl) detector system components.

Table 2. Radiation detection/multichannel analysis component list.

<u>Component</u>	<u>Model</u>	<u>Manufacturer</u>
NIM bin	401A	Ortec Oak Ridge, TN
NaI(Tl) detector	8S8 (50 mm x 50 mm)	Harshaw Chemical Co. Solon, OH
Preamplifier (NaI(Tl))	805	Canberra Industries Meriden, CT
Amplifier (NaI(Tl))	451	Ortec Oak Ridge, TN
High voltage power supply (NaI(Tl))	TC940A	Tennelec Oak Ridge, TN
Binary Counter	32 bit latched	Homemade
Ge(Li) detector	RG-11	Princeton Gamma-Tech Princeton, NJ
Preamplifier (Ge(Li))	RG-11AC	Princeton Gamma-Tech Princeton, NJ
Amplifier (Ge(Li))	2020	Canberra Industries Meriden, CT
High voltage power supply (Ge(Li))	403B	Nuclear Diodes Prairie View, IL
Pulser	1451	OSU Radiation Center Corvallis, OR
Oscilloscope	T932A	Tektronix, Inc. Beaverton, OR
Multichannel buffer module	ADCAM 918	EG&G Ortec Oak Ridge, TN
Microcomputer	Personal Computer XT	IBM Corp. Armonk, NY
Printer	Microline 92	Okidata Corp. Mt. Laurel, NJ

Ge(Li) Detector System

A 49 mm x 52 mm coaxial lithium-drifted germanium detector is used for gamma ray spectrometric measurements of liquids in the sampling system counting loop. The detector possesses a 2.03 keV full-width at half maximum (FWHM) at 1.33 MeV, and a 13.2% efficiency at 25 cm distance relative to a 76 mm x 76 mm NaI(Tl) detector at 1.33 MeV. The detector and cryostat are horizontally mounted on a liquid nitrogen dewar. This allowed the cryostat and detector crystal to project into the sampling system lead cave for insertion into the Marinelli beaker counting loop. A preamplifier is integrated into the detector cryostat assembly, and is connected to a spectroscopy amplifier NIM module by three meters of 93 ohm coaxial cable. Additional spectroscopy electronics include a 60 Hz electronic pulser and a detector high voltage power supply. The Ge(Li) detector system output is connected to an analog-to-digital converter/multichannel buffer module in a separate counting room by approximately 30 meters of coaxial cable. The configuration of the Ge(Li) detector system components is illustrated in Figure 7. A list of the system components is included in Table 2.

Multichannel Analyzer System and Data Reduction Software

Pulse height analysis of ATLAS sample gamma ray spectra is performed by a microcomputer-based multichannel analyzer (MCA) system. A multichannel buffer module with an internal successive approximation analog-to-digital converter accumulates the detector signal pulse height distribution in its memory buffer. Multichannel

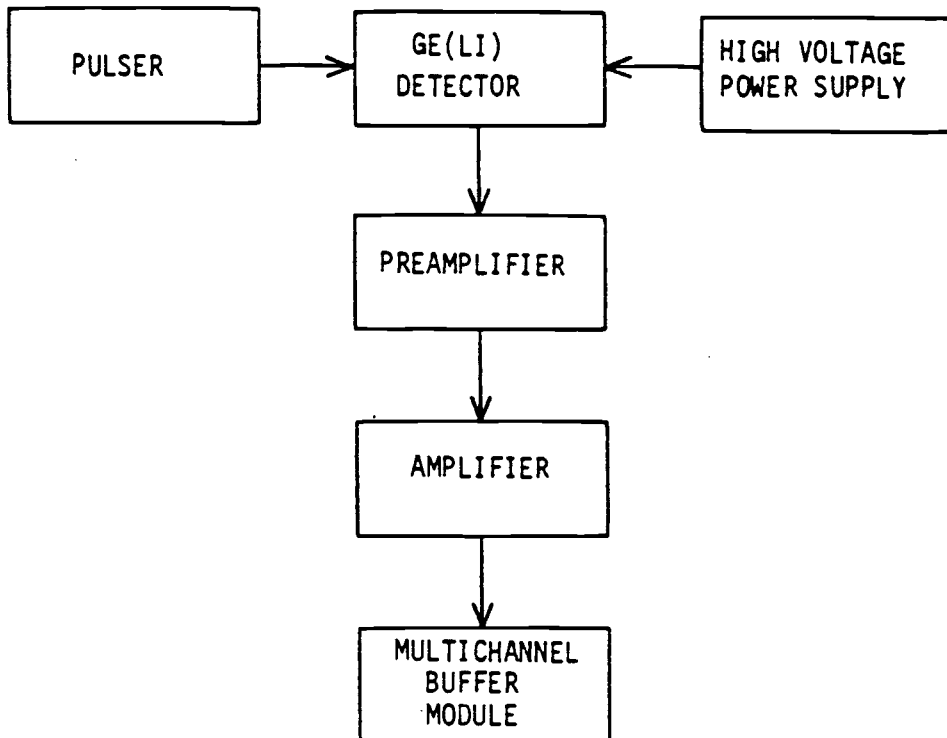


Figure 7. Configuration of Ge(Li) detector system components.

analyzer functions are accessed by displaying the buffer module memory on an IBM personal computer using MCA emulation software. MCA spectra are written to an IBM fixed disk for subsequent data reduction. A list of the MCA equipment is included in Table 2.

The data reduction software works in several stages to bring together all the information necessary for the radionuclide analysis into a single file. The sequence begins by converting the original MCA emulation software pulse height distribution (filename.CHN) to a real number format spectrum (filename.SPC). At this point the pulse height spectrum has been converted to a gamma ray spectrum by incorporating detector efficiency versus energy information from the detector calibration file (filename.CLB). Additional information about the detector used, the sample counted and the efficiency function employed is also added at this time.

The first part of the analysis (program AN1) is a brief routine which merges the analysis parameters (file GERPAR), the type of analysis requested, the nuclide gamma ray library information and the spectrum file into a single unformatted file (filename.UFO). In the second part of the analysis (program AN2), the radionuclide data are calculated from the information in the unformatted file, and the results are returned to the unformatted file. Finally, a report is extracted from the unformatted file and written to an output device by executing a report routine (program RPT).

AIM Microcomputer

An expanded Rockwell AIM 65 microcomputer is used to coordinate all ATLAS functions. The AIM microcomputer contains an eight bit 6502 central processing unit operating at 1 MHz, an applications connector to access peripherals and expansion accessories, and a keyboard. Expanded features include 36 kilobytes total random access memory (RAM), three 6522 versatile interface adapters (VIA), a video display interface card and a floppy disk interface card. The component circuit boards are inserted in a protective plastic case containing a regulated power supply for the microcomputer system. Printer output is directed to a teletype using a 20 mA current loop. However, during normal system operation the current loop was used to communicate ASCII characters to and from the MCA system rather than for teletype output. A list of the AIM microcomputer system components is given in Table 3.

Two of the three 6522 versatile interface adapters provided are used for bidirectional input and output to the ATLAS sampling system and the binary counting chip, respectively. To allow software control of the peripheral devices, each VIA is addressed in the AIM microcomputer memory. The AIM memory register addresses interfaced to sampling system VIA are A000 and A001 hexadecimal. Hexidecimal addresses 9F90 and 9F91 are interfaced to the 32 bit binary counting chip. An outline of the AIM microcomputer interfaces is provided in Table 4. The sampling system and the binary counting chip are each connected to a VIA by a 25 pin D connector. The D connector pins are individually connected to the

Table 3. AIM microcomputer system components.

<u>Component</u>	<u>Model</u>	<u>Manufacturer</u>
Microcomputer	AIM 65	Rockwell, Intl. Anaheim, CA
Video display interface	2340 STD VID 64/80	Forethought Products Eugene, OR
Floppy disk controller	STD DOS-1	Forethought Products Eugene, OR
Memory expansion board	2610 STD MEM-24	Forethought Products Eugene, OR
Card cage with power supply	2472 STD G10	Forethought Products Eugene, OR
Video display	ZUM-121	Zenith Corp. Chicago, IL
Disk drives	TM100-4	Tandon Corp. Torrance, CA
Disk drive enclosure	END-000226	Jade Computer Prod. Hawthorne, CA
Teletype	DECwriter II	Digital Equipment Corp Maynard, MA

Table 4. AIM microcomputer versatile interface adapter connections.

<u>VIA Hexidecimal Address</u>	<u>Bit</u>	<u>Component</u>
A000	3	Valve 9
	2	Valve 8
A001	5	Valve 5
	4	Valve 4
	0	Pump
9F90	2-6	Counter chip control
9F91	0-7	Counter chip data byte

sampling system components using small diameter coaxial cable terminated with standard BNC connectors. System components are controlled by sending 5 V logic signals over the VIA interface lines. The counting chip is connected to its VIA by a 50 cm long parallel transmission cable bundle. Data are retrieved from the counting chip by determining the voltage state of the counter VIA lines, which corresponds to a single binary byte value.

The AIM microcomputer controls the MCA system as a peripheral using ASCII characters sent and received over the AIM 20 mA current loop teletype interface. A modem was used to convert the 20 mA current loop convention to the RS-232 EIA serial format used by the MCA system IBM PC.

ATLAS Software Architecture

Just as diverse hardware components are used by the ATLAS to perform the required analyses, several computer programs are invoked to control the system components and analyze the data. A master program named ATLAS.INT is executed on the AIM microcomputer to coordinate the various analysis procedures with a minimum of operator intervention. ATLAS.INT is a compiled BASIC language file which is executed by the AIM-Mate disk operating system (DOS) BASIC interpreter, RUN.COM.

To operate the ATLAS components, ATLAS.INT works in several steps. First, the software queries the operator for information as to which ATLAS functions are desired. This process begins with the selection of a main menu option. Each menu option leads to an

additional series of questions. The input provided by the operator is used by ATLAS.INT to set program variables to execute the system operations requested. For example, if hold-up container number three is selected for sample storage, a VALVB(n) subscripted variable is set to 9, the valve responsible for selecting the hold-up container, STATEB(n) is set to 3, the valve position for hold-up 3, and VALVSIX is set equal to the number of six way valves to change. The valve information is stored in several one dimensional arrays, each array assigned to a variable. The subscript 'n' indicates the array position of a particular value.

Once the program variables have been set, ATLAS.INT BASIC subroutines call assembly language subroutines from the file PASSASSE.KIM. All system functions are then executed by PASSASSE assembly language routines using the versatile interface adapters. The ATLAS.BAS BASIC subroutines and their variables are listed in Table 5. A listing of ATLAS.BAS is given in Appendix A, and a listing of PASSASSE.PRN is given in Appendix B.

When ATLAS.INT is started, the operator is requested to wait as the PASSASSE subroutines are loaded into the AIM microcomputer random access memory. Once PASSASSE is loaded, the operator is prompted to switch on the sampling system power, turn on the valve air pressure, and to open the primary water tap valve. The program then queries the operator to determine if the system hardware has been set up as required. If the operator responds "no", then the program returns with the set-up instructions and the query. When the operator indicates the hardware is ready, a menu is

Table 5. ATLAS.BAS subroutine functions.

<u>Subroutine Entry Point</u>	<u>Function</u>	<u>Variables</u>
200	Timed delay	DDDT=multiplier FUDD=1; seconds 2; minutes 3; hours
225	Gamma spectrum acquisition	None
1000	Beep tone	None
1500	Read counter chip	Returns TOTALCTS=cps
8040	Change valve positions	VALVTHREE=Total 3-way valves to change. VALVSIX=Total 6-way valves to change. VALVA(k)=3-way valve #. STATEA(k)=3-way valve position. VALVB(k)=6-way valve #. STATEB(k)=6-way valve position.
8210	Start and stop pump(s)	PUM=1 (Total pumps) PUMP(k)=pump # PUMPSTATE(k)=0; off 1; on
9000	Stop pump(s)	None

displayed. The options available are:

- 1) Tap the primary water sample line.
- 2) Tap liquid from a hold-up container.
- 3) Tap HCl rinse solution.
- 4) Read the binary count chip.
- 5) Acquire a gamma spectrum from the flow loop.
- 6) Begin the coolant autoanalysis procedure.
- 7) Exit the program to DOS.

The first five options are "interactive", meaning that the user may execute ATLAS functions on a step-by-step basis. The sixth option is an automated sampling and radioanalysis of OSTR primary water.

The autoanalysis consists of a sequence of radiation detection operations and sampling system operations coordinated by the ATLAS.INT program. The sequence begins with several questions. The operator is asked what gross gamma count rate threshold will be used to initiate the sampling and analysis procedure, the volume of coolant to be sampled, whether to route flow to waste or store flow in a hold-up container, and, if selected, which hold-up container to use. The threshold value for the autoanalysis mode may be established prior to ATLAS.INT execution by running a user-written counting statistics calculation routine, STATCALC.INT. STATCALC reads a series of one second counts from the counting chip and calculates a mean, standard deviation, maximum, minimum, baseline

level, and three sigma maximum. A listing of STATCALC.BAS is given in Appendix C.

After gathering the information needed to perform the analysis, the program displays a title header and enters a looping algorithm to read and reset the counting chip each second. During the looping algorithm, the total count accumulated on the binary chip is compared to the threshold value. If the threshold value is not exceeded, then the count is displayed and the next count is read. If the threshold is exceeded, valves are automatically repositioned to allow primary water to flow from the OSTR primary system to the sampling loop and out to the waste container. A timed delay allows coolant flow to displace the sample loop volume. If hold-up storage was selected, the valves are repositioned after the flushing delay to allow the specified volume of coolant to flow to the designated hold-up container. After the specified volume is obtained, the coolant tap valve is automatically repositioned to stop the primary water flow, and a carriage return and line feed are sent over the AIM 20 mA current loop to the IBM PC-based MCA system, located in a separate counting room.

The IBM PC controls multichannel analyzer and data reduction functions. By typing a command line ANALYZE filename, a gamma spectrometry sequence is initiated using filename as the spectral data work file. The gamma spectroscopy programs are executed in sequence using DOS command lines in a user-written batch file, ANALYZE.BAT. The first program in the batch file is a user-written BASIC program, MCBSET.EXE. MCBSET initializes the multichannel

buffer module, loads a user selected preset count time, and sets a communications trap on the serial line connected to the AIM. When MCBSET detects the AIM microcomputer signal, the ADC is switched on and the spectrum is acquired. An MCA utility program STORE.EXE waits for the spectrum acquisition to finish, and then stores the spectral data to filename.CHN on the IBM PC fixed disk. The MCA file sequence CONVERT.EXE, AN1.EXE and AN2.EXE performs the analysis of the spectrum. RPT.EXE then prints a report of the results. A user written BASIC file, RXTRAN.EXE, returns an ASCII character string to the AIM microcomputer to finish ANALYZE.BAT. Listings of the user-written MCA utility programs ANALYZE.BAT, MCBSET.BAS and RXTRAN.BAS are presented in Appendix D.

The AIM microcomputer communications trap returns ATLAS.INT to the main menu upon receipt of the RXTRAN string from the IBM PC. At this point the user may select an interactive ATLAS function, restart the autoanalysis, or exit the program.

An overview of all the ATLAS software routines and their relationships to one another is provided in Figure 8.

