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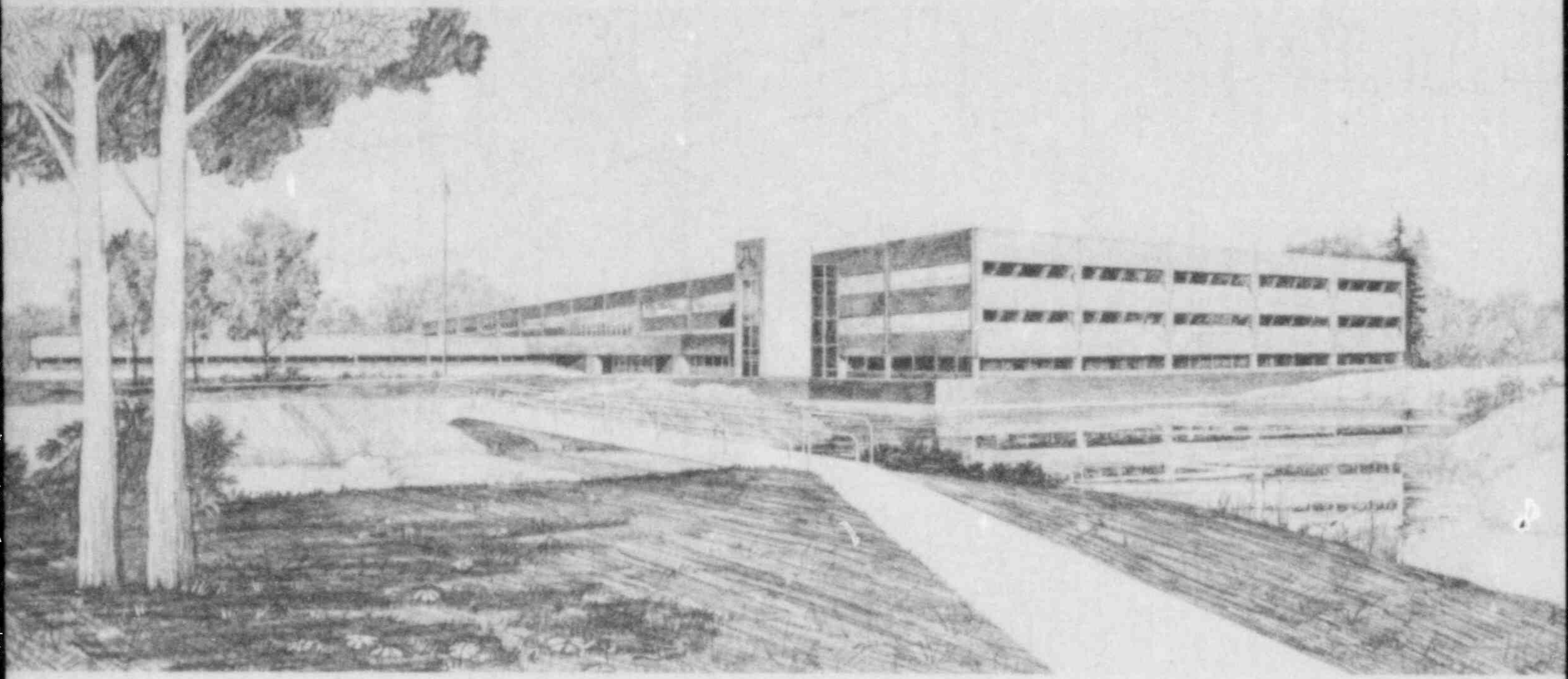

Idaho National Engineering Laboratory
Operated by the U.S. Department of Energy

Detection of Steam Generator Tube Leaks in Pressurized Water Reactors

William H. Roach

November 1984

Prepared for the
U.S. Nuclear Regulatory Commission
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DETECTION OF STEAM GENERATOR TUBE LEAKS IN PRESSURIZED WATER REACTORS

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Idaho Falls, Idaho 83415

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FIN No. A6380

ABSTRACT

This report addresses the early detection of small steam generator tube leaks in pressurized water reactors. It identifies physical parameters, establishes instrumentation performance goals, and specifies sensor types and locations. It presents a simple algorithm that yields the leak rate as a function of known or measurable quantities. Leak rates of less than one-tenth gram per second should be detectable with existing instrumentation.

FIN No. A6380—Diagnostic Instrumentation Evaluation

SUMMARY

This report discusses the third, and final, year's work on an NRC-funded project examining diagnostic instrumentation in water reactors. The first two years were broad in coverage, concentrating on anticipatory measurements for detection of potential problems in both pressurized- and boiling-water reactors, with recommendations for areas of further study. One of these areas, the early detection of small steam tube leaks in pressurized water reactors, formed the basis of study for the last year of the project.

Four tasks are addressed in this study of the detection of steam tube leaks.

