2021 NRC Staff Training

Calibration
of
Containment & Dry Well
Ion Chamber
High Range Rad Monitors

(CHRMs)

Disclaimer

- This was a training course in 2021 for NRC inspection staff. This training is intended to provide inspectors with basic knowledge of the calibration process.
- This training is not an instruction manual for licensees to use in the calibration of radiation monitors.
- This training does not establish any new NRC position on calibration of radiation monitoring equipment.
- The training material should not be used by licensees to demonstrate compliance with NRC requirements.
- NRC does not endorse or make any recommendations on selection of any vendor radiation monitoring equipment.

Table of Contents

Module 1

Introduction
&
Background

Training Objectives

- Provide inspector training on calibration of CHRMs
- Provide the regulatory basis for calibration requirements
- Describe calibration methods for the:
  - Primary calibration of the original "Design" detector
  - Calibration of "Production" (replica) detectors
  - "Transfer" calibration using "Field Calibrator"
  - "In Situ" (in-plant) calibration

Detector Terminology

- Prototype (design) ion chamber/detector
  - The original design detector that is fully-tested by the manufacturer/vendor
  - Was used to establish a generic calibration constant of approximately **(1E-11** $\frac{Amps}{R/hr}$**)**
- Production (replica) detectors
  - Production detectors are replicas of the "Design" detector made for sale to power plants
  - Manufacturers made several production detectors (~200 - ~300 detectors were sold to plants)
- Field Calibrators – calibration jigs

LND Ion Chambers

- Ion chambers are made commercially and sold to vendors
- Some ion chambers have an energy response (flattening) shield
- Ion chambers are tested for dose-rate linearity to ~ 10,000,000 R/hr
- Ion chambers are energy response tested from ~ 80 keV to 3 MeV

Typical CHRM Ion Chamber

~ 3 inch diameter

~ 8 inch length

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Module 2

Regulatory Basis

Regulatory Basis

- NRC Regulations
  - General Design Criteria 64 – Accident Monitoring
  - 10 CFR 50.34 – Plant Design Criteria
  - 10 CFR 20.1501(c) - Calibration
  - Tech Specs on CHRMs and Post Accident Monitoring
- Regulatory Guides
- NUREGs
- HPPOS

General Design Criterion 64
Monitoring Radioactivity Releases

- Provide radioactivity monitoring, including postulated accidents for:
  - containment atmosphere
  - effluent discharges
  - (offsite) plant environs

NRC Regulations

- 10 CFR 50.34 (f) "Additional TMI-related requirements"
  - paragraph 50.34(f)(2)(xvii) - Provide for containment radiation intensity (high level), and noble gas effluents, and continuous sampling of iodines and particulates in gaseous effluents
- 10 CFR 20.1501(c) calibration
  - Instruments and equipment must be calibrated periodically for the radiation measured

Example: Tech Specs
NUREG-1431

3.3 INSTRUMENTATION

3.3.3 Post Accident Monitoring (PAM) Instrumentation

LCO 3.3.3 The PAM instrumentation for each Function in Table 3.3.3-1 shall be OPERABLE.

SURVEILLANCE		FREQUENCY
SR 3.3.3.1	Perform CHANNEL CHECK for each required instrumentation channel that is normally energized.	[31 days <u>OR</u> In accordance with the Surveillance Frequency Control Program]

Tech Specs

Table 3.3.3-1 (page 1 of 1)
Post Accident Monitoring Instrumentation