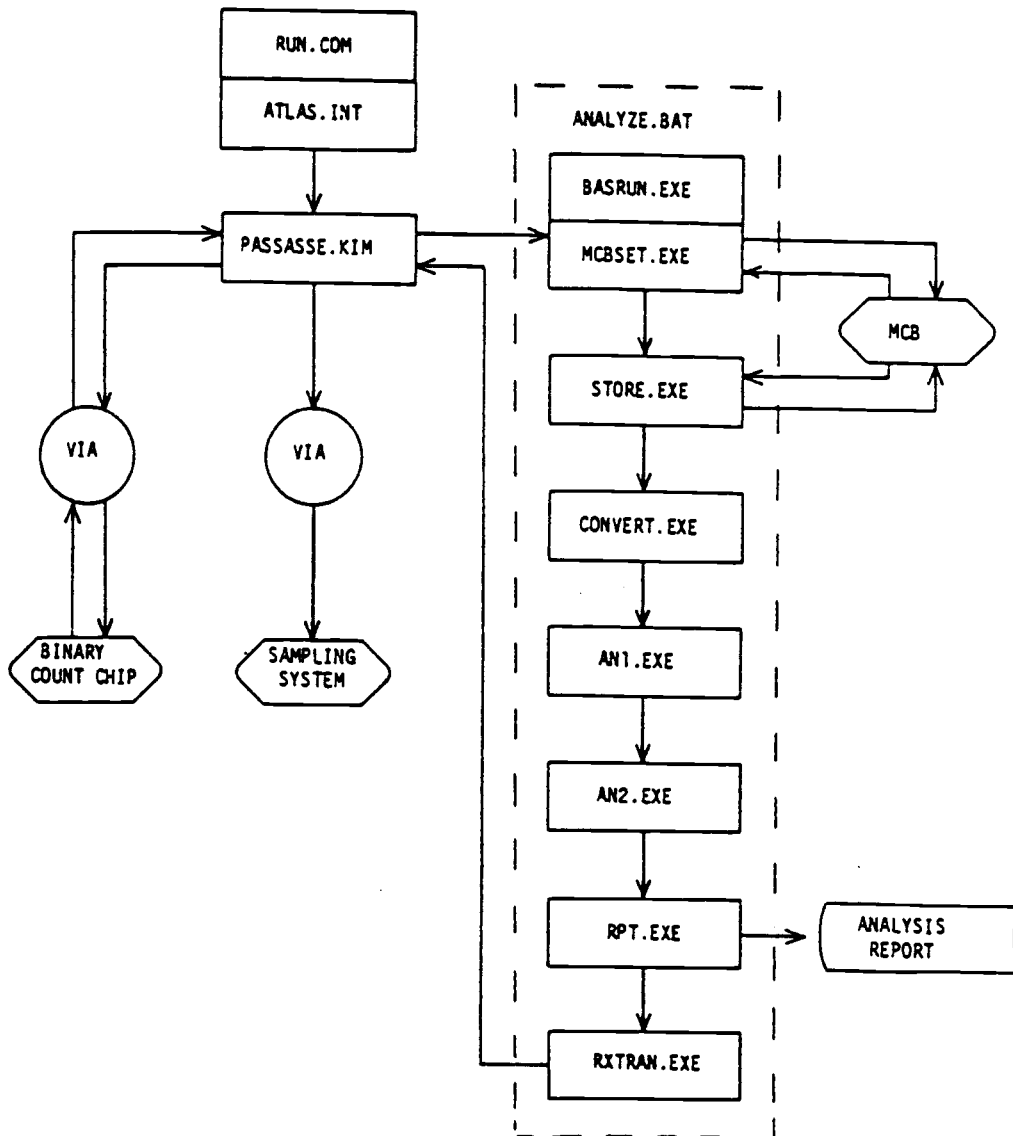


Figure 8. ATLAS software architecture overview.

EXPERIMENTAL METHODS

Ge(Li) Detector System Calibration

The detection efficiency versus energy function for a given gamma spectrometry system is determined by comparing the net photopeak areas in the gamma ray spectrum of a radioactive standard with the known gamma ray emission rates of the standard. The efficiency function depends on the source-to-detector solid angle and distance, the gamma absorption characteristics of the sample matrix, and the characteristics of the particular detector used. The best method for determining an accurate efficiency function is to standardize the pulse height spectra using the same radionuclides that are expected to be present in the analytes and to perform the calibration under identical conditions to those used for the sample analyses. However, when the expected sample radionuclide identities cannot be assumed, it is necessary to use a mixed gamma ray standard emitting prominent gamma rays over the energy region of interest.

A ^{152}Eu standard solution was used to determine the ATLAS Ge(Li) detector system counting efficiency. A liquid ^{152}Eu standard has several advantages for the ATLAS calibration. First, it is long lived, which is convenient for timely and frequent calibrations. Second, it emits several prominent gamma rays over a wide energy range, 121.8 keV to 1408 keV. Finally, the liquid could be injected

into the ATLAS sampling geometry to minimize geometry dependent effects.

The ^{152}Eu standard solution activity was determined using a Ge(Li) detector system and counting geometry possessing a known efficiency function. The OSTR health physics low-level environmental monitoring system was employed for this purpose. The health physics detector system was calibrated using a solid-matrix mixed gamma ray reference source in a 450 ml Marinelli beaker geometry. The reference source gamma spectrum was acquired with the health physics monitoring system, and an analysis report was obtained using the same gamma ray spectrum analysis software as was used for the ATLAS experiments. The prominent reported photopeak channel positions and their presumed corresponding energies were entered into the MCA system calibration utility file CLB.EXE, which then calculated an energy versus channel number function and an energy versus peak full width at half maximum (FWHM) function from the reference source spectrum work file. Next, the microcurie activity of the reference source was entered into the calibration file, and several corresponding pairs of energy and absolute efficiency values were calculated from the reference source spectrum work file. A quadratic log-log fit was done on the efficiency data, and the calculated efficiency values generated by the fitted curve were compared with the measured efficiency values obtained from the spectrum.

Following the detector calibration, a 50 ml aliquot of ^{152}Eu solution was poured into a 500 ml volumetric flask and diluted to

the mark. This was necessary to reduce the sample count rate and the corresponding dead time counting losses experienced by the health physics detector system. A 450 ml volume of the dilute solution was poured into a standard Marinelli beaker, sealed with electrical tape, put into a plastic bag, and counted on the health physics detector system for 20 000 seconds. An analysis was performed on the spectral data and the ^{152}Eu activity in microcuries was obtained from the analysis report. The reported Marinelli beaker activity was divided by 450 ml to determine the specific activity of the standard solution in $\mu\text{Ci/ml}$.

The standardized ^{152}Eu solution was then used to calibrate the flow loop reference geometry of the ATLAS. First, 250 ml of the standardized solution was poured into a 500 ml volumetric flask to dilute the solution and thus decrease the risk of europium contamination in the ATLAS system without drastically decreasing the standard count rate. Approximately 400 ml of the doubly diluted solution was poured into a 500 ml Erlenmeyer flask, and the flask was temporarily incorporated into the ATLAS sampling system as a holding container. The ATLAS program was started on the AIM microcomputer, and the sampling hardware was activated. A main menu selection was invoked to remove approximately 400 ml of ^{152}Eu solution from the holding container, route the solution through the counting loop, and return the liquid to the holding container from which it came. The process was monitored to be certain the flow loop was properly filled.

Upon completion of the sample manipulations, a gamma spectrum was acquired from the standard solution in the flow loop geometry. This gamma spectrum was analyzed using a "dummy" calibration file to determine the channel positions of the salient photopeaks. The centroid channel numbers and the presumed energies of the selected peaks were entered into the calibration utility program, and energy and FWHM calibration functions were determined from the data. All ^{152}Eu gamma ray energies within approximately one FWHM of a ^{154}Eu contaminant gamma ray energy were eliminated from the calibration data to reduce errors from interferences. Also, photopeaks with one sigma counting statistics error greater than 10% were eliminated.

To normalize the detector system efficiency function to specific activity units, the microcurie activity of the solution per 10 ml was entered as the total ^{152}Eu activity in the counting loop. Ten ml was chosen as the lowest convenient normalization volume that would generate absolute efficiency coefficients of less than unity throughout the operational energy range of the system. The calibration utility program used the entered activity per 10 ml to determine the efficiencies of photopeaks in the ATLAS calibration spectrum. Again, peaks suspected of exhibiting interference from the ^{154}Eu contaminant and peaks with greater than 10% one-sigma counting statistics error were eliminated. An efficiency function was then fitted on the remaining data.

To verify the calibration technique, the ^{152}Eu calibration spectrum was analyzed as an "unknown". The specific activity calculated by the analysis sequence was then compared to the

standardized ^{152}Eu specific activity previously entered in the calibration routine.

Analysis of Sequential Samples of OSTR Primary Coolant

As a demonstration of the interactive use of the ATLAS, several OSTR primary cooling water samples were removed from the primary water system and analyzed to determine the variation of the specific activities of activation product contaminants over time. The primary water samples were obtained during a single day of reactor operation at one megawatt steady power. The first sample was removed shortly before reactor startup, and additional samples were removed each hour after startup. Preparation for the sampling procedure involved execution of the ATLAS software, followed by manual set up of the sampling system hardware. A menu option was used to tap 300 ml of cooling water from the primary cooling system and route the sample to the counting loop. Any excess cooling water exiting the counting loop was shunted to the waste container. A six minute sampling time was required to fill the counting loop, and the sampling operation was started three minutes before the completion of each megawatt-hour of reactor operation. The sample end-of-bombardment (EOB) time was noted as coinciding with the number of hours of reactor operation time from startup.

Upon completion of the sampling operation, the gamma spectrum acquisition was started. The acquisition was terminated and the multichannel spectrum was stored early enough to allow the next sampling operation to be initiated on schedule. Each succeeding

coolant sample displaced the volume of the previous sample in the counting loop. The previous sample was then expelled to the waste container. It was assumed that the small diameter (64 mm inner diameter) counting loop tubing would not permit any significant mixing between successive samples. Seven spectra were acquired during the sequential experiment, corresponding to hourly samples from 0 to 6 megawatt-hours operation.

To reproduce the background radiation spectra that occurred during the coolant sampling, gamma spectra were acquired at hourly intervals during a different 6 megawatt-hour reactor operating day to correct for the fraction of the observed count rates due to ambient background gamma radiation in the reactor bay. An ATLAS software menu option was used to pump a dilute hydrochloric acid rinse solution into the counting loop. The uncontaminated rinse solution served as a non-radioactive blank to replicate the absorption characteristics of the coolant samples.

The background spectra were analyzed to determine the nominal background activity observed by the Ge(Li) detector system during the coolant sample spectral analyses. These activities were extracted from the unformatted analysis file and included in several radionuclide gamma ray libraries by means of a peaked background correction program. Each library corresponded to a particular portion of the reactor operating time, and was differentiated from the other libraries solely by the amount of peaked background associated with particular isotopes. For example, a background spectrum was acquired for approximately one hour between 2 MWH and 3

MWH of reactor operation. This spectrum would correspond to the reactor bay background contribution to the coolant sample spectrum acquired between 2 MWH and 3 MWH. The peaked background correction routine then determined the radionuclides responsible for the background peaks and their peaked background count rates. These data were stored in a gamma library named 2MWH.LIB in order to associate that library's particular peaked background data with the time during the reactor operating day that the data were obtained. Therefore, any sample spectrum acquired between 2 MWH and 3 MWH of reactor operation could be background corrected by employing 2MWH.LIB as the gamma ray reference library for the radionuclide analysis. This assumes that the reactor bay ambient background spectra were substantially the same as those occurring on the day the sequential water sample spectra were acquired. Seven background spectra were obtained and seven libraries were prepared from the background data, each spectrum and library corresponding to a coolant sample background correction.

Once the background corrections were determined, the cooling water analyses were done using the appropriate software gamma reference library in each case. A decay correction during spectrum acquisition was specified, and the activities were additionally decay corrected to the EOB time.

Analysis of OSTR Primary Water Using a Long Counting Time

The constraints of the sequential sample experiment precluded the use of long spectrum acquisition time intervals. Health physics

procedures typically require that environmental and reactor water grab samples be counted for periods longer than one hour to determine low-level radionuclide activities. Standard water sample analysis procedure at the Oregon State University Radiation Center involves filling a 450 ml Marinelli beaker with the water sample and acquiring a gamma spectrum with a Ge(Li) detector system. An 11 hour overnight spectrum acquisition is used to increase sensitivity and avoid daytime reactor operation Compton background.

As a test of the capabilities of the ATLAS system for routine OSTR primary water analysis, a primary water sample was removed from the OSTR primary line during a normal operating day. The sample was obtained by calling the coolant tap option from the ATLAS software main menu. This option routed primary water through the flow loop, and routed the excess flow leaving the loop to the waste container. After the flow operation was completed, the ATLAS system was deactivated.

A preset counting time of 40 000 seconds was specified on the MCA system, and the gamma spectrum acquisition was started approximately one hour after reactor shutdown. The sample gamma spectrum was stored to a fixed-disk memory the following morning.

To determine the reactor bay peaked background, a 40 000 second background spectrum was acquired overnight using the rinse solution as a flow loop blank. This spectrum was analyzed using the peaked background correction program, and the resulting data were written to a radionuclide gamma ray reference library NIGHT.LIB. The overnight primary water spectrum was then analyzed using

NIGHT.LIB as the gamma ray library to properly correct the sample spectrum for overnight reactor bay background radiation. An analysis report was printed, listing the background-corrected specific activities of radionuclides in the coolant.

Automated Analysis of OSTR Primary Cooling Water

The full capabilities of the ATLAS system were demonstrated by performing a parallel study of two reactor primary coolant samples obtained using the ATLAS software autoanalysis protocol. The first coolant sample was routed through the counting loop and out to a holding container for independent analysis using a separate counting system. The second sample was the cooling water remaining in the flow loop, which was analyzed under software control by the ATLAS.

The experiment began with a brief spectrum acquisition from the ATLAS Ge(Li) detector system to establish an energy calibration, using reactor background as a radioactivity source. An analysis report was obtained using the old calibration file. The identified peak centroid channel numbers and their known library energies were entered into the calibration utility program, and updated energy and FWHM calibration functions were generated and stored.

The NaI(Tl) detector system was checked using a 31.5 MHz oscilloscope to determine a proper gain setting for the amplifier. Gain was decreased from an overdriven level until no significant clipping of the detector signal was observed. The oscilloscope was disconnected, and the amplifier output was connected to the binary counting chip. The AIM microcomputer was activated so the counting

statistics calculation routine, STATCALC, could be used to measure the one-second accumulated count rates obtained from the counting chip. A sixty hertz pulser was then connected to the amplifier input and counts were accumulated on the chip. One hundred accumulations of one second each were acquired using the STATCALC routine, and the 60 cps pulse rate was verified.

After the gross radioactivity monitor check, the pulser signal was removed from the amplifier, and the counting chip was used to acquire gross gamma counts over several hundred one second counting intervals. STATCALC graphed the count rates on the video display as they were acquired, allowing the operator to see the variation in count rate from second to second. After the specified number of count cycles was completed, the program displayed the number of counts acquired, the mean, standard deviation, maximum count, minimum count, baseline, and a maximum at the 99.73% confidence level. This information was noted and the program was exited.

To prepare the ATLAS software for the autoanalysis, the batch file ANALYZE.BAT was initiated on the multichannel analyzer system IBM PC. The IBM disk operating system was instructed to change its default directory to the reactor monitor directory \RXMONIT, and the analysis batch file was started by entering ANALYZE AUTOPW1 in the command line. This executed the MCBSET program immediately. The preset live time was entered into MCBSET, and the program set the preset acquisition time in the multichannel buffer module. MCBSET then set a communications trap on the IBM PC serial line COM1 to react to the incoming AIM microcomputer signal. MCBSET halted at

this point and did not continue execution until reception of the AIM signal.

Next, the ATLAS program was run on the AIM microcomputer. The autoanalysis option was selected from the main menu and the analysis set-up conversation was initiated. A gross count per second value one standard deviation above the mean, as indicated by STATCALC, was entered as the autoanalysis action threshold. The coolant sample volume was specified such that approximately 500 ml of primary water would exit the counting flow loop. The program was then instructed to route the 500 ml of primary water from the counting loop exit to holding container number 3.

Once the analysis set-up conversation was complete, the system began the autoanalysis procedure. Count rates were acquired each second from the NaI(Tl) detector on the primary water line using the binary counting chip. The count rate was then presented each second on the video display. After several minutes, the gross count rate rose above the selected threshold, and the position of valve 5 was automatically switched to allow coolant to flow into the counting loop. An algorithm in the ATLAS software routed the counting loop exit flow to the waste container for a predetermined time to eliminate any liquid previously present in the counting loop. When the counting loop was filled with flowing primary cooling water, valve 8 was automatically switched to the holding container 3 position and valve 4 was automatically switched to route the counting loop exit flow to the holding containers. At this point, primary water was observed flowing into holding container 3. This

continued until approximately 500 ml was accumulated in the flask. Subsequently, the position of valve 5 was automatically switched to terminate the primary water flow.