1. Determination of which physical parameters indicate the onset of steam generator tube leaks
2. Establishing performance goals for diagnostic instruments which could be used for early detection of steam generator tube leaks.
3. Defining the diagnostic instrumentation and their location which satisfy Items 1 and 2 above
4. Assessing the need for diagnostic data processing and display.

Parameters are identified, performance goals established and sensor types and locations are specified in the report, with emphasis on the use of existing instrumentation with a minimum of retrofitting. A simple algorithm is developed which yields the leak rate as a function of known or measurable quantities. The conclusion is that leak rates of less than one-tenth gram per second should be detectable with existing instrumentation.

ACKNOWLEDGMENTS

The following persons have given valuable assistance to this project: Dr. Judy Partin and Mr. Vance Deason for a literature and fact finding search; Dr. Gordon Lassahn for reviews and discussions; Dr. Richard Helmer for learned advice and calculations; Dr. Scott Bowen and Dr. Clyde Frank for their innovative ideas and work in isotopic separation; Mr. Alan Stalker for sharing his knowledge of operating Pressurized Water Reactors (PWRs); and Mr. John Mandler and his group for discussions on source terms in PWRs.

CONTENTS

DETECTION OF STEAM GENERATOR TUBE LEAKS IN PRESSURIZED WATER REACTORS

PREVIOUS WORK

During the first year of the project (reported in Reference 1), event tree analysis was used to assess anticipatory measurement requirements for nuclear power plants. Events studied were those that could lead to breach of cladding, breach of pressure boundary, and breach of containment. Several hundred events were identified; from the analysis a list of fifty-one useful anticipatory measurements was developed, covering potential problems in reactor power, core heat removal, secondary side heat removal, primary pressure boundary integrity, and containment integrity. Diagnostic instrument performance characteristics for these measurements were then developed and listed. The report concluded with recommendations for future work in three areas:

- Valve status monitoring by acoustic analysis
- Leak detection and location by acoustic analysis
- Instrument integrity methodology development (self-test capability).

During the second year of the project (reported in Reference 2), the potentially useful anticipatory measurements identified during the first year's work were ranked in importance according to the expected frequency of occurrence of the accidents that the measurement might prevent or mitigate. Development and implementation costs were also estimated. Cost and benefit were then combined to arrive at a qualitative estimate of the cost/benefit ratio for each measurement. Several types of measurements were recommended for implementation and/or further investigation. Three major areas were suggested: acoustic techniques, instrument performance diagnostics, and general signature analysis. Several specific tasks were also suggested:

- Flow rate pressure drop for pumps
- Lateral shaft motion detection
- Secondary coolant monitoring to detect steam generator tube leaks.

DIAGNOSTIC INSTRUMENTATION EVALUATION TASK FOR FY 1984

The broad, nonspecific nature of this project during the first two years, FY 1982 and FY 1983, changed considerably for FY 1984. One of the recommended areas of work in the final report for FY 1983 was to examine methods for the early detection of steam generator tube leaks in pressurized water reactors. This task was drafted into a statement of work, which is included as Appendix A.

A literature survey showed that some work had been done on steam tube leak location after reactor shutdown[3] and a mathematically oriented study[4] had been done in which loop equations were developed for radiation levels in the PWR secondary. But no reference was found which specifically addressed the tasks given in the statement of work. Monitoring of the secondary to detect steam tube leaks is done at many, if not all, operating PWRs and is described in varying detail in plant Final Safety Analysis Reports (FSARs).

Task 2.1.1: Physical Parameter Identification

Task 2.1.1 of the Statement of Work became a search to determine what physical parameters indicate onset of steam generator tube leaks, since there appeared to be no way to determine an impending leak condition. Further, very small leaks are probably difficult, if not impossible, to detect through any of the coolant parameters such as pressure, fluid flow, or coolant level. For such leaks, the parameter to choose is one which is unique to the primary system, in a no-leak condition, and which is detectable, with great sensitivity, in the secondary when a leak occurs.

Radioactive isotopes formed in the primary as a result of fission or neutron capture fulfill the above requirement and are monitored in some PWRs to indicate primary-secondary leakage. Task 2.1.1 thus became a search for suitable radioactive isotopes that are born in the primary and can migrate to the secondary via small steam tube leaks.

In-plant measurements[5] conducted during the past years did examine secondary coolant and steam in those plants where steam tube leaks were known to exist. Table 1 lists isotopes that transport readily from primary to secondary. Some fission products plate out, to varying degrees, hence are not useful as quantitative indicators of leakage and are not listed. And not all isotopes in Table 1 are suitable as leak detectors. For example, tritium decays by a weak beta; hence, it is difficult to detect in a plant situation. In addition, tritium cannot be scrubbed from a coolant, and makeup water may contain tritium that has entered the water through some other process than leakage.