Upon completion of the sampling procedure, the AIM microcomputer sent a carriage return and line feed over the 20 mA current loop interface to the MCA system IBM PC. The MCBSET communications trap was activated by this signal, causing the program to turn on the ADC and acquire the coolant sample gamma spectrum. After MCBSET began the count, an MCA utility program, STORE, waited for the spectrum acquisition to finish before proceeding.

During the count of the flow loop sample, holding container 3 was removed from the ATLAS and 450 ml of the collected primary water was poured into a Marinelli beaker. The Marinelli beaker was sealed with electrical tape and placed in a plastic bag to prevent contamination of the secondary Ge(Li) detector system.

When the counting loop sample spectrum had finished, the STORE program recorded the multichannel pulse height distribution on the IBM PC fixed-disk under filename AUTOPW1.CHN. This file was subsequently converted to a spectrum file AUTOPW1.SPC by the conversion file, CONVERT. Next, the batch file sequence analyzed the spectrum file using the AN1 and AN2 programs, and an analysis report containing the identified radionuclide specific activities was generated by the report program, RPT. Finally, the program RXTRAN was executed by the batch file sequence, which returned a control character to the AIM microcomputer using the IBM PC serial

communications port. When the AIM microcomputer received the completion signal from the MCA system, the ATLAS software returned to the main menu. This completed the ATLAS autoanalysis sequence.

To determine if the autoanalysis report data could be replicated, the Marinelli beaker sample of primary water collected during the autoanalysis was analyzed using the OSTR health physics Ge(Li) detector system. The ATLAS Ge(Li) detector system was disconnected from the multichannel buffer, and the OSTR health physics detector system was reconnected. A spectrum was acquired for one hour, and the spectrum was analyzed using an OSTR health physics calibration. A decay correction to sampling time EOB and a decay correction during acquisition were included in the software's spectral analysis parameters to negate the effects of different spectrum acquisition start times. The radionuclide specific activities determined by the health physics detector system, calibration and analysis parameters were compared to the results obtained from the ATLAS autoanalysis sequence.

Software Gamma Spectrum Analysis Parameters

The gamma spectrum analysis software package includes an analysis parameters program GERPAR. This file is used to configure the software gamma ray analysis calculations and ultimate output to the user's particular application. Several options were changed from their default values for the sample analyses. Each primary water sample spectrum EOB time (sample removal time) and date were noted and entered into GERPAR. Decay corrections were enabled to

correct the activity values to the start of acquisition and to the EOB time. The peaked background correction option and the gamma reference library applicable to the sample were also entered into GERPAR. Units were specified as $\mu\text{Ci/ml}$, and a multiplier of 0.1 was specified to normalize the results from activity per 10 ml to activity per ml. An intermediate report was also specified to obtain the maximum information on the spectrum from the unformatted file. The analysis start channel was adjusted to correspond to approximately 122 keV, the beginning of the calibrated energy range. Sensitivity limits were set to suppress identification of any sample radionuclide with a total counting statistics uncertainty greater than 30%.

Background spectra analysis parameters were slightly different. No decay corrections were employed and the peaked background correction was disabled. A multiplier of 3700 was entered to convert the calculated activities from microcuries per 10 ml to becquerels per ml.

Analysis of Sequential Primary Coolant Sample Data

To establish the significance of the activity variation in the sequential primary water samples, a coolant activation equation was used to determine if the observed progression of activity of each radionuclide followed a predictable function.

As a differential volume of cooling water passes through the reactor core, it is exposed to an average thermal neutron flux, ϕ_{av} , over an average in-core residence time, t_r . This will give

rise to radioactivity at the end of irradiation from neutron activation of target atoms in the primary water according to the expression

$$A(tr) = n\sigma\phi_{av}(1 - e^{-\lambda tr}) + A_0e^{-\lambda tr} \quad (1)$$

where A_0 is the specific activity of the cooling water before irradiation, λ is the radionuclide decay constant, and n is the number of target atoms per unit volume of coolant. σ is given by the following expression

$$\sigma = \sigma_0 + \frac{\phi_{epi}}{\phi_0} Ir$$

where σ_0 is the thermal neutron cross section, ϕ_0 is the thermal neutron flux, ϕ_{epi} is the epithermal neutron flux, and Ir is the resonance integral of the target element of interest.

After the coolant leaves the region of significant thermal neutron flux, the radioactivity decays without production. If a small volume of coolant spends a time t_d outside the region of significant flux before returning to the core, the following expression yields the specific activity of the radionuclide prior to reentry into the core.

$$A(tr+t_d) = n\sigma\phi_{av}(1 - e^{-\lambda tr})e^{-\lambda t_d} + A_0e^{-\lambda(tr+t_d)} \quad (2)$$

Equation (2) represents the coolant activity after one primary water cycle through the reactor system.

Let $P = n\sigma\phi_{av}$, the production rate, and let $T = t_r + t_d$, the total time for a volume of coolant to complete one primary water system cycle. After two cycles, the activity is given by

$$A(2T) = P(1 - e^{-\lambda t_r} e^{-\lambda t_d}) + P(1 - e^{-\lambda t_r} e^{-\lambda t_d} e^{-\lambda T} + A_{oe} e^{-\lambda(2T)}) \quad (3)$$

Equation (3) simplifies to

$$A(2T) = P(e^{-\lambda t_d} - e^{-\lambda T})(e^{-\lambda T} + 1) + A_{oe} e^{-\lambda(2T)} \quad (4)$$

After three cycles, the activity is

$$A(3T) = P(e^{-\lambda t_d} - e^{-\lambda T})(e^{-\lambda(2T)} + e^{-\lambda T} + 1) + A_{oe} e^{-\lambda(3T)} \quad (5)$$

After N cycles, the activity is

$$A(NT) = A_{oe} e^{-\lambda(NT)} + P(e^{-\lambda t_d} + e^{-\lambda T}) \sum_{k=0}^{N-1} e^{-\lambda(kT)} \quad (6)$$

which reduces to

$$A(NT) = A_{oe} e^{-\lambda(NT)} + \frac{P(e^{-\lambda t_d} + e^{-\lambda T})(1 - e^{-\lambda(NT)})}{(1 - e^{-\lambda T})} \quad (7)$$

For a given flow rate, only the terms containing N are time dependent. By absorbing the constant terms into a new constant, P_0 , the following expression is obtained:

$$A(NT) = A_{oe} e^{-\lambda(NT)} + P_0(1 - e^{-\lambda(NT)}) \quad (8)$$

Solving for P_0 gives

$$P_0 = \frac{A(NT) - A_{oe} e^{-\lambda(NT)}}{(1 - e^{-\lambda(NT)})} \quad (9)$$

The activity, $A(NT)$, from the sequential coolant samples, and the reactor operating time, NT , were inserted into Equation (9), and the production constant P_0 was determined for each nuclide over the reactor operating day. The variation in P_0 was then used as an indicator of a particular nuclide's divergence from the idealized activation equation.

Error Analysis of Gamma Spectrometry Data

Several sources of uncertainty contribute to the total uncertainty in a gamma spectrometry measurement. The two major types of error are random uncertainties, which change for each measurement, and systematic uncertainties, which are constant for each measurement. An example of random uncertainty is the counting statistics error. An efficiency calibration error is constant for all measurements, so it is a systematic uncertainty. The total

uncertainty of a given measurement is given by the following expression from ANSI50

$$\%U_{1\sigma} = 100\sqrt{(\Sigma_{or}^{**2}) + (\Sigma_{os}^{**2} / 3)}$$

where $\%U$ = % uncertainty at the 1 σ confidence level.

Σ_{or}^{**2} = Sum of the squares of the random uncertainties.

Σ_{os}^{**2} = Sum of the squares of the systematic uncertainties.

The random uncertainty incorporated into the error measurements was the counting statistics error as reported by the analytical software. The reported counting uncertainty incorporates an additional random pulse summation error based on two conditions. The first condition assumes that no pulse pileup rejector was used. The second condition assumes that no other dead time counting loss corrections were calculated. The random summing error is calculated by the software according to the following equation from Zimmer51

$$\text{ors at 68 \% confidence} = \frac{(\text{Integrated count rate of spectrum})}{1500}$$

The random summing error was easily tolerated since the ATLAS measurements were done with relatively low count rate standards and samples.

The major systematic uncertainties were the efficiency calibration error and a liquid volumetric measurement error. The average calibration function uncertainty was derived by the software from the differences between the fitted curve and the measured photopeak data. The calibration uncertainty incorporated the uncertainty of the calibration standard activity, which was specified during the calibration procedure. A 3% true coincidence summing error was incorporated into the error of the Marinelli beaker calibration standard because of ^{60}Co and ^{88}Y cascade gamma rays, and in the error of the ^{152}Eu standard solution, which also emits coincident gamma rays.

The systematic volumetric uncertainty used was derived from the total uncertainty of a 450 ml Marinelli beaker volume when filled by four 100 ml volumes and one 50 ml volume measured with a 100 ml graduated cylinder. Each volume measurement was assumed to have a 1σ error of 1%, based on 1 ml of liquid likely to remain in the container after each measurement, yielding 2.4% total error.

EXPERIMENTAL RESULTS

Calibration of Ge(Li) Detector Systems

Both Ge(Li) detector systems used for this study were calibrated for gamma energy versus channel number, photopeak full-width-at-half-maximum versus gamma energy, and counting efficiency versus gamma energy. A solid matrix mixed gamma ray reference source in a Marinelli beaker geometry was used to calibrate the OSTR health physics Ge(Li) detector system. The specifications of the Marinelli beaker reference source are given in Table 6. A gamma spectrum was acquired from the reference source over a 36 hour time interval, and the spectrum was analyzed using the MCA utility program CLB. The calibration results generated by the CLB routine are presented in Table 7. A plot of the obtained efficiency versus energy function is given in Figure 9.

The Marinelli beaker reference standard calibration was used to ascertain the concentration of ^{152}Eu in the liquid standard. The standard was diluted to 10% of original concentration to reduce the detector dead time losses during the acquisition. A 450 ml volume of the dilute standard solution were poured into a Marinelli beaker and counted on the health physics Ge(Li) detector system. The spectrum was analyzed using the MCA analytical software package. A summary of the photopeak data and radionuclide specific activities in the liquid standard is provided in Table 8.

Table 6. Specifications of the Marinelli beaker gamma reference.

Source Designation: New England Nuclear Marinelli beaker calibrated reference source, Model NES-600, Serial 600061583-0.

Manufacturer's Calibration Date: June 15, 1983; 1200 EST.

Matrix Mass: 513 g.*

Matrix Volume: 450 ± 0.8 ml.

<u>Radionuclide</u>	<u>Half-life</u>	<u>Gamma Energies</u>	<u>Calibrated Intensities</u>
109Cd*	464 d	88.034 keV	703 $\gamma/s \pm 2.3\%$
57Co	270.9 d	122.063 keV	762 $\gamma/s \pm 1.7\%$
139Ce	137.7 d	165.850 keV	900 $\gamma/s \pm 2.3\%$
113Sn	115.0 d	391.688 keV	2909 $\gamma/s \pm 2.6\%$
137Cs	30.0 y	661.660 keV	2774 $\gamma/s \pm 2.0\%$
88Y	106.6 d	898.021 keV	8831 $\gamma/s \pm 2.3\%$
		1836.010 keV	9393 $\gamma/s \pm 2.3\%$
60Co	5.271 y	1173.237 keV	3535 $\gamma/s \pm 1.7\%$
		1332.501 keV	3538 $\gamma/s \pm 1.7\%$

Overall source uncertainty: 2.3%

* The calibration standard solid matrix is approximately 14% denser than water; A more accurate calibration for gamma rays < 100 keV from water samples would include an absorption correction.

Table 7. OSTR health physics Ge(Li) detector calibration data.

$$E_{\gamma} \text{ keV} = 0.758717 + 0.249676(\text{Channel}) + 3.164278\text{E-}9(\text{Channel})^{**2}$$

$$\text{keV FWHM} = 4.00956 + 9.0201\text{E-}4(\text{Channel}) - 6.023153\text{E-}9(\text{Channel})^{**2}$$

True Energy (keV)	Calculated Energy (keV)	Difference (%)	Measured FWHM (keV)	Calculated FWHM (keV)	Difference (%)
88.03	88.09	0.06	1.082	1.080	-0.17
122.06	122.08	0.02	1.085	1.110	2.29
165.85	165.82	-0.02	1.143	1.149	0.57
391.69	391.62	-0.02	1.407	1.350	-4.03
661.66	661.62	-0.01	1.560	1.587	1.68
898.02	898.07	0.01	1.803	1.791	-0.66
1173.24	1173.26	0.00	2.015	2.025	0.51
1332.50	1332.50	0.00	2.149	2.159	0.48
1836.01	1836.00	0.00	2.583	2.575	-0.30

Calculated efficiency function below 120.0 keV:

$$\text{Ln}(\text{Efficiency}) = -11.0584 + 1.62854(\text{Ln}(E \text{ keV}))$$

Calculated efficiency function above 120.0 keV:

$$\text{Ln}(\text{Efficiency}) = -2.62675 + 0.296071(\text{Ln}(E \text{ keV})) - 8.955166\text{E-}2(\text{Ln}(E \text{ keV}))^{**2}$$

Energy (keV)	Measured Efficiency	Calculated Efficiency	Difference (%)
88.0	0.02313643	0.02313865	0.0
122.1	0.03711847	0.03795175	-2.2
391.7	0.01927143	0.01740028	9.7
661.7	0.01069325	0.01131876	-5.8
898.0	0.00841306	0.00861272	-2.4
1173.2	0.00644651	0.00668856	-3.8
1332.5	0.00578826	0.00590328	-2.0
1836.0	0.00450444	0.00425528	5.5

Overall efficiency calibration uncertainty: 6.3%

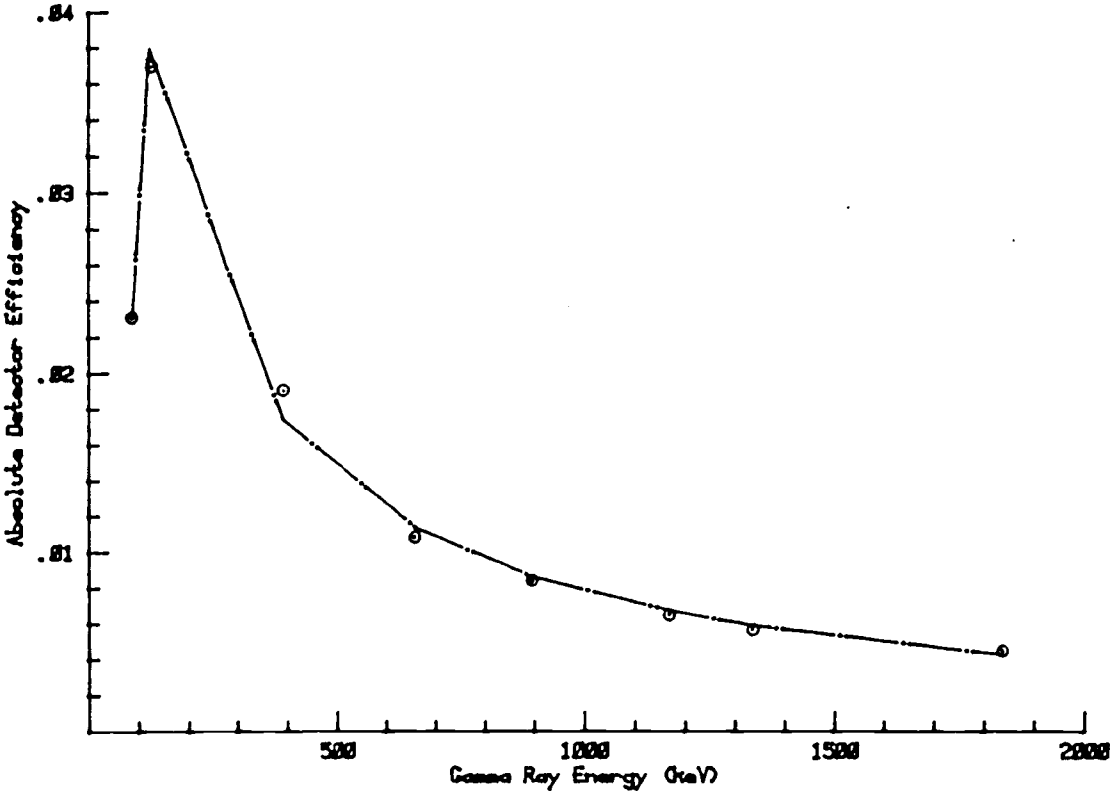


Figure 9. Health physics Ge(Li) detector system counting efficiency coefficient versus gamma ray energy.

Table 8. Summary of ^{152}Eu liquid standard spectral data.

Acquisition Live Time: 20 000 seconds

<u>Radionuclide</u>	<u>Gamma Ray Energy</u>	<u>Net Counts/Second</u>	<u>Counting Uncertainty</u>
^{152}Eu	122.78 keV	125.4	0.1%
	244.70	25.47	0.2
	295.94	1.342	2.1
	329.43	0.4069	6.8
	344.28	71.54	0.1
	367.79	2.457	1.0
	411.11	4.755	0.6
	416.05	0.2412	7.6
	443.98	6.320	0.5
	488.66	0.7399	2.7
	503.39	0.3257	6.6
	564.02	0.8192	3.2
	566.42	0.2787	9.7
	586.29	0.7228	2.9
	656.48	0.2819	8.3
	674.68	0.2488	10.9
	678.58	0.6367	4.2
	688.68	1.194	1.8
	719.35	0.4145	7.7
	778.91	16.33	0.2
964.13	15.66	0.2	
1112.12	13.36	0.2	
1408.01	16.46	0.2	
^{154}Eu	123.14	22.30	0.6
	248.04	2.237	2.9
	591.74	0.7617	2.7
	723.30	2.641	1.1
	873.19	1.343	1.6
	996.32	1.111	1.5
	1004.76	2.536	0.7
	1274.45	3.040	0.5
	1596.48	0.1571	1.9

Specific activities of identified nuclides:

<u>Radionuclide</u>	<u>Microcuries/ml</u>	<u>Counting Uncertainty</u>
^{152}Eu	8.518E-4	0.2%
^{154}Eu	8.296E-5	0.5%

The ^{152}Eu standard solution was diluted a second time to 5% of its original concentration. The standard was pumped into the ATLAS counting flow loop, and a gamma spectrum was acquired over approximately 8.3 hours using the ATLAS Ge(Li) detector system.

The spectrum was analyzed using the CLB calibration program with a specified ^{152}Eu source activity of $0.004259 \pm 3.9\%$ microcuries. This was the microcurie activity present in 10 ml of the liquid standard diluted to 5% of original concentration. The results of the calibration routine are given in Table 9. A plot of the efficiency data is presented in Figure 10.

To doublecheck the system calibration, the original spectrum from the 5% standard solution in the ATLAS flow loop was analyzed using the ATLAS calibration file to determine if the source strength could be verified. The software analysis reported the ^{152}Eu specific activity as $432.2 \text{ pCi/ml} \pm 3.8\%$, which was 1.5% in excess of the 425.9 pCi/ml standardized specific activity, but well within bounds of reasonable uncertainty.

The ATLAS Ge(Li) detector system energy and FWHM functions were recalibrated periodically to compensate for amplifier gain drift and other long-term instabilities. Typically, reactor bay ambient background gamma rays from ^{24}Na , ^{41}Ar and 511 keV annihilation radiation were used to establish an updated calibration. The updated energy and FWHM calibration functions were then merged with the ^{152}Eu standard efficiency calibration function to produce a complete updated calibration file.

Table 9. ATLAS Ge(Li) detector system calibration using the ^{152}Eu standard solution at 5% concentration.

$$E_{\gamma} \text{ keV} = -5.01335 + 0.503224(\text{Channel}) - 2.274562\text{E-}4(\text{Channel})^{**2}$$

$$\text{keV FWHM} = 3.86034 + 1.003540\text{E-}3(\text{Channel}) - 3.049123\text{E-}8(\text{Channel})^{**2}$$

True Energy (keV)	Calculated Energy (keV)	Difference (%)	Measured FWHM (keV)	Calculated FWHM (keV)	Difference (%)
344.28	344.25	-0.01	2.272	2.286	0.61
411.11	411.14	0.01	2.394	2.350	-1.87
778.91	778.97	0.01	2.603	2.692	3.41
964.13	964.10	0.00	2.837	2.858	0.76
1112.12	1112.07	0.00	3.108	2.988	-3.85
1408.01	1408.03	0.00	3.199	3.240	1.26

Calculated efficiency function above 120.0 keV:

$$\text{Ln}(\text{Efficiency}) = -0.208742 + 0.313224(\text{Ln}(E \text{ keV})) - 8.865165\text{E-}2(\text{Ln}(E \text{ keV}))^{**2}$$

Energy (keV)	Measured Efficiency	Calculated Efficiency	Difference (%)
121.8	0.46507600	0.4728384	-1.7
295.9	0.28168900	0.2734058	2.9
344.3	0.26211580	0.2455918	6.3
411.1	0.20081010	0.2154440	-7.3
488.7	0.19464830	0.1886280	3.1
564.0	0.16574690	0.1682457	-1.5
778.9	0.12207790	0.1283440	-5.1
964.1	0.10452900	0.1062366	-1.6
1112.1	0.09520755	0.0931885	2.1
1408.0	0.07598259	0.0744554	2.0

Overall efficiency calibration uncertainty: 6.5%

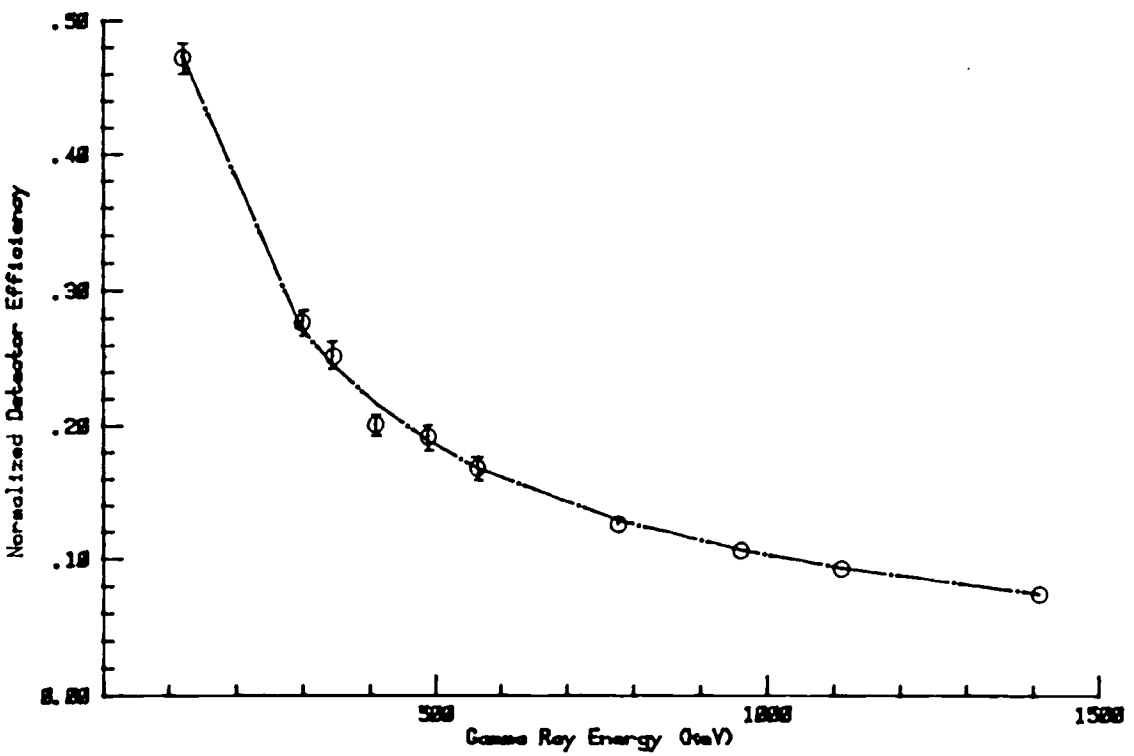
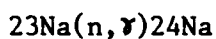
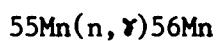
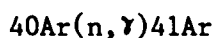


Figure 10. ATLAS Ge(Li) detector system counting efficiency coefficient versus gamma ray energy.

Analysis of Sequential Samples of OSTR Primary Coolant

OSTR primary water samples were obtained hourly during one megawatt power operation using the ATLAS sampling hardware and the interactive software options. The sample spectra were analyzed using the gamma spectroscopy software package, and the specific activities of the radionuclides in the water were presented in the analysis report. A summary of the specific activities reported and their overall uncertainties is given in Table 10.

The radionuclides that consistently appeared in the sequential samples were ^{41}Ar , ^{56}Mn and ^{24}Na . These radionuclides are activation products resulting from the following nuclear reactions:



Since these radionuclides are activation products resulting from neutron bombardment of target nuclei in the water, the variation of activity in the sequential samples should increase during the reactor operating day according to a neutron activation function. The progression of the specific activity versus the reactor operating time is illustrated for each radionuclide in Figures 11, 12 and 13.

An upward progression can be observed in these data, except for one inconsistency in the specific activity of ^{41}Ar . Also, Figures 11 and 12 reveal a tendency toward equilibrium near the end of the reactor operating day for ^{41}Ar and ^{56}Mn .

Table 10. Summary of radionuclide specific activities appearing in sequential samples of OSTR primary cooling water.

Spectra acquired on April 18, 1986

Acquisition live time: 2800 seconds

Megawatt-Hours Operating Time	Specific Activity in pCi/ml		
	⁴¹ Ar	⁵⁶ Mn	²⁴ Na
0.0	*	*	151 ± 3.9%
1.0	729 ± 3.8%	47.8 ± 5.3%	149 ± 3.9%
2.0	1410 ± 3.8%	72.7 ± 4.8%	166 ± 3.9%
3.0	1870 ± 3.8%	88.2 ± 4.6%	184 ± 3.9%
4.0	1630 ± 3.8%	98.3 ± 4.7%	197 ± 3.9%
5.0	1950 ± 3.8%	107 ± 4.4%	218 ± 3.9%
6.0	2030 ± 3.8%	110 ± 4.4%	226 ± 3.9%

* Nuclide was not identified; Counting statistics uncertainty > 30%.

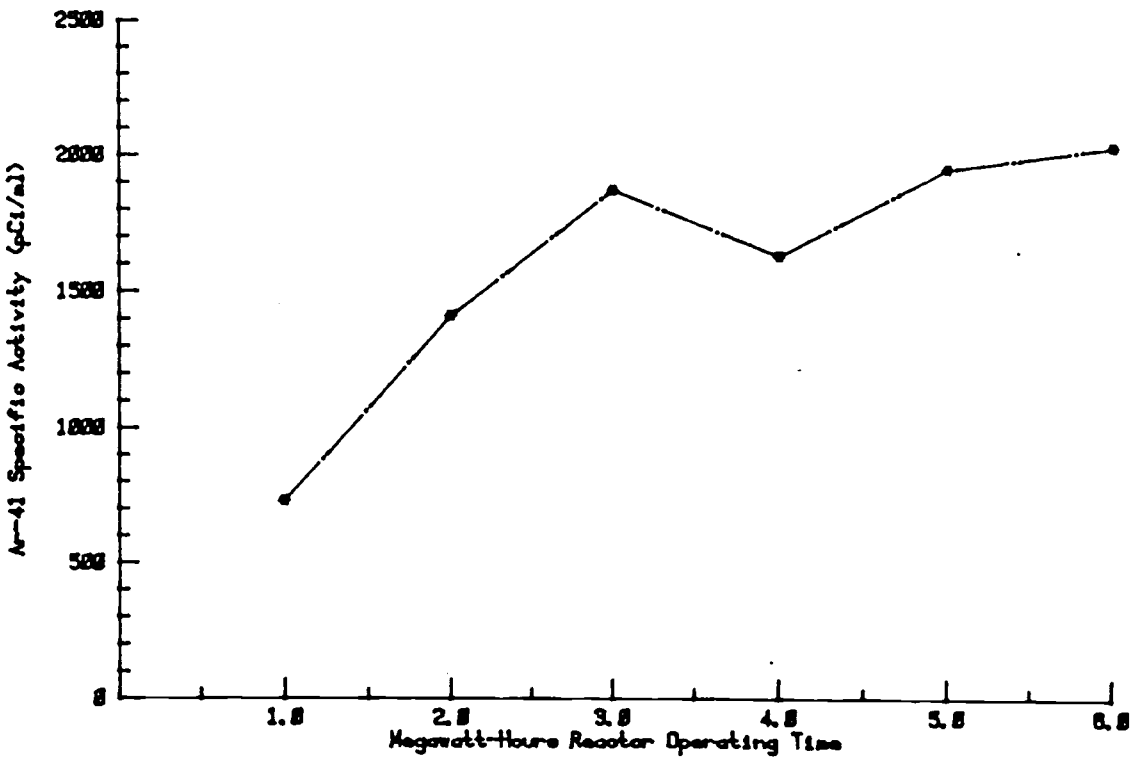


Figure 11. Specific activity of ⁴¹N in OSIR primary water versus reactor operating time.

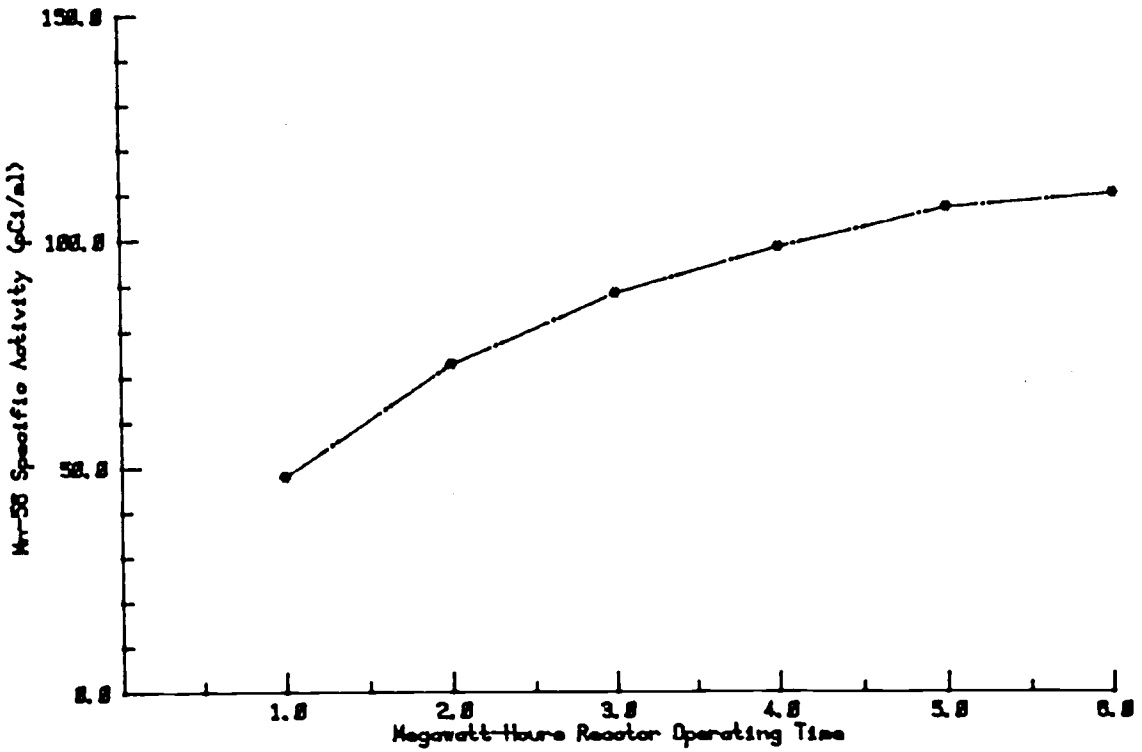


Figure 12. Specific activity of ^{90}Sr in OSTF primary water versus reactor operating time.