Of the isotopes in Table 1, those selected for further scrutiny were the iodines, the noble gases, and sodium-24. Analysis shows that the iodines remain, to a large extent, in the steam generator rather than follow the steam path. Detection of the iodines would be the most productive, then, in the steam generator water; for example, in the downcomer. Physical inaccessibility to the downcomer, which is in reactor containment, plus the high radiation background expected in such a location, largely precludes a monitoring site on the steam generator itself. In addition, retrofitting costs for existing plants would be high even if the location were feasible.

Sodium-24, with an energetic gamma ray decay and a useful half-life, is one of the isotopes that existing plants monitor at the steam generator blowdown line, either on-line or on a grab sample-laboratory basis. Two items suggest that the blowdown line location is not ideal: (a) the possibly high background level, and (b) the relatively long time between leak onset and detection at the blowdown line location.

Noble gases are noncondensable and follow the steam path from the secondary. A separation of the

Table 1. Parameters for steam tube leak detection

Isotopes(s)	Formation	Predominant Decay Mode	$T_{1/2}$	Remarks
^{3}H	Neutron capture, Tertiary fission	β	12.7 yr	Low energy β
^{16}N	Neutron capture	γ	7 s	High energy γ, Short half-life
^{24}Na	Neutron capture	γ	15 h	Energetic γ, Good half-life
Noble Gases	Fission	γ and β	Several[a]	Follow steam cycle
Iodines	Fission	γ and β	Several[a]	Follow water cycle

---

[a] See Table 2.

noncondensable gases and water occurs at the condenser, the gases then proceeding to the steam generator air ejector. The air ejector location for a radiation monitor is acceptable since expected radiation background is low. Finally, some existing plants have air ejector monitors already in place.

The detection of noble gases at the air ejector appears to be the best method to use to detect early onset of steam generator tube leaks. This selection is based on the following facts:

- Noble gases leaving the steam generator are totally discharged via the air ejector; none are returned to the steam generator
- The transit time from steam tube leak to air ejector is less than two minutes
- The air ejector is located in an acceptable environment from a sensor point of view.

Task 2.1.2: Establish Performance Goals

This task, the establishment of performance goals for diagnostic instruments being evaluated, was closely tied to the actual selection of the instrumentation, Task 2.1.3. In order to define performance goals in a quantitative sense, it was felt that some small but realistic radiation level in the secondary must be assumed. An American National Standard[6] has addressed the problem of source term specifications for both PWRs and Boiling Water Reactors (BWRs). In particular, numerical examples are given in the report for both primary and secondary radiation levels in a PWR, assuming nominal radiation buildup mechanisms in the primary and a small (0.4-g/s) leak in the steam generator tubes. Since this document, now in a draft stage, should soon be available as a national standard, the calculated radiation levels in Reference 6, assuming a 0.4-g/s leak rate, are used here to establish performance goals for diagnostic instrumentation.

In the following development, expressions are derived for the buildup of noble gases in the steam generator secondary after leak onset; for the noble gas arrival rate, in μCi/s, at the steam generator air ejector; and for the primary-to-secondary leak rate. These expressions are then used in a sample calculation that shows what activity might be expected at the air ejector in a typical PWR with a small steam tube leak. Performance goals are then given for the required monitoring systems. Several assumptions are made:

- The noble gas activity in the primary coolant is in equilibrium or a slowly varying function of time
- The half-lives of the most abundant noble gas isotopes are long compared to both the transit time of steam from the steam generator to the air ejector and the cycle time from steam generator through the turbines and condenser and return to the steam generator, the latter time being of the order of two minutes or less for a typical PWR
- Complete mixing of the noble gases with the secondary coolant occurs in times much less than the steam generator cycle time.

The time rate of increase of total noble gas activity in the steam generator secondary coolant after leak onset is

$$\frac{dA_s(t)}{dt} = \ell\, C_p - \frac{m}{M} A_s(t) \,, \qquad (1)$$

where

$A_s(t)$ = the total noble gas, in μCi, in the steam generator secondary at time t

C_p = the primary coolant noble gas activity, in μCi/g

ℓ = leak rate, primary to secondary, g/s

m = mass of water per second converted to steam

M = mass of water in steam generator.

Equation (1) assumes steady-state conditions in the primary coolant and for the leak rate. The transient case, where either or both ℓ and C_p are time dependent, is not treated here.

Solving Equation (1) for $A_s(t)$,

$$A_s(t) = \ell\, C_p \frac{M}{m}\left(1 - e^{-\frac{m}{M}t}\right) . \qquad (2)$$

For times long after leak onset, the total noble gas activity in the steam generator secondary is

$$A_s(t \rightarrow \infty) = \ell C_p \frac{M}{m} .$$

The noble gas activity per second arriving at the air ejector, A_E, is the same as that leaving the steam generator per second, neglecting noble gas decay in the short transit time between steam generator and air ejector. From Equation (2), this quantity is

$$A_E = \frac{m}{M} A_s(t) = \ell C_p(1 - e^{-\frac{m}{M}t}) , \qquad (3)$$

in μCi/s.