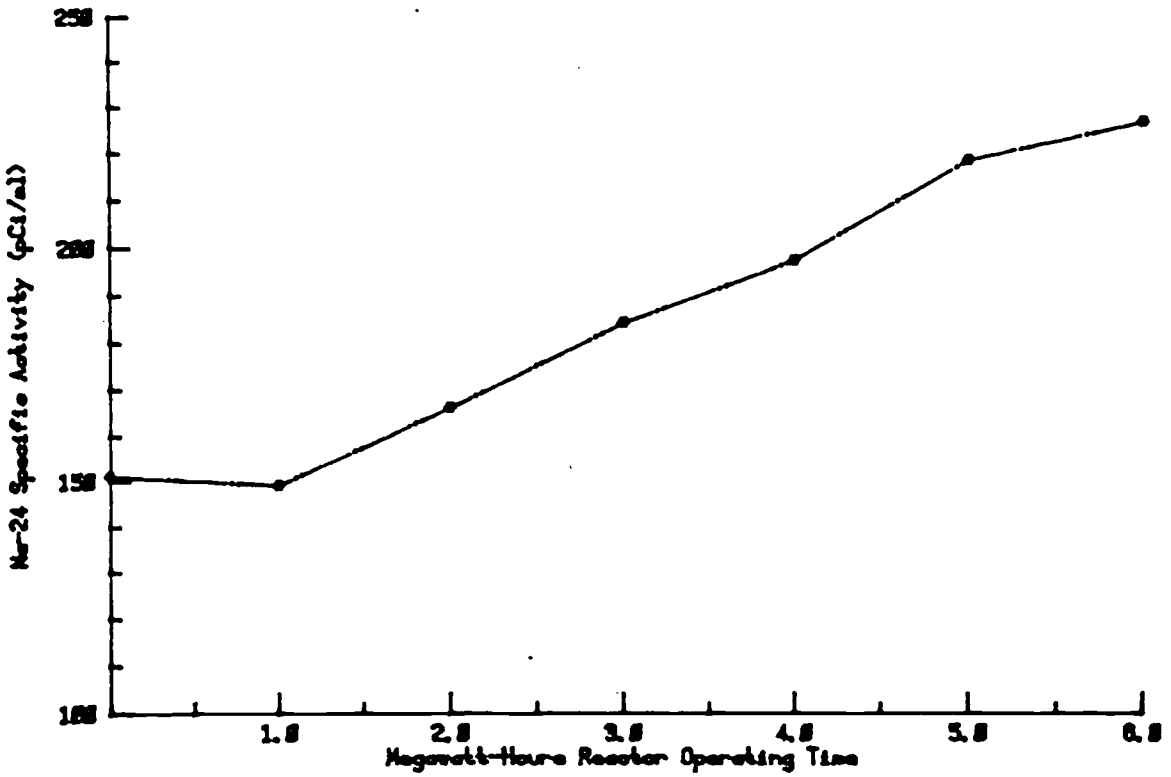


Figure 13. Specific activity of ²⁴Na in OSTR primary water versus reactor operating time.

The primary water data sequence must be tested to determine if the reported activities approximate a neutron activation function. An equation to verify the activity progression was derived in the previous chapter. The production factor, P_o , was determined for each sample by substituting the reported primary water sample activity at 1 MWH for A_o , and referencing to at the time the A_o sample was obtained. However, the sample data obtained at startup were not adequate for this purpose, since the activity data for ^{41}Ar and ^{56}Mn at startup were eliminated by the analytical sensitivity limit setting in the analysis parameters. Also, the 0 MWH datum for ^{24}Na was unapplicable to the mathematics since it was higher than the 1 MWH value. The calculated values of P_o are given in Table 11.

The relatively small variations of the production rates of ^{56}Mn and ^{24}Na indicate that a neutron activation production function is indeed present. The ^{24}Na data are somewhat better, which could be a result of the longer half-life of ^{24}Na , and hence its greater inherent stability. Also, sodium may be more homogeneously distributed in the reactor water than manganese. The ^{41}Ar production rate is variable. This wide variance may be caused by changes in target atom concentration in the primary water due to deaeration, or by a non-homogeneous distribution of ^{41}Ar in the primary system.

Table 11. Production factors of radionuclides in sequential primary water samples.

t	P_o ^{41}Ar	P_o ^{56}Mn	P_o ^{24}Na
1.0 h	2980 pCi/ml	154 pCi/ml	535 pCi/ml
2.0 h	2940	145	544
3.0 h	2080	139	523
4.0 h	2330	165	558
5.0 h	2280	132	527
Mean	2522	147	537
σ	410	13	14
$\sigma\%$	16%	9%	3%

Analysis of OSTR Primary Water Using a Long Counting Time

To assess the ATLAS counting geometry and radiological environment, an experiment was done to determine the radionuclides in a primary water sample counted overnight in the ATLAS counting flow loop. The analysis results are presented in Table 12. By way of comparison, the results of a typical OSTR health physics primary water analysis are also provided in Table 12.

The absence of ^{41}Ar activity in the ATLAS sample is most conspicuous. Analyses were done on the ATLAS sample spectrum with and without peaked background correction to determine if the gamma radiation from ambient ^{41}Ar in the reactor bay was obscuring the activity in the sample. The specific activity of ^{41}Ar was identified to 1.3% counting statistics uncertainty when the peaked background correction was disabled. The reappearance of ^{41}Ar activity indicated that the great majority of overnight ^{41}Ar activity observed by the ATLAS detector system was ambient background, obscuring the relatively small amount of activity remaining in the sample at acquisition time. Conversely, the OSTR health physics primary water analysis was done in a separate counting laboratory that had no appreciable ^{41}Ar background, thereby improving the sensitivity for ^{41}Ar activity.

The sample decay time before acquisition contributed to the loss of sensitivity for ^{41}Ar activity due to background interference. The time between the health physics primary water sample removal and the spectrum acquisition was approximately one half hour. The delay before the flow loop sample spectrum

Table 12. Radionuclides identified in OSTR primary water using long spectrum acquisition times.

OSTR Health Physics Primary Water Analysis

Date of analysis: July 22, 1985
 Sample removal time: 1625 hrs
 Sample volume: 450 ml
 Acquisition starting time: 1700 hrs
 Acquisition live time: 10 000 seconds

<u>Radionuclide</u>	<u>Specific Activity, pCi/ml ± counting uncertainty</u>
56Mn	57.8 ± 0.6%
24Na	176 ± 0.3%
41Ar	306 ± 0.2%

ATLAS Primary Water Analysis

Date of analysis: April 23, 1986.
 Sample removal time: 1200 hrs
 Sample volume: ~300 ml
 Acquisition starting time: 1703 hrs
 Acquisition live time: 40 000 seconds

<u>Radionuclide</u>	<u>Specific Activity, pCi/ml ± counting uncertainty</u>
56Mn	37.2 ± 4.0%
24Na	58.6 ± 0.8%

acquisition was approximately five hours. Although both samples were decay corrected to compensate for differing delays between sample removal time and spectrum acquisition time, the actual ^{41}Ar activity present in the flow loop sample was much smaller because of decay before spectrum acquisition. The smaller amounts of activity in the counting loop were more susceptible to peaked background subtraction regardless of any additional decay corrections in the analysis.

The specific activity data for ^{41}Ar obtained from the sequential primary water samples indicates that the difference in ^{41}Ar concentration in the water at 3 MWH and 6 MWH was not as significant an effect as the decay before acquisition.

Automated Analysis of OSTR Primary Cooling Water

The autoanalysis capability of the ATLAS was demonstrated by executing the autoanalysis software menu option. The parameters were set so that approximately 500 ml of coolant were stored in a holding container in addition to the liquid in the counting loop. The sampling and gamma spectral analysis were accomplished with no operator interaction.

The analytical results from the counting loop autoanalysis were compared with data determined from the gamma spectrum of the 500 ml holding container sample. The holding container primary water was poured into a Marinelli beaker and analyzed using the OSTR health physics Ge(Li) detector system. The radionuclides identified

in both samples and their specific activities are provided in Table 13.

The activities of ^{24}Na and ^{56}Mn reported by the autoanalysis were verified by the OSTR health physics gamma analysis to 31% and 3% percent difference, respectively. However, the activity of ^{41}Ar reported by the autoanalysis was two orders of magnitude higher than the activity reported in the holding container sample. The decrease of activity in the holding container sample is probably caused by the volatilization of ^{41}Ar during the sampling process and during the four hour delay before the spectrum acquisition. The fluid flow to the holding container was allowed to drip to the bottom of the flasks from the terminal end of the flow tubing. This was done so that the liquid could be easily observed flowing into the proper container. However, the small flow rates used in the ATLAS increased the sample surface area-to-volume ratio. This would allow greater quantities of ^{41}Ar to escape from the primary water to the ambient atmosphere during sampling. In contrast, the ATLAS sampling loop was a sealed system which retained far more ^{41}Ar specific activity than the holding container. It is credible to suggest that other standard grab sampling procedures used to obtain OSTR primary water for analysis cause a significant volatilization of gaseous contaminants in the sample prior to analysis.

Table 13. Radionuclides identified in an ATLAS autoanalysis flow loop sample and a holding container sample.

Samples obtained at 2 MWH, May 9, 1986.

ATLAS autoanalysis sample data

Spectrum acquired using ATLAS Ge(Li) detector system.

Acquisition start time: 1103 hrs Live time: 2400 seconds

<u>Radionuclide</u>	<u>Specific Activity, pCi/ml ± total uncertainty</u>
41Ar	1510 ± 3.8%
56Mn	51.1 ± 5.2%
24Na	59.4 ± 4.3%

Holding container sample data

Spectrum acquired using OSTR health physics Ge(Li) detector system.

Acquisition start time: 1513 hrs Live time: 2400 seconds

<u>Radionuclide</u>	<u>Specific Activity, pCi/ml ± total uncertainty</u>
41Ar	40.2 ± 3.3%
56Mn	49.7 ± 2.9%
24Na	81.0 ± 2.7%

CONCLUSIONS

Several characteristics of the ATLAS were demonstrated by the gamma spectrometric analysis of OSTR primary water. This chapter describes the advantages and disadvantages of the ATLAS as an analytical instrument generally, and as a reactor primary water monitor in particular.

The ATLAS is very "user-friendly", since the software prompts for all information needed to configure the system to a user's particular application. These prompts also include software messages to assist the operator in activating and deactivating the system hardware. These features make the ATLAS more attractive to potential users who are not familiar with the system.

Although the ATLAS design emphasizes research reactor primary cooling water monitoring, it can be used to analyze other radioactive liquids. However, the gamma ray peaked background and the Compton continuum in the OSTR reactor bay reduces the analytical sensitivity of the apparatus for samples containing very low-level activity. It is impractical to use the ATLAS for the determination of radionuclide specific activities of less than 10 pCi/ml without increasing peak-to-background ratios. The use of ion exchange resin preconcentration to increase the sensitivity of an analytical system of this type is detailed by Bennett⁴⁷. A small ion-exchange column

could be integrated into the sampling system without sacrificing any automated capabilities. However, an accurate quantitative analysis is made difficult by the differing column retention times and differing resin adsorption characteristics of radionuclides in various ionic states. Bennett also describes how additional pump and valve hardware may be interfaced to the AIM microcomputer to incorporate ion-exchange columns and other components into the sampling system.

The use of the ATLAS for the study of reactor primary water specific activity over time demonstrated the versatility of the apparatus in the interactive mode. A reproducible sampling and analysis procedure can be executed using the ATLAS menu options, thus avoiding any variations caused by inconsistent sampling technique. The automated capability allowed the system to produce analytical results for non-volatile activation products that were consistent with an idealized activation equation.

The observed decrease in the ^{41}Ar production factor over time could be caused by a variety of conditions. The first two ^{41}Ar production data are very close to one another, but a significant decrease is observed thereafter, which could indicate a sharp decrease in dissolved air in the pool water after three megawatt-hours. Another explanation could involve a non-homogeneous distribution of ^{41}Ar in the primary water. This hypothesis gains credibility when one considers that the on-line gross gamma ray count rate acquired with the NaI(Tl) detector varied by an order of magnitude during normal operation. Since ^{41}Ar possesses the highest

specific activity of any gamma emitter in the primary water, it is the likely cause of the gross activity variation. The non-homogeneity could have increased the ^{41}Ar concentrations in the samples obtained at 1 MWH and 2 MWH, thus grossly increasing the calculated production factor.

The ATLAS is best used as a continuous on-line primary water monitor in its present software/hardware configuration. The system is capable of analyses that are in some ways superior to those done using manual grab sampling techniques. The primary advantages of the ATLAS for primary water monitoring are the promptness of analysis, reproducibility of sampling technique, and containment of volatile contaminants before and during the assay. The loss of system sensitivity due to high reactor bay ambient background radiation levels is the major weakness of the ATLAS. However, this does not preclude the use of the ATLAS for preliminary primary water surveys to determine volatile and short-lived contaminants, followed by grab sample analysis to determine non-volatile contaminants in low concentrations.

Crud contamination of sampling lines and let-down lines is a frequent concern in the design of primary water monitoring systems at power reactors. This problem is of less concern in a research reactor facility. The normal activation product contaminants observed in research reactor primary water are short-lived, and are present in low concentrations. In any case, the ATLAS incorporates a dilute hydrochloric acid rinse solution to remove any long-lived radionuclides following an analysis. This rinse solution was used

to successfully remove all of the ^{152}Eu liquid standard activity from the counting loop after the system efficiency calibration. This solution was also used to clean the counting loop after each experiment. If long-lived contamination persists after thorough rinsing, the contaminated sample loop may be disposed of, and a new loop may be constructed and calibrated.

The reliable operation of the ATLAS for primary water monitoring depends largely on the detection of the gross gamma radiation from contaminants of concern in the primary water. If relatively innocuous activation product gross gamma radiation obscures the gross gamma radiation emitted by abnormal fission and activation products, the sampling and analysis will not be initiated.

Several techniques could be used to assure adequate on-line monitoring sensitivity. First, pulse height discrimination could be applied to the NaI(Tl) detector signal to eliminate counts below a selected gamma ray energy, thus decreasing the background count rate contribution from selected contaminants that are normally expected to be present. Alternatively, a single channel analyzer could be used to allow a small range of pulse heights to pass to the binary counter. The energy window selected could be adjusted to correspond to a fission or activation product gamma energy of interest. A third alternative could involve the use of a different type of monitoring instrument. For example, a conductivity cell could be connected to an AIM microcomputer versatile interface adapter using a simple analog-to-digital converter to pass the signal voltage to

the AIM VIA. This would provide a very sensitive indicator of an abnormal contaminant in the primary water. The OSTR continuous air monitor could also be interfaced to the ATLAS software in this way. Given the additional versatile interface adapters provided on the AIM microcomputer, the NaI(Tl) detector measurements could be performed concurrently with other on-line measurements to assure highly sensitive on-line primary water monitoring data.

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APPENDICES

Appendix A

ATLAS.BAS Listing

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REM      FILE ATLAS.BAS : AUTOMATED LIQUID ANALYSIS SYSTEM
REM
REM      THIS PROGRAM OPERATES AUTOMATED LIQUID FLOW HARDWARE
REM      AND RADIATION DETECTION INSTRUMENTATION TO PERFORM
REM      RADIOACTIVITY ANALYSES ON LIQUID SAMPLES.
REM
20 REMARK VIDEO INITIALIZATION
    N$=CHR$(78)      :REM NO
    Y$=CHR$(89)      :REM YES
    H0$=CHR$(8)      :REM HOME
    CL$=CHR$(3)      :REM CLEAR
    CB$=CHR$(2)      :REM CURSOR LEFT
    CU$=CHR$(21)     :REM CURSOR UP
    CD$=CHR$(4)      :REM CURSOR DOWN
    BS$=CHR$(127)    :REM CURSOR BACK
    RV$=CHR$(18)     :REM REVERSE VIDEO
    GM$=CHR$(7)      :REM GRAPHICS MODE
    AL$=CHR$(1)      :REM ALPHA MODE
    CF$=CHR$(30)     :REM CHANGE FORMAT
30 REMARK SET BAUD RATE FOR SERIAL COMM WITH LSI
    POKE 42007,13
    POKE 42007,183
35 REM INITIALIZE ARRAYS
    DIM VALVA(8),VALVB(4),STATEA(8),STATEB(10),PUMP(10)
    DIM PUMPSTATE(3),COUNTS(200),XSECT(20)
    DIM MASS(15),FRAC(15),LIFE(15),GAW(15),CROSS(15)
    DIM DIS(15),CURIE(15),ATOMS(15)
    DIM HOLD(6)
40 REM INITIALIZING DELAY VARIABLES AND HOLD-UPS.
    H=3
    M=2
    S=1
    ANHOLD=1
    HOLDUP=1
    PRINT CL$
PRINT *          AUTOMATED LIQUID ANALYSIS SYSTEM*
PRINT CD$;CD$
PRINT *          BY W. K. TENBROOK*
PRINT *          1986*
PRINT CD$;CD$
    PRINT CD$;CD$
PRINT *          LOADING SYSTEM OPERATION ROUTINES*
PRINT *          INTO RANDOM ACCESS MEMORY.*
PRINT CD$
PRINT *          PLEASE WAIT.....*
    PRINT CD$;CD$;CD$;CD$
    DIM HEX(70)
    FOR X=0 TO 15
        READ I
        HEX(I)=X
    NEXT X
    DATA 48,49,50,51,52,53,54,55,56,57,65,66,67,68,69,70
    A$="PASSASSE.KIM"
    FILE AS
    IF END #1 THEN 80
60    READ #1;RECS
    INDX=2
    GOSUB 70
    LENGTH=BYTE
    GOSUB 70
    ADDR=BYTE*256
    GOSUB 70
    ADDR=ADDR+BYTE
    FOR K=ADDR TO ADDR+LENGTH-1
        GOSUB 70
        POKE K, BYTE
    NEXT K
    GOTO 60
70 REM READ DATA CODE
    BYTE=HEX(ASC(MID$(RECS,INDX,1)))*16
    BYTE=HEX(ASC(MID$(RECS,INDX+1,1)))+BYTE
    INDX=INDX+2
    RETURN
80 REM END OF DATA INPUT
    CLOSE 1
90 REM SETTING UP REGISTERS AND DATA PORTS
    SETUP=53298      :rem D032 hex
    X=CALL(SETUP)    :rem initializing res
    PORRS=53400      :rem D098 hex
    X=CALL(PORRS)    :rem direction ports
97    PRINT CL$

```

```

PRINT 'AIM MICROCOMPUTER INITIALIZED AND READY.'
PRINT CD$;CD$
PRINT 'SAMPLING SYSTEM SET-UP CHORES:'
PRINT CD$
PRINT '1) TURN ON VALVE AND PUMP A.C. POWER.'
PRINT '2) APPLY 40 PSI AIR PRESSURE TO VALVES.'
PRINT '3) OPEN FLOW METER TAP VALVE ON PRIMARY WATER PIPE.'
PRINT '4) SET MCA SYSTEM TO INTERACT WITH AIM MICROCOMPUTER.'
PRINT CD$;CD$;CD$
INPUT 'IS THE SYSTEM SET UP?';YNS
IF YNS=N$ THEN GOTO 97

PRINT CL$
95 REM MAIN MENU
PRINT CD$;CD$
GOSUB 1000
PRINT 'MENU'
PRINT CD$
PRINT '1) TAP COOLANT SAMPLE LINE.'
PRINT '2) TAP A HOLD-UP CONTAINER.'
PRINT '5) ACQUIRE SAMPLE GAMMA SPECTRUM.'
PRINT '6) PRIMARY COOLANT AUTOANALYSIS.'
PRINT '7) EXIT THE PROGRAM.'
GOSUB 1000
PRINT CD$;CD$
INPUT 'WHICH OPTION?';MENU
PRINT CD$
IF MENU < 4 THEN GOTO 300
IF MENU=4 THEN GOSUB 105
IF MENU=5 THEN GOSUB 225
IF MENU=6 THEN GOTO 98
IF MENU=7 THEN GOSUB 9950
IF MENU=7 THEN GOTO 9970
GOTO 95
105 GOSUB 1500
PRINT CD$
GOSUB 1000
PRINT 'GROSS COUNT RATE: ;TOTALCTS; CPS.'
RETURN
98 PRINT CL$
INPUT 'WHAT ACTION THRESHOLD DO YOU WANT?';SETLIMIT
PRINT CD$;CD$;CD$
FUDD=S
PRINT 'HOW MANY SECONDS DO YOU WANT TO DELAY BETWEEN'
INPUT 'SAMPLING AND SPECTRUM AQUISITION?';COMPDELAY
PRINT CD$;CD$;CD$
INPUT 'WHAT GLITCH REJECTION LEVEL?';GLITCHLIMIT
PRINT CD$;CD$;CD$
PRINT 'NOTE:'
PRINT 'YOU MUST SPECIFY AT LEAST 100 ML SAMPLE VOLUME'
PRINT 'IF YOU WISH TO FILL THE REFERENCE GEOMETRY LOOP.'
PRINT CD$
INPUT 'WHAT SAMPLE VOLUME (NOMINAL ML) DO YOU WANT?';VOL
PRINT CD$;CD$;CD$
INPUT 'ROUTE EXCESS FLOW TO (1) WASTE, OR (2) HOLD-UP?';ROUTE
PRINT CD$;CD$;CD$
IF ROUTE=1 THEN GOTO 99
INPUT 'ROUTE FLOW TO HOLD-UP ?';HOLDUP
99 PRINT CD$;CD$;CD$
INPUT 'ANY CHANGES (Y/N)';YNS
IF YNS=Y$ THEN GOTO 98
PRINT CL$
PRINT CD$
PRINT 'PROCEEDING WITH PRIMARY COOLANT MONITORING.'
PRINT CD$;CD$;CD$;CD$
GOSUB 1000
GOSUB 1500
101 REM CHECK IF TOTALCTS IS CHIP GLITCH
IF TOTALCTS > GLITCHLIMIT THEN GOTO 101
110 IF TOTALCTS > SETLIMIT THEN GOTO 190
PRINT CL$
PRINT ' *****'
PRINT ' *'
PRINT ' * OSTR AUTOMATED COOLANT ANALYSIS SYSTEM *'
PRINT ' *'
PRINT ' *****'
PRINT CD$;CD$;CD$;CD$
PRINT ' ON-LINE GROSS GAMMA COUNT RATE'
PRINT ' IN DESIGNATED NOMINAL RANGE.'
GOSUB 1000
PRINT CD$
115 GOSUB 1500
REM CHECK IF TOTALCTS IS A CHIP GLITCH
IF TOTALCTS > GLITCHLIMIT THEN GOTO 115

```

```

120     IF TOTALCTS > SETLIMIT THEN GOTO 190
PRINT CU$; '      ***;TAB(24);TOTALCTS;CPS;TAB(48);***'
      GOTO 115
190  REM STARTING ANALYSIS ROUTINE
REM   SET UP FLOW EQUIPMENT TO TAP PRIMARY WATER
REM   # OF THREE WAY VALVES TO CHANGE
      VALVTHREE=2
REM   CHANGE V5 TO SAMPLE TAP
      VALVA(1)=5
      STATEA(1)=1
194  REM SET V4 TO WASTE
      VALVA(2)=4
      STATEA(2)=0
      VALVSIX=0
REM   SUBROUTINE TO EXECUTE VALVE CHANGES
      GOSUB 8040
      GOSUB 1000
PRINT CL$
PRINT 'GROSS COUNT RATE ON PRIMARY PIPE: ;TOTALCTS;CPS.'
PRINT 'EXCEEDS ;SETLIMIT;CPS ACTION POINT.'
PRINT CD$;CD$
      PRINT 'FLOW SYSTEM IS TAPPING COOLANT SAMPLE.'
      PRINT CD$;CD$;CD$
      GOSUB 1000
IF ROUTE=1 THEN GOTO 202
DDDT=120/(.2453*1.11)
FUDD=S
GOSUB 200
REM   SET HOLD UP
      VALVSIX=2
      VALVB(1)=8
      STATED(1)=4
      VALVB(2)=9
      STATED(2)=HOLDUP
REM   SET V4 TO HOLDUP
      VALVTHREE=1
REM   EXECUTE CHANGES
      GOSUB 8040
202  REM SET VALUES FOR TAP FLOW TIME
      DDDT=VOL/(.2453*1.11)
      FUDD=S
REM   START DELAY
      GOSUB 200
GOTO 218
200  REM SUBROUTINE TO EXECUTE DELAY
IF FUDD=3 THEN DDDE=DDDT*3600
IF FUDD=2 THEN DDDE=DDDT*60
IF FUDD=1 THEN DDDE=DDDT
VTI=1
IF DDDE < 256 THEN GOTO 216
212  DDDE=DDDE-255
POKE 53820,255
POKE 53846,VTI
X=CALL(53819)
IF DDDE > 255 THEN GOTO 212
216  POKE 53820,DDDE
      POKE 53846,VTI
      X=CALL(53819)
RETURN
218     GOSUB 1000
REM   SETTING V5 BACK TO POS. 0 TO STOP SAMPLE TAP
      VALVSIX=0
      VALVTHREE=1
      VALVA(1)=5
      STATEA(1)=0
REM   EXECUTE VALVE CHANGE
      GOSUB 8040
PRINT CL$
      PRINT 'PRIMARY WATER SAMPLE COLLECTED.'
PRINT CD$
IF COMPDELAY=0 THEN GOTO 221
PRINT 'STARTING ;COMPDELAY;SECOND DELAY BEFORE ANALYSIS.'
PRINT CD$;CD$;CD$;CD$
      DDDT=COMPDELAY
      FUDD=S
      GOSUB 200
      PRINT CL$
      GOSUB 1000
      PRINT 'DELAY COMPLETE.'
      PRINT CD$;CD$
221  REM REENTER JOBSTREAM W/OUT DELAY
      PRINT 'PROCEEDING WITH GAMMA ANALYSIS OF SAMPLE'
      PRINT 'IN REFERENCE GEOMETRY.'

```

```

REM GO TO COUNTING SUBROUTINE
GOSUB 225
GOTO 230
225 REM SUBROUTINE TO INTERACT WITH MCA TO ACQUIRE SPECTRUM.
POKE 53846,1
PRINT CD$
PRINT 'SENDING START CHARACTER TO MCA SYSTEM.'
TTYOUT=53896
X=CALL(TTYOUT)
PRINT CD$;CD$
GOSUB 1000
PRINT 'ACQUIRING GAMMA SPECTRUM.'
REM GET CHARACTER WHEN COUNT SEQUENCE COMPLETE
GETTY=53889
X=CALL(GETTY)
RETURN
230 PRINT CD$
PRINT CL$
REM REENTERING SEQUENCE AFTER COUNT ROUTINE
GOSUB 1000
PRINT 'MCA ACQUISITION OF PRIMARY WATER SAMPLE'
PRINT 'GAMMA RAY SPECTRUM COMPLETED.'
GOTO 95
300 REM INTERACTIVE MENU QUERIES AND SETTINGS
IF MENU=1 THEN GOTO 400
IF MENU=3 THEN GOTO 400
305 INPUT 'WHICH HOLD-UP DO YOU WANT TO TAP';ANHOLD
400 INPUT 'HOW MANY ML';HL
PRINT CD$
PRINT 'SHUNT EXCESS FLOW TO:'
PRINT '1) WASTE'
PRINT '2) HOLD-UP'
PRINT CD$
INPUT 'SHUNT TO';SHUNT
IF SHUNT=1 THEN GOTO 408
INPUT 'ROUTE FLOW TO HOLD-UP ( )';HOLDUP
408 REM # OF VALVES TO CHANGE
VALUETHREE=2
VALUSIX=2
IF MENU=1 THEN GOTO 410
IF MENU=2 THEN GOTO 420
REM MENU=3: TAP DISTILLED WATER
VALVA(1)=5
STATEA(1)=0
VALVA(2)=4
IF SHUNT=1 THEN STATEA(2)=0 ELSE STATEA(2)=1
VALVB(1)=8
STATEB(1)=6
VALVB(2)=9
STATEB(2)=HOLDUP
GOTO 450
410 REM TAP SAMPLE LINE
VALVA(1)=5
IF SHUNT=1 THEN STATEA(2)=0 ELSE STATEA(2)=1
VALVB(1)=8
STATEB(1)=ANHOLD
VALVB(2)=9
STATEB(2)=HOLDUP
GOTO 450
420 REM TAP HOLD-UP
VALVA(1)=5
STATEA(1)=0
VALVA(2)=4
IF SHUNT=1 THEN STATEA(2)=0 ELSE STATEA(2)=1
VALVB(1)=9
STATEB(1)=HOLDUP
VALVB(2)=8
STATEB(2)=ANHOLD
450 REM CHANGE VALUES
GOSUB 8040
REM SET DELAY FOR FLOW OPERATION
DDDT=HL/(.2453*1.11)
FUDD=S
PRINT CL$
GOTO 470
460 REM SUBROUTINE SET P-1 AND START
PUM=1
PUMP(1)=1
PUMPSTATE(1)=1
GOSUB 8210
RETURN
470 REM OPERATOR INFO.

```

```

IF MENU=1 THEN PRINT "TAPPING SAMPLE LINE."
IF MENU=2 THEN PRINT "TAPPING HOLD-UP " ;ANHOLD
IF MENU=3 THEN PRINT "TAPPING DISTILLED WATER CONTAINER."
IF SHUNT=1 THEN PRINT "ROUTING FLOW TO WASTE."
IF SHUNT=2 THEN PRINT "ROUTING FLOW TO HOLD-UP " ;HOLDUP
  GOSUB 1000
  PRINT CD$;CD$;CD$;CD$;CD$
IF MENU > 1 THEN GOSUB 460
  GOSUB 200
IF MENU=1 THEN GOTO 490
PRINT CL$
GOSUB 9000
GOTO 500
490 REM ROUTINE TO RESET V5 TO POSITION 0
VALVTHREE=1
VALVSIX=0
VALVA(1)=5
STATEA(1)=0
REM EXECUTE CHANGE
GOSUB 8040
PRINT CL$
500 PRINT CD$
PRINT "FLOW OPERATION COMPLETED."
PRINT CD$;CD$
GOTO 95
505 RETURN
1000 REM SINGLE BEEP
  BEEP=54363 :rea d45b hex
  X=CALL(BEEP)
  RETURN
1500 REM READING THE UPCOUNTER
  TOTALCTS=0
  COUNT=54208 :rea d3c0 hex
  X=CALL(COUNT)
  NIBBLE=53262 :rea d00e hex
  MONITOR=0
  FOR K=1 TO 4
    RED=PEEK(NIBBLE)
    FAKE=RED*255*MONITOR
    MONITOR=MONITOR+1
    NIBBLE=NIBBLE+1
    TOTALCTS=FAKE+TOTALCTS
  NEXT K
  RETURN
8040 REM SUBROUTINE TO OPERATE VALUES
  IF VALVTHREE=0 THEN GOTO 8170
  FOR K=1 TO VALVTHREE
    IF VALVA(K)<>1 THEN GOTO 8050
    VALUE31=1
    IF STATEA(K)<>1 THEN GOTO 8060
    STATE31=1
    REGV1=2 :rea load value bit 2 a001
    GOTO 8100
8060 STATE31=0
    REGV1=0 :rea load value
    GOTO 8100
8050 IF VALVA(K)<>2 THEN GOTO 8065
    VALUE32=1
    IF STATEA(K)<>1 THEN GOTO 8070
    STATE32=1
    REGV2=4 :rea load value bit 2 a001
    GOTO 8100
8070 STATE32=0
    REGV2=0
    GOTO 8100
8065 IF VALVA(K)<>3 THEN GOTO 8080
    VALUE33=1
    IF STATEA(K)<>1 THEN GOTO 8075
    STATE33=1
    REGV3=8 :rea bit 3 a000
    GOTO 8100
8080 IF VALVA(K)<>4 THEN GOTO 8090
    VALUE34=1
    IF STATEA(K)<>1 THEN GOTO 8085
    STATE34=1
    REGV4=16 :rea bit 4 a000
    GOTO 8100
8085 STATE34=0
    REGV4=0
    GOTO 8100
8090 IF VALVA(K)<>5 THEN GOTO 8150
    VALUE35=1

```