A_E approaches the product ℓC_p after a few steam generator cycle times, $\frac{M}{m}$, which is typically about 100 s. Figure 1 plots the dimensionless quantity $A_E/\ell C_p$ as a function of steam generator cycles after onset, $\frac{m}{M}$ t.

The separation of the noble gases from the secondary loop return coolant appears to be complete. The source term survey (see Reference 5) did not detect any noble gas activity in the return water in those plants where steam tube leakage was observed.

Solving Equation (3) for the leak rate yields

$$\ell = \frac{A_E(t)}{C_p(1 - e^{-\frac{m}{M}t})} . \qquad (4)$$

Equation (4) assumes that the noble gas activity both at the air ejector and in the primary coolant are known. An existing air ejector monitoring system, shown schematically in Figure 2 (see Reference 7 and Appendix B), counts activity from noble gases only; hence, such systems are only required to be gross activity detectors. To obtain the noble gas activity in the primary coolant, however, requires an isotopic analysis, since the primary contains all the fission products in addition to radionuclides produced by other (e.g., neutron capture) processes. Such analyses are routinely done using, for example, a Ge(Li) detector in a gamma ray spectrometer system. Since the above development for leak rate has assumed that the primary activity is approximately constant with time, on-line real-time spectral analysis in the primary would not be required. Grab samples at regular intervals (each shift) should be sufficient, with the precaution that such samples must be kept sealed.

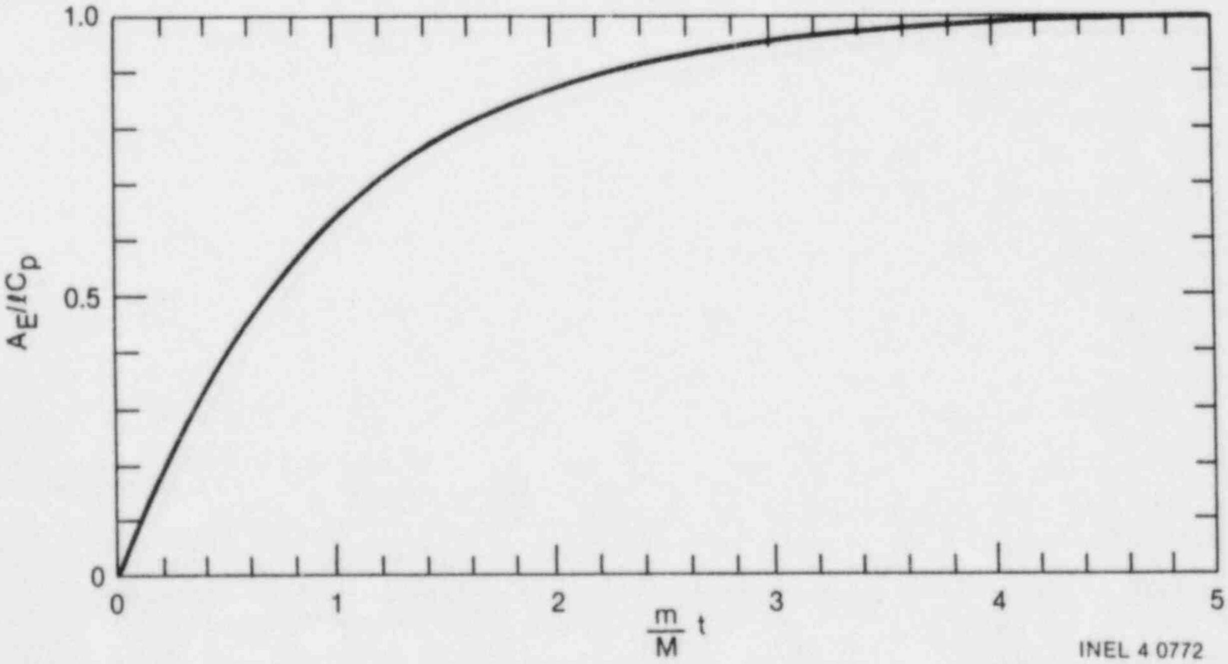

Figure 1. Normalized air ejector activity versus number of steam generator cycles.

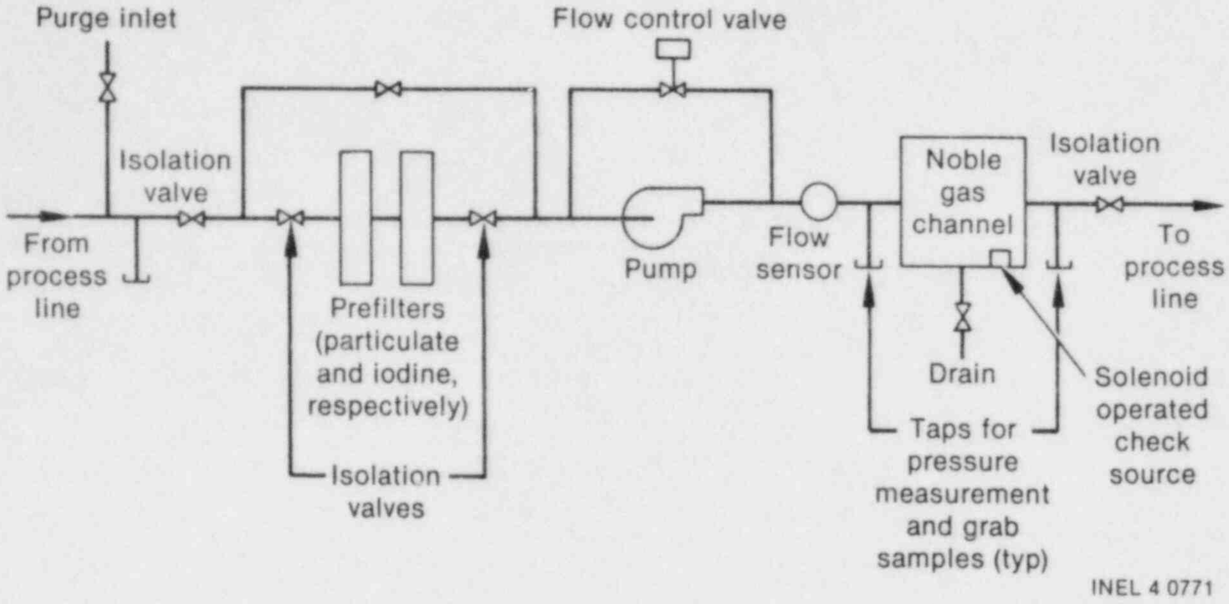

Figure 2. Single stage gaseous monitor.

A sample calculation of what the air ejector activity would be, using assumptions from the references, is included here in order to estimate what performance goals should be set for the two monitors, air ejector and primary coolant.

The activity per second at the air ejector, from Equation (3), must be converted to activity per unit volume, since it is the latter quantity that is obtainable from a count rate. Such a conversion requires that the gas flow rate, in cm^3/s, is known in the air ejector sampling system. Reference 7, included in part in Appendix B, gives the specifications for an air ejector monitoring system and assumes a flow rate at the air ejector sample system of one standard cubic foot per minute (scfm). That assumption will be used in this sample calculation.

From Table 2 (see Reference 6) the sum of the isotopic noble gas activities in the primary coolant yields

$C_p = 5.6\ \mu Ci/g$.

The air ejector activity per cm^3 is given by

$$A'_E = \frac{A_E}{(\text{Sample Flow Rate})} = \frac{\ell C_p}{\dot{V}_E} \qquad (5)$$

where it is assumed that A_E has attained a steady-state value and where

$\dot{V}_E$ = volumetric flow rate in the air ejector sample line, cm^3/s.

Assume a leak rate (see Reference 6),

$\ell = 0.4\ g/s$.

Equation (5) then gives

$A'_E = 4.7 \times 10^{-3}\ \mu Ci/cm^3$.

This activity is some three orders of magnitude greater than the detection limit given for existing single-stage gaseous monitoring systems (see Appendix B) and perhaps five orders of magnitude greater than that attainable with available gamma ray spectrometers using Ge(Li) detectors. (See Reference 5.)

Performance goals for the air ejector and primary coolant monitoring systems are taken from Reference 7 and are given as system specifications that are probably representative of commercially available systems. Appendix B of the same reference discusses these systems in greater detail.

Specification for Air Ejector Monitor. The air ejector monitor will be a single-stage gaseous monitor consisting of a beta sensitive plastic scintillation radiation detector, coupled to a photomultiplier tube that is protected by an electromagnetic shield. Figure 2 diagrams the components of the monitor.

Table 2. Representative source terms[1] (μCi/g)

			Secondary Coolant[b]	
Nuclide	$T_{1/2}$	Reactor[a] Coolant	Water[c]	Steam[d]
^{85m}Kr	4.5 h	1.6 E-01	0	3.4 E-08
^{85}Kr	10.7 yr	4.3 E-01	0	8.9 E-08
^{87}Kr	76 min	1.5 E-01	0	3.0 E-08
^{88}Kr	2.8 h	2.8 E-01	0	5.9 E-08
^{131m}Xe	12 day	7.3 E-01	0	1.5 E-07
^{133m}Xe	2.2 day	7.0 E-02	0	1.5 E-08
^{133}Xe	5.2 day	2.6 E-00	0	5.4 E-07
^{135m}Xe	15.3 min	1.3 E-01	0	2.7 E-08
^{135}Xe	9.1 h	8.5 E-01	0	1.8 E-07
^{137}Xe	3.8 min	3.4 E-02	0	7.1 E-09
^{138}Xe	14.1 min	1.2 E-01	0	2.5 E-08
^{131}I	8 day	4.5 E-02	1.8 E-06	1.8 E-08
^{132}I	2 h	2.0 E-01	2.9 E-06	2.9 E-08
^{133}I	20 h	1.4 E-01	4.8 E-06	4.8 E-08
^{134}I	53 min	3.4 E-01	2.5 E-06	2.5 E-08
^{135}I	6.7 h	2.6 E-01	6.6 E-06	6.6 E-08
^{3}H	12.7 yr	1.0 E-00	1.0 E-03	1.0 E-03
^{16}N	7 s	4.0 E+01	1.0 E-06	1.0 E-07
^{24}Na	15 h	4.7 E-02	1.5 E-06	7.6 E-09