```

      IF STATEA(K)<>1 THEN GOTO 8155
      STATE35=1
      REGV5=32           :rem bit 5 aooo
      GOTO 8100
8155  STATE35=0
      REGV5=0
      GOTO 8100
8150  IF VALVA(K)<>6 THEN GOTO 8160
      STATE36=1
      IF STATEA(K)<>1 THEN GOTO 8165
      STATE36=1
      REGV6=64
      GOTO 8100
8165  STATE36=0
      REGV6=0
      GOTO 8100
8160  PRINT 'THIS IS NOT A THREE WAY VALVE DESTINATION'
8100  NEXT K
      REGA1=REGV1+REGV2+REGV3+REGV4+REGV5+REGV6
      MONPUMPO=REGPUMP1+REGPUMP2
      MONPUMP1=REGPUMP3
      REGA1=MONPUMPO+REGA1   :rem current pump&valve stats
8170  REM DEALING WITH THE SIX WAY VALVES
      VBC7=0:VBC8=0:VBC9=0
      IF VALVSIX=0 THEN GOTO 8195
      FOR K=1 TO VALVSIX
        IF VALVB(K)<>7 THEN GOTO 8172
        VBB7=1
        VBC7=VBB7
        IF STATEB(K)=1 THEN POS67=1
        IF STATEB(K)=2 THEN POS67=2
        IF STATEB(K)=3 THEN POS67=3
        IF STATEB(K)=4 THEN POS67=4
        IF STATEB(K)=5 THEN POS67=5
        IF STATEB(K)=6 THEN POS67=6
      IF STATEB(K)<1 OR STATEB(K)>6 THEN GOTO 8185
      GOTO 8183
8172  VBB7=0
      IF VALVB(K)<>8 THEN GOTO 8174
      VBB8=1
      VBC8=VBB8
      IF STATEB(K)=1 THEN POS68=1
      IF STATEB(K)=2 THEN POS68=2
      IF STATEB(K)=3 THEN POS68=3
      IF STATEB(K)=4 THEN POS68=4
      IF STATEB(K)=5 THEN POS68=5
      IF STATEB(K)=6 THEN POS68=6
      IF STATEB(K)<1 OR STATEB(K)>6 THEN GOTO 8185
      GOTO 8183
8174  VBB8=0
      IF VALVB(K)<>9 THEN GOTO 8186
      VBB9=1
      VBC9=VBB9
      IF STATEB(K)=1 THEN POS69=1
      IF STATEB(K)=2 THEN POS69=2
      IF STATEB(K)=3 THEN POS69=3
      IF STATEB(K)=4 THEN POS69=4
      IF STATEB(K)=5 THEN POS69=5
      IF STATEB(K)=6 THEN POS69=6
      IF STATEB(K)<1 OR STATEB(K)>6 THEN GOTO 8185
8183  NEXT K
      IF K=VALVSIX AND VALVB(VALVSIX)<>9 THEN VBB9=0
      GOTO 8195
8185  PRINT 'ENTERED STATE NOT ALLOWED'
      GOTO 8040
8186  PRINT 'ENTERED 6-WAY VALVE NO. NOT ALLOWED'
      VBB9=0
      GOTO 8040
8195  REM ENGAGING THE VALVES
      POKE 40961,REGA1       :rem a001
      POKE 40960,MONPUMP1:rem current p-3 status
      IF VALVSIX=0 THEN GOTO 505
      IF VBC7=0 THEN GOTO 8196
      VPOS17=54752          :rem d5e0 hex
      MUNN7=PEEK(53251)     :rem d003 vstor7
      IF MUNN7=POS67 THEN GOTO 8196
      IF MUNN7=0 THEN GOTO 9903
      IF POS67<MUNN7 THEN GOTO 9902
      TOG07=POS67-MUNN7     :rem desired - actual
      GOTO 9904
9902  REM SENDING VALVE 7 HOME FIRST
      HOMIE7=53949         :rem home7 d2bd hex

```

```

X=CALL(HOMIE7) :rem send it home
DDELAY=53910 :rem d296 hex dtime
X=CALL(DDELAY)
9903 TOGO7=POS67
9904 FOR K=1 TO TOGO7
X=CALL(VPOSI7)
MUNN8=PEEK(53254) :rem d006 hex vstor8
IF MUNN8=0 THEN GOTO 9907
IF MUNN8=POS68 THEN GOTO 8197
IF POS68<MUNN8 THEN GOTO 9906
TOGO8=POS68-MUNN8
GOTO 9908
9906 REM SENDING VALVE 8 HOME
HOMIE8=53980 :rem d2dc hex
X=CALL(HOMIE8)
DEELAY=53910 :rem d296 hex
X=CALL(DEELAY)
9907 TOGO8=POS68
9908 FOR K=1 TO TOGO8
X=CALL(VPOSI8)
NEXT K
8197 IF VBC9=0 THEN GOTO 505
POSI9=54786 :rem d602 hex
MUNN9=PEEK(53257) :rem d009 hex vstor9
IF MUNN9=0 THEN GOTO 9911
IF MUNN9=POS69 THEN GOTO 505
IF POS69<MUNN9 THEN GOTO 9910
TOGO9=POS69-MUNN9 :rem desired - actual
GOTO 9912
9910 REM SENDING VALVE 9 HOME
HOMIE9=54011 :rem home9 d2fb hex
X=CALL(HOMIE9)
DEEELAY=53910 :rem d296 hex
X=CALL(DEEELAY)
9911 TOGO9=POS69
9912 FOR K=1 TO TOGO9
X=CALL(POSI9)
NEXT K
GOTO 505
8210 REM FIG OUT PUMP SETTINGS
FOR K=1 TO PUM
IF PUMP(K)<>1 THEN GOTO 8230
PUMP1=1
IF PUMPSTATE(K)<>1 THEN GOTO 8220
PUMPSTAT1=1
REGPUMP1=1 :rem bit 0 a000
GOTO 8300
8220 PUMPSTAT1=0
REGPUMP1=0
GOTO 8300
8230 IF PUMP(K)<>2 THEN GOTO 8250
PUMP2=1
IF PUMPSTATE(K)<>1 THEN GOTO 8240
PUMPSTAT2=1
REGPUMP2=128 :rem bit 7 a000
GOTO 8300
8240 PUMPSTAT2=0
REGPUMP2=0 :rem bit 7 a000
GOTO 8300
8250 IF PUMP(K)<>3 THEN GOTO 8270
PUMP3=1
IF PUMPSTATE(K)<>1 THEN GOTO 8280
PUMPSTAT3=1
REGPUMP3=2 :rem bit 2 a001
GOTO 8300
8280 PUMPSTAT3=0
REGPUMP3=0
GOTO 8300
8270 PRINT 'THIS IS NOT A PUMP DESIGNATION';CDs
GOTO 8210
8300 NEXT K
PIMPREGA1=REGPUMP1+REGPUMP2
PIMPREGA0=REGPUMP3
GOTO 8800
GOTO 505
8400 REM READING THE UPCOUNTER
PRINT 'READING THE UPCOUNTER'
GOSUB 1500
PRINT 'COUNT RATE=';TOTALCTS;' CPS'
GOTO 505
8800 REM START THE PUMPS
PRINT 'STARTING THE PUMPS AND SEQUENCE'

```


Appendix B
PASSASSE.PRN Listing

```

0000      ; THIS PROGRAM IS CALLED PASSASSE.ASM
0000      ;
0000      ;   DOS PASS ASSEMBLY PROGRAMS
0000      ;
0000      ;   PRODUCED BY CASEY W. BENNETT
0000      ;   OREGON STATE UNIVERSITY
0000      ;   RADIATION CENTER
0000      ;
0000      ;   WITH SUBSEQUENT MODIFICATIONS
0000      ;   BY WARREN TENBROOK
0000      ;   1986
0000      ;
0000      ;   STARTING ADDRESS FOR ASSEMBLY LANGUAGES
0000      ;   IS AT D000 FOR NOW
0000      ;
0000      ;   This first program is to initialize the
0000      ;   pass monitoring system
0000      ;
0000      ;   INITIALIZATION OF MAINTENANCE REGISTERS
0000      ;
0000      ;   START   = $D000
0000      ;
0000      ;
0000      ;   VMON=  START   ;VALUE 6 FOR VALVE MONITOR
0000      ;   VCOUNT=START+1 ;#fc (252)10 for counter
0000      ;
0000      ;   VSHIF7=START+2 ;shift res for vaonitor division
0000      ;   VSTOR7=START+3 ;store remainder for vaon7
0000      ;   VSUBT7=START+4 ;# positions from home 6 wsv #7
0000      ;
0000      ;   VSHIF8=START+5 ;shift res for vaon valve 8
0000      ;   VSTOR8=START+6 ;store remainder from vaon8
0000      ;   VSUBT8=START+7 ;# positions from home 6 wsv val #8
0000      ;
0000      ;   VSHIF9=START+8 ;shift res for vaon valve 9
0000      ;   VSTOR9=START+9 ;store remainder from vaon div
0000      ;   VSUBT9=START+10 ;# positions from home 6 wsv val 9
0000      ;
0000      ;   BEEP=START+11 ;beeper storage
0000      ;   BEEP1=START+12 ;beeper storage
0000      ;   BEEP2=START+13 ;beeper storage
0000      ;
0000      ;   BYTE1=START+14 ;first byte counter
0000      ;   BYTE2=START+15 ;second byte counter
0000      ;   BYTE3=START+16 ;third byte counter
0000      ;   BYTE4=START+17 ;fourth byte counter
0000      ;
0000      ;   HOME7=START+18 ;home position for valve 7
0000      ;   HOME8=START+19 ;home position for valve 8
0000      ;   HOME9=START+20 ;home position for valve 9
0000      ;
0000      ;   ASCII=START+21 ;ascii storage for lsi character
0000      ;
0000      ;   VALV7A=START+22 ;valve monitor storage valve 7
0000      ;   VALV7B=START+23 ;valve monitor storage valve 7
0000      ;   VALV8A=START+24 ;valve monitor storage valve 8
0000      ;   VALV8B=START+25 ;valve monitor storage valve 8
0000      ;   VALV9A=START+26 ;valve monitor storage valve 9
0000      ;   VALV9B=START+27 ;valve monitor storage valve 9
0000      ;
0000      ;   PASS=START+28 ;storage res for loop status
0000      ;   RESERV=START+29 ;second storage res for fill res
0000      ;   VTIME=START+30 ;#07 countdown time for dtine
0000      ;   FREQQ=START+31 ;beeper frequency register
0000      ;
0000      ;   ADCLO=START+32 ;res for adc storage lo byte
0000      ;   ADCHI=START+33 ;res for adc storage hi byte
0000      ;   NADCLO=START+34 ;res for adc after rearrange lo
0000      ;   NADCHI=START+35 ;res for adc after rearrange hi
0000      ;
0000      ;   TOMAG=START+36 ;res for order of magnitude ctins
0000      ;   TSIGF=START+37 ;res for sis fis count time
0000      ;
0000      ;
0000      ;   PORT ADDRESSES
0000      ;
0000      ;   PORTB=$A000
0000      ;
0000      ;
0000      ;   PORTA   =PORTB+1
0000      ;   DDRB   =PORTB+2
0000      ;   DDRA   =PORTB+3
0000

```



```

D25A      ;      This program is timer 2 set in free run mode
D25A      ;      and called from timer 1 above
D25A      ;
D25A      ;
D25A A9 14      timeb LDA      $s14
D25C 8D 1E D0      timeab STA      VTIME
D25F A9 40      LDA      $s40      ;set timer to free run
D261 8D 0B A0      STA      ACR      ;acr A00B
D264 A9 4E      LDA      $s4E      ;load low byte (78)
D266 8D 04 A0      STA      TIMEL1
D269 A9 C3      LDA      $sC3      ;load hi byte (49920)
D26B 8D 05 A0      STA      TIMEH1
D26E A9 40      chris LDA      $s40
D270 2C 0D A0      ck      BIT      AIFR      ;ck time 1 flag bit ifr
D273 50 FB      BVC      ck
D275 CE 1E D0      DEC      VTIME
D278 F0 06      BEQ      sune
D27A AD 04 A0      LDA      TIMEL1
D27D 4C 6E D2      JMP      chris
D280 60      sune      RTS      ;return
D281      ;
D281      ;
D281      ;
D281      ;      This subroutine is called settv for communicatins
D281      ;      with the lsi
D281      ;
D281      ;
D281      ;
D281      ;
D281      ;      GETTY      =sEBDB
D281      ;
D281 20 DB EB      JSR      GETTY      ;Jump to settv
D284 8D 15 D0      STA      ASCII      ;store value
D287 60      RTS      ;return
D288      ;
D288      ;
D288      ;
D288      ;
D288      ;      This subroutine is called ttout
D288      ;      used to send character to lsi
D288      ;
D288      ;
D288      ;
D288      ;
D288      ;      TTYOUT      =sEEAB
D288 A9 0D      LDA      $s0D
D28A 20 A8 EE      JSR      TTYOUT
D28D A9 0A      LDA      $s0A
D28F 20 A8 EE      JSR      TTYOUT
D292 60      RTS
D293      ;
D293 60      RTS
D294 60      RTS
D295 60      RTS
D296      ;
D296      ;
D296      ;
D296      ;
D296      ;      This subroutine is called DTIME for
D296      ;      the valve delay time
D296      ;
D296      ;
D296      ;
D296      ;
D296 A9 07      dtime LDA      $s07
D298 8D 1E D0      STA      VTIME
D29B A9 40      LDA      $s40      ;timer free run
D29D 8D 0B A0      STA      ACR
D2A0 A9 FF      LDA      $sFF
D2A2 8D 04 A0      STA      TIMEL1
D2A5 A9 FF      LDA      $sFF
D2A7 8D 05 A0      STA      TIMEH1
D2AA A9 40      do      LDA      $s40      ;load mask
D2AC 2C 0D A0      ct      BIT      AIFR      ;timed out
D2AF 50 FB      BVC      ct      ;no
D2B1 CE 1E D0      DEC      VTIME
D2B4 F0 06      BEQ      son
D2B6 AD 04 A0      LDA      TIMEL1      ;dummy read
D2B9 4C AA D2      JMP      do
D2BC 60      son      RTS      ;return
D2BD      ;
D2BD      ;
D2BD      ;
D2BD      ;

```