a. Coolant entering letdown line.

b. Primary-to-secondary leakage rate of 0.4 g/s (75 lb/day).

c. Water in steam generator.

d. Steam leaving steam generator.

The minimum detectable limit of the monitor for Xe-133 in a 1 mr/h background at a 95% confidence level is 1×10^{-6} μCi/cm^3, based on a sample flow rate of 1 scfm and a one-half minute counting time. The response of the detector is at least three times the square root of the background above background.

Specification for Primary Coolant Monitor. The primary coolant monitor will be a single-stage liquid monitor consisting of a gamma sensitive scintillation detector, coupled to a photomultiplier tube that is protected by an electromagnetic shield. The minimum detection limit of the monitor for Cs-137 in a 1 mr/h background of Co-60 gamma radiation at a 95% confidence level is 1×10^{-6} μCi/cm^3 for a one minute counting time. The resolution of the detector is <10% Full Width at Half Maximum (FWHM) at 0.662 MeV (Cs-137).

Existing Ge(Li) gamma ray pulse height analyzers have sensitivities exceeding those in the above specification by several orders of magnitude and typically can resolve 1- to 2-keV peaks at several MeV energy. Such a primary coolant monitor should be able to resolve the noble gas photopeaks at a 95% or greater confidence level.

Self-test capability for the systems described in Appendix B is provided by means of a built-in, pop-up source, remotely or manually operated. A self-test capability, which tests everything except the detector itself, is incorporated in many of the gamma ray spectrometer systems in use at the Idaho National Engineering Laboratory. This consists of an electronic pulser that injects double pulses of known energy equivalent and repetition rate into the counting data. Since the energies are precisely known, the pulser acts also as a system calibration and, by knowing the pulse rate, indicates whether or not counts are being lost because of excessive count rate. Such a modification to existing gamma ray systems is recommended.

The drift rate during the data-taking interval of the referenced gross beta detector is not known. However, the short counting interval (30 s) coupled with good design, should ensure that the drift rate is within the 0.5% requirement of the Work Statement. Gamma ray spectrometers, with the detector kept at constant temperature, are well within the above stability criteria over long periods of time.

The analysis suggested here—isotopic noble gas activity in the primary coolant using a Ge(Li) based gamma ray spectrometer and a beta detector at the air ejector—attempts to utilize existing or commercially available monitoring systems.

Task 2.1.3: Define Diagnostic Instrumentation

This task, defining of the diagnostic instrumentation, is covered in the preceding section. Only a summary is given here.

Secondary Monitor

Location: Air Ejector
Suggested System: Gross Beta Detector
Detected Species: Noble Gases
Duty Cycle: Continuous

Primary Monitor

Location: Existing or Grab Sample Line
Suggested System: Ge(Li) Gamma Ray Spectrometer Pulse Height Analyzer
Detected Species: Isotopic Abundance of Noble Gases
Duty Cycle:

Grab sample during operating shift; more often if primary conditions are altered.

Task 2.1.4: Assess Need for Data Processing and Display

This task is defined to assess the need for diagnostic data processing and display in order to provide plant operators with primary-secondary leak information.

Both primary and air ejector noble gas activities must be available for control room display. These are used, together with the ratio m/M, to determine leak rate, in g/s, from Equation (4), where t is measured from the first indication of leak onset. Since the water/steam cycle time, M/m, is of the order of a few minutes, the leak rate quite rapidly approaches its limiting value. If the leak rate, ℓ, is a slowly varying function of time, i.e., leak rate slowly increasing, then the time dependent leak rate can be approximated as

$$\frac{\Delta \ell}{\Delta t} \simeq \frac{1}{C_p} \frac{\Delta A_E(t)}{\Delta t} ,$$

for C_p = a constant. Thus, the rate of change of leak rate can be determined, at least in principle, by successive measurements of A_E, for time long compared to M/m.

To convert count rate at the air ejector to leak rate requires data reduction as outlined below. The count rate at the air ejector should be the sum of the noble gas contribution and any background count rate, presuming that the monitoring system filters particulates and iodines upstream of the noble gas counting geometry. After background subtraction, the count rate must be reduced to units of μCi/s. To accomplish this, from gross count rate, one must know the relative abundances of the noble gases, their decay constants, and counting efficiencies for each of the isotopic energies. To obtain A_E in μCi/s requires that flow rate, $\dot{V}_E$, in cm^3/s, be known. Decay constants for the noble gases are known; counting efficiencies must be determined at the time the counting system is calibrated. (Gross beta counting systems such as described here are routinely used for monitoring air ejectors in BWRs; calibration requirements and frequencies are part of BWR technical specifications.) Relative isotopic abundances are determined from analysis of the primary coolant, yielding C_p. The ratio, $\frac{m}{M}$, is known from reactor design specifications. The air ejector count rate can then be converted to the total activity, A_E, in μCi/s. The leak rate is then obtained from Equation (4).

CONCLUSION

This study has examined the early detection of onset of steam tube leaks in pressurized water reactors. It has identified which physical parameters in an operating reactor may be used in identifying a steam tube leak condition, has established performance goals required for detection of small leaks, has defined monitoring instruments and their locations for detection of early onset of a leak condition, and has discussed requirements for data processing and display. Steam tube leaks of <0.1 g/s should be detectable with existing instrumentation at existing sensor locations, i.e., the combination of a gross beta detection system for noble gases at the steam generator air ejector, installed at some operating plants, and a high resolution gamma ray spectrometer for a detection of noble gas activity in the primary coolant, also a part of some plants' instrumentation inventory.

Close monitoring of a steam generator tube leak could allow a scheduled shutdown of the reactor for steam tube repair, with attendant savings. Complete tube rupture could possibly be averted by instrumenting the derivative of the leak rate and providing the necessary alarms.

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APPENDIX A
STATEMENT OF WORK
DIAGNOSTIC INSTRUMENT EVALUATION

APPENDIX A
STATEMENT OF WORK
DIAGNOSTIC INSTRUMENT EVALUATION

B&R: 60190102

FIN: A6380

CONTRACTOR: IDAHO NATIONAL
ENGINEERING
LABORATORY

PRINCIPAL INVESTIGATOR: W. H. Roach

SITE: Idaho Falls

STATE: Idaho

FY 1984 PROGRAM BUDGET: $100,000

1.0 Background

Diagnostic instrumentation is desirable to (a) detect plant and equipment anomalies, (b) detect precursors to accidents, and (c) supply the plant operator with information on the status of systems important to the safety of a nuclear power plant (NPP).

The objective of this project is to evaluate key instrumentation that would diagnose plant status during normal, abnormal and shutdown conditions.

An evaluation of the state of the art (theory and hardware) and current practice in the use of diagnostic instrumentation and corresponding measurement methods important to safety was begun in FY 1982 and is scheduled for completion of FY 1984. Performance goals will be established and used as a guide in evaluating current diagnostic instrumentation system capabilities and needed improvements. Special emphasis will be given diagnostic instrumentation needs associated with the detection of PWR steam generator leaks in the FY 1984 efforts. Diagnostic measurements may include selected instrument readings, their trends, signatures and other significant information.

2.0 Work Required

The following tasks shall be performed by the contractor in FY 1984:

2.1 PWR Steam Generator Tube Leak Diagnostics

Complete detailed evaluation of diagnostic instrumentation needs for the timely detection of PWR Steam Generator tube leaks, which would include the identification of optimal sensor location.

2.1.1 Determine what physical parameters indicate degrading performance or onset of PWR steam generator tube leaks. List these parameters.

2.1.2 Establish performance goals for the diagnostic instruments being evaluated. These goals should be a trade-off between their reliability and cost. A suggested goal for the reliability should be 95% for the measuring system self-test and 90% for diagnostic ability, with appropriate confidence levels. Also, the system must be stable with time and for most measurements, the instrument channel drift should be smaller than 0.5% during the surveillance interval.

2.1.3 Define diagnostic instrumentation to monitor the parameters identified in Subtask 2.1.1, that will fulfill the performance goals established in Subtask 2.1.2. Evaluate the need to implement (periodic or on-line) self-testing, in these instruments to ensure fulfillment of these performance goals.

2.1.4 Assess needs for diagnostic data processing and display. Needs should be identified in sufficient detail to enable comparison with existing plant data processing and display capabilities.

APPENDIX B
EXCERPT FROM THE FINAL SAFETY ANALYSIS REPORT

APPENDIX B
EXCERPT FROM THE FINAL SAFETY ANALYSIS REPORT[7]

Radiation Detectors

The detector assembly is a completely weatherproof assembly, housing a detector, photomultipliers, and radiation check source. The assembly is capable of withstanding the design pressure and temperature of the piping system of which it is a part.