```

D4A1      ;
D4A1      ;      trv and inc instruction (ee) in place of dec
D4A1      ;      for different tones
D4A1      ;
D4A1      ;
D4A1      ;      this is the alarm routine used to set someones
D4A1      ;      attention.  it continues to make noise until
D4A1      ;      the keyboard is pressed any key
D4A1      ;
D444      ;
D444 A9 00 settle LDA    $s00
D446 8D 9B 9F STA    ACR3          ;set for one shot
D449 A9 FF LDA    $sFF          ;low byte 255 aics
D44B 8D 9B 9F STA    TAHIL
D44E A9 00 LDA    $s00
D450 8D 99 9F STA    TAHIH
D453 A9 20 LDA    $s20          ;load ask
D455 2C 9D 9F fin BIT    IFR3          ;ifr3 9f9d
D458 F0 FB BEQ    fin
D45A 60 RTS          ;return to counter
D45B      ;
D45B      ;
D45B      ;
D45B      ;      this subroutine is the beeper called BEEP and is
D45B      ;      used for single beep, variable pitch beep, and
D45B      ;      steady frequency beep
D45B      ;
D45B      ;
D45B      ;      SPKR    =s9FBD
D45B      ;      KEYCK   =sECEf
D45B      ;
D45B      ;
D45B      ;      this sub is for end of line beep or continual beep
D45B      ;      until operator presses keyboard (beep2)
D45B      ;
D45B      ;
D45B      ;
D45B 20 80 D4 beeps JSR    beepb          ;do a beep
D45E 4C 7F D4 JMP    don          ;leave
D461      ;
D461      ;      this sub beeps until someone presses a key
D461      ;
D461 20 80 D4 beepc JSR    beepb          ;do a beep
D464 A9 03 LDA    $s03          ;lensth of beeps
D466 8D 0C D0 STA    BEEP1
D469 8D 0D D0 STA    BEEP2
D46C 20 EF EC wait JSR    KEYCK          ;key pressed ?
D46F 98 TYA
D470 D0 0D BNE    don
D472 CE 0C D0 DEC    BEEP1
D475 D0 F3 BNE    wait
D477 CE 0D D0 DEC    BEEP2
D47A D0 F0 BNE    wait
D47C 4C 61 D4 JMP    beepc          ;do another beep
D47F 60 don RTS          ;return
D480      ;
D480      ;
D480      ;      the actual beeper routine is called for single
D480      ;      tone.  pitch can be changed is desired
D480      ;
D480      ;
D480      ;
D480 A9 FF beepb LDA    $sFF          ;tone lensth
D482 8D 0C D0 STA    BEEP1
D485 A2 2C A8 LDX    $s2C          ;pitch value
D487 CA A6 DEX
D488 D0 FD BNE    A6
D48A 8D BD 9F STA    SPKR          ;tossle speaker
D48D CE 0C D0 DEC    BEEP1
D490 D0 F3 BNE    A8
D492 60 RTS          ;return
D493      ;
D493      ;
D493      ;      for interesting effects trv beepd
D493      ;      changes frequency with each cycle
D493      ;      press reset button to stop
D493      ;
D493      ;
D493 A2 00 beepd LDX    $s00
D495 CA A9 DEX
D496 D0 FD BNE    A9

```

```

D4A1      ;
D4A1      ;
D4A1      ;
D4A1 20 A5 D4 alarm JSR alarm          ;do an alarm
D4A4 60                      RTS          ;return
D4A5 A9 03 alarm LDA #03              ;itone lensth
D4A7 8D 0C D0 STA BEEP1
D4AA 8D 0D D0 STA BEEP2
D4AD 20 EF EC JSR KEYCK                ;key pressed ?
D4B0 98 TYA
D4B1 F0 01 BEQ A10                      ;no continue
D4B3 60                      RTS          ;return
D4B4 CE 0C D0 A10 DEC BEEP1
D4B7 D0 1A BNE tone
D4B9 CE 0D D0 DEC BEEP2
D4BC D0 15 BNE tone
D4BE A9 24 LDA #24                      ;hi pitch
D4C0 CD 1F D0 CMP #freea
D4C3 F0 04 BEQ A11
D4C5 8D 1F D0 STA #freea
D4C8 4C A5 D4 JMP alarm
D4CB A9 2B A11 LDA #2B                  ;low pitch
D4CD 8D 1F D0 STA #freea
D4D0 4C A5 D4 JMP alarm
D4D3 AE 1F D0 tone LDX #freea          ;do it
D4D6 CA A12 DEX                          ;set tone free
D4D7 D0 FD BNE A12
D4D9 8D BD 9F STA SPKR
D4DC 4C B4 D4 JMP A10
D4DF      ;
D4DF      ;
D4DF      ; this subroutine is to fill the reservior
D4DF      ;
D4DF      ;
D4DF A9 80 LDA #80
D4E1 8D 01 A0 STA PORTA
D4E4 A2 25 LDX #25
D4E6 20 3B D2 JSR timea
D4E9 A9 00 LDA #00
D4EB 8D 01 A0 STA PORTA
D4EE A9 02 LDA #02
D4F0 8D 00 A0 STA PORTB
D4F3 20 EF EC JSR KEYCK
D4F6 A9 00 LDA #00
D4F8 60 RTS
D4F9      ;
D4F9      ; second half of volume
D4F9      ;
D4F9 A9 80 LDA #80
D4FB 8D 01 A0 STA PORTA
D4FE A2 25 LDX #25
D500 20 3B D2 JSR timea
D503 A9 00 LDA #00
D505 8D 01 A0 STA PORTA
D508 A9 02 LDA #02
D50A 8D 00 A0 STA PORTB
D50D 20 EF EC JSR KEYCK
D510 A9 00 LDA #00
D512 8D 00 A0 STA PORTB
D515 60 RTS          ;return
D516      ;
D516      ;
D516      ;
D516      ; this subroutine is for the ion exchange
D516      ; routine called IONXC
D516      ;
D516      ;
D516 48 ionxc PHA                       ;save status
D517 20 1A D3 JSR chew                    ;flush system
D51A A9 01 LDA #01
D51C 8D 01 A0 STA PORTA
D51F A9 28 LDA #28
D521 20 96 D2 JSR dtime
D524 68 PLA
D525 8D 1C D0 STA PASS
D528 A9 01 LDA #01
D52A CD 1C D0 CMP PASS
D52D B0 05 BCS A20
D52F A9 3D LDA #3D
D531 4C 36 D5 JMP A21
D534 A9 0D A20 LDA #0D
D536 8D 01 A0 A21 STA PORTA

```


Appendix C
STATCALC.BAS Listing


```

A>TYPE STATCALC.BAS
REM THIS PROGRAM DOES STATISTICS ON A SERIES OF GROSS COUNTS
20 REMARK VIDEO INITIALIZATION
    N$=CHR$(78)      :REM NO
    Y$=CHR$(89)      :REM YES
    CL$=CHR$(3)      :REM CLEAR
    CD$=CHR$(4)      :REM CURSOR DOWN
    RV$=CHR$(18)     :REM REVERSE VIDEO
    CF$=CHR$(30)     :REM CHANGE FORMAT
35 REM INITIALIZE ARRAYS
    DIM COL(14),SS$(14)
    DIM DDD(14),PIMPREGA1(14),PIMPREGA0(14)
    DIM ST$(14),POS67(14),POS68(14),POS69(14),STATE31(14)
    DIM STATE32(14),STATE33(14),STATE34(14),STATE35(14)
    DIM STATE36(14),REGA1(14),REGA1(14)
    DIM VALVE31(14),VALVE32(14),VALVE33(14),VALVE34(14)
    DIM VALVE35(14),VALVE36(14),TFLAG(14),SFLAG(14)
    DIM VALVA(14,10),VALVB(14,4),STATEA(14,8),STATEB(14,10)
    DIM PUMP(14,10),PUMPSTATE(14,3),COUNTS(180)
40 REM REV. FILLING
PRINT CL$
PRINT "          COUNTING STATISTICS CALCULATION ROUTINE"
PRINT CD$;CD$
PRINT "          WARREN TENBROOK, 1985"
PRINT "          BY WAY OF C. W. BENNETT"
PRINT CD$;CD$;CD$
PRINT "          THE ASSEMBLY LANGUAGE PROGRAMS ARE BEING"
PRINT "          LOADED INTO THE MICRO WITH STARTING ADDRESS"
PRINT "          AT D000 HEXIDECIMAL"
    PRINT CD$;CD$
    DIM HEX(70)
    FOR X=0 TO 15
        READ I
        HEX(I)=X
    NEXT X
    DATA 48,49,50,51,52,53,54,55,56,57,65,66,67,68,69,70
    A$="PASSASSE.KIM"
    FILE A$
    IF END #1 THEN 80
60 READ #1;REC$
    INDX=2
    GOSUB 70
    LENGTH=BYTE
    GOSUB 70
    ADDR=BYTE*256
    GOSUB 70
    ADDR=ADDR+BYTE
    FOR K=ADDR TO ADDR+LENGTH-1
        GOSUB 70
        POKE K,BYTE
    NEXT K
    GOTO 60
70 REM READ DATA CODE
    BYTE=HEX(ASC(MID$(REC$,INDX,1)))$16
    BYTE=HEX(ASC(MID$(REC$,INDX+1,1)))+BYTE
    INDX=INDX+2
    RETURN
80 REM END OF DATA INPUT
    CLOSE #1
    PRINT "DATA READ FUNCTION COMPLETE"
    X=CALL(SETUP)      :rem initializing res
    PORRS=53400        :rem D098 hex
    X=CALL(PORRS)      :rem direction ports
PRINT CL$
PRINT "THIS PROGRAM FINDS STATISTICAL RELATIONS IN THE SET"
PRINT "OF 32-BIT COUNTER ACCUMULATED VALUES OVER TIME."
PRINT CD$
95 GOSUB 1000
INPUT "HOW MANY COUNT CYCLES DO YOU WANT";CYCLE
PRINT CD$
INPUT "HOW MANY CYCLES FOR BASELINE CALCULATION";BASE
PRINT CD$
INPUT "WHAT IS THE COUNTER GLITCH REJECTION LIMIT";GLITCH
PRINT CD$
PRINT "CHOOSE HORIZONTAL SCALE:"
PRINT "1) LOGARITHMIC"
PRINT "2) LINEAR"
INPUT "WHICH SCALE, 1 OR 2";SCALE
IF SCALE=2 THEN GOTO 96
PRINT CD$
INPUT "HOW MUCH EXPANSION OF HORIZONTAL SCALE";EXPAND
GOTO 99

```

```

96 PRINT CD$
INPUT "WHAT DIVIDE FACTOR FOR HORIZONTAL COUNT SCALE";DIVISOR
99 PRINT CL$
PRINT "ACCUMULATING COUNTS ON 32-BIT COUNT CHIP."
PRINT CD$;CD$
IF SCALE=2 THEN GOTO 102
PRINT "TIME VS. LOG OF GROSS COUNTS*";EXPAND
GOTO 104
102 PRINT "TIME VS. GROSS COUNTS/";DIVISOR
104 PRINT CD$
GOSUB 1000
LET MAXCTS=0
LET SIGSQ=0
LET BASESUM=0
MINBASE=111111111111
LET MINCTS=1000000000000000000
LET SIGMA=0
LET BASELOOP=0
LET ESCAPER=0
GOSUB 1500
OLDCTS=TOTALCTS
110 GOSUB 1500
LET ESCAPER=ESCAPER+1
IF TOTALCTS > GLITCH THEN GOTO 120
GOSUB 2500
IF ESCAPER > CYCLE THEN GOTO 200
IF TOTALCTS < MINCTS THEN MINCTS=TOTALCTS
IF TOTALCTS > MAXCTS THEN MAXCTS=TOTALCTS
LET SIGMA=TOTALCTS+SIGMA
SIGSQ=SIGSQ+(TOTALCTS*TOTALCTS)
IF SCALE=2 THEN GOTO 118
LOGCTS=LOG(EXPAND*TOTALCTS+3)
PRINT TAB(LOGCTS);"*";TOTALCTS
GOTO 110
118 LINCTS=(TOTALCTS+DIVISOR)/DIVISOR
PRINT TAB(LINCTS);"*";TOTALCTS
GOTO 110
120 PRINT "AQUISITION ERROR: ";TOTALCTS
GOTO 110
200 LET CNTMEAN=SIGMA/CYCLE
LET ROOT=(SIGSQ/CYCLE)-(CNTMEAN*CNTMEAN)
IF ROOT > 0 THEN 210
SD=0
GOTO 220
210 SD=SQR(ROOT)
220 UPPERBOUND=CNTEAN+(3*SD)
PRINT CL$
GOSUB 1000
PRINT "THE NUMBER OF COUNTS PERFORMED WAS:",CYCLE
PRINT "THE MEAN OF THE SET OF COUNTS IS:",CNTMEAN
PRINT "THE STANDARD DEVIATION FROM THE MEAN WAS:",SD
PRINT "THE MAXIMUM SINGLE ACCUMULATED COUNT WAS:",MAXCTS
PRINT "THE BASELINE LEVEL WAS:",MINBASE
PRINT "THE MINIMUM SINGLE ACCUMULATED COUNT WAS:",MINCTS
PRINT "THE UPPER LIMIT FOR THIS SERIES"
PRINT "AT THE 99.73% CONFIDENCE LEVEL IS:",UPPERBOUND
PRINT CD$;CD$;CD$;CD$
228 REM BRANCHING
GOSUB 1000
INPUT "DO YOU WANT START AGAIN";YN$
IF YN$=N$ THEN GOTO 20000
GOTO 95
1000 REM SINGLE BEEP
      X=CALL(54363)
      RETURN
1500 REM READING THE UPCOUNTER
      TOTALCTS=0
      X=CALL(54208)           ;rea d3c0 hex
      NIBBLE=53262         ;rea d00e hex
      MONITOR=0
      FOR K=1 TO 4
        RED=PEEK(NIBBLE)
        FAKE=RED*255~MONITOR
        MONITOR=MONITOR+1
        NIBBLE=NIBBLE+1
        TOTALCTS=FAKE+TOTALCTS
      NEXT K
      RETURN

```

```
LET BASESUM=TOTALCTS+BASESUM
LET BASELOOP=BASELOOP+1
IF BASELOOP=BASE THEN GOTO 2550
2510 RETURN
2550 BASELOOP=0
HTBASE=BASESUM/BASE
IF HTBASE < MINBASE THEN GOTO 2580
BASESUM=0
GOTO 2510
2580 MINBASE=HTBASE
BASESUM=0
GOTO 2510
20000 PRINT CL$
      PRINT '                THAT'S ALL FOR NOW FOLKS'
      GOSUB 1000
      PRINT CD$;CD$;CD$;CD$;CD$
      END
```

Appendix D

ANALYZE.BAT Listing

MCBSET.BAS Listing

RXTRAN.BAS Listing

```

PATH=C:\:\DOS:\A18;\A30;\A23
MCBSET
STORE MCA:1 SEGMENT:1 FILE:X1.CHN
CONVERT X1.CHN
AN1 X1.SPC X1.UFO 0 0 2
AN2 X1.UFO 0 0
RPT PRN.RPT X1.UFO 0 0 0
DEL X1.SPC
DEL X1.UFO

```

```

RXTRAN10 'File MCBSET.BAS.....Warren TenBrook. 1986
15 'This file opens I/O files to the RS-232C ports to send control ASCII
20 'strings to the ADCAM MCB, and to receive and send control characters
21 'to and from the AIM microcomputer. Operation is prompted by the file.
23 CLS
25 PRINT "AUTOMATED LIQUID ANALYSIS SYSTEM: MCB/IBM/AIM COORDINATION ROUTIN
E"
27 PRINT " "
30 INPUT "What preset Live Time. in seconds, do you desire";LT
35 LT=LT*50
40 PRINT " "
50 PRINT "Clearing ADCAM MCB, setting communications trap on COM2."
60 'Open COM1 for MCB instructions/status
70 OPEN "COM1:9600,N,8" AS #1
71 RS%="X000000069"
90 'Initialize MCB to known state.
95 PRINT #1. "INITIALIZE"
96 INPUT #1,X$
97 IF X$(<>)RS% THEN PRINT X$: STOP
105 PRINT #1, "SET_LIVE_PRESET ":LT
106 INPUT #1,X$
107 IF X$(<>)RS% THEN PRINT X$: STOP
130 'Open COM2 to receive AIM start character
140 OPEN "COM2:150,N,,CS,DS,CD" AS #2
145 PRINT "Waiting for AIM start character."
150 X$=INPUT$(1,#2)
160 PRINT " "
170 PRINT "AIM start character received. Starting spectrum acquisition."
180 'Set MCB preset LT
210 PRINT #1. "START"
211 INPUT #1,X$
212 IF X$(<>)RS% THEN PRINT X$: STOP
240 PRINT "ADC on."
250 END

```

```

10 'File RXTRAN.BAS.....Warren TenBrook. 1986
20 'This file opens an output file to RS-232C port COM2, sends an ASCII
30 'string to the AIM microcomputer and terminates.
40 CLS
50 PRINT "Spectrum acquired. Sending completion signal to AIM."
60 OPEN "COM2:150,N,,CS,DS,CD" AS #2
70 PRINT #2. "GO"
80 PRINT " "
90 PRINT "You may now run the ADCAM MCA software to examine and manipulate"
100 PRINT "the spectral data."
110 END

```