The detector assembly is incorporated in the sampler assembly. All detector assemblies are designed to detect over their specified ranges in a 2.5-mr/h (1 MeV gamma) external field.

A shielded photomultiplier is provided integral with the detector to ensure reliable transmission of a high signal-to-noise ratio.

Scintillation detectors are beta- or gamma-sensitive detectors suitable for analysis of photopeaks up to 2.5 MeV and beta energy up to 5.0 MeV.

The detector is one of the following types.

Single-Stage Liquid Monitor

A single-stage liquid monitor consists of a gamma sensitive scintillation detector, coupled to a photomultiplier tube which is protected by an electromagnetic shield. The minimum detection limit of the monitor for Cs-137 in a 1-mr/h background of Co-60 gamma radiation at a 95% confidence level is 1×10^{-6} μCi/cm^3 for one minute counting time. The resolution of the detector is less than 10% Full Width at Half Maximum (FWHM) at 0.662 MeV (Cs-137).

Single-Stage Gaseous Monitor

A single-stage gaseous monitor consists of a beta sensitive plastic scintillation radiation detector, coupled to a photomultiplier tube which is protected by an electromagnetic shield. Figure 2 (see Figure 2 in text) is a block diagram showing the components of the monitor.

The minimum detectable limit of the monitor for Xe-133 in a 1-mr/h background at a 95% confidence level is 1×10^{-6} μCi/cm^3, based on a sample flow rate of 1 scfm and a one-half minute counting time. The response of the detector is at least three times the square root or background above background.

Condenser Air Ejector Monitor

The condenser air ejector monitor is a single-stage gaseous monitor. The monitor measures noncondensable fission product gases in the condenser air ejector discharge to detect any primary-to-secondary leakage. The presence of radioactivity in this line indicates a primary-to-secondary leak in the steam generators. The predominant isotopes would be Kr-85 and Xe-133, with presence of iodine. The function of this monitor is to alarm in the event of a primary-to-secondary steam generator tube leak.

The monitor is located on the common header downstream of the air ejector after condensers discharge. The alarm set point would be set slightly higher than expected plant background.

Calibration and Inspection

A remotely- or manually-operated check source is provided with each detector assembly. The check source isotope has a half-life >7 yr, with emissions in the energy range and of the same type as being monitored, and is usable as a convenient operational and gross calibration check of the associated detection and readout equipment. The check source strength provides a count rate of ∿1.5 decades above background. The check source controls are mounted on the channel indicator module in the control cabinets. These check sources can be activated automatically through the CRT keyboards in the control room, the health physics office or radiochemistry laboratory.

Isotopic calibration of the complete radiation monitoring system is performed at the factory. Field calibration sources, with their decay curves, are provided with the system hardware. For the high range in containment monitor, a current source will be used for calibration of the radiation ranges above 10 R/h.

Further isotopic calibrations are not required, since the geometry cannot be altered significantly within the sampler. Calibration of samplers is then performed, based on a known correlation between the detector responses and field calibration standards.

This single-point calibration confirms the detector sensitivity. The field calibration is performed by removing the detector and placing the calibration source on the sensitive area of the detector.

The radiation monitoring channels are checked and inspected in accordance with the Technical Specifications. Grab samples are collected for isotopic analysis weekly as described in the subsequent sections. Set point adjustment and functional testing are done on a monthly basis, and calibration is performed at each refueling shutdown or indication of equipment malfunction.

Controls and Alarms

All monitors are provided with either a local control and display unit located near the monitor or a portable indicator control box capable of accessing the monitor control features and data base. Either of the two units provide information relating to operational mode, alarm status and data output. Purging, check source actuation, valve and pump control, and various test mode actuations may be done locally and with the exception of valve control, within the cabinets at the various operator's terminals.

The digital information from all channels is stored by the redundant computer and displayed at the three operator consoles on cathode-ray tube (CRT) displays. If an alarm condition is detected, a status change occurs at each of the three CRTs and logging of the alarm occurs automatically. Monitor status, radiation level, and alarm status are displayed. Alarms include two up-scale trips to indicate high radiation levels and one downscale trip to indicate instrument trouble. For those channels designated as safety related, data displays and strip-chart recorders are also present in a safety related panel in the control room.

For those channels which perform control action, any one of the following automatically sends an isolation signal to the valve located on the monitored line to prevent further flow; radionuclide concentrations above the preset "high" radiation trip point, failure of the detector or sample pump, or loss of flow to the sampling chamber.

Alarm set points are variables over the entire dynamic range and are set from the control room. Alarm set points may be introduced or changed from the following locations: (a) for safety related monitors; from the individual channel control and display units located in the control room safety cabinets, and (b) for non-safety related monitors; from any of the three CRTs, locally by means of the local control unit. All alarm set points are protected and changed only by means of proper access identification. Exact set point depends on background and plant conditions. For effluent monitors, high-high alarms indicate before 10 CFR 20 limits are reached.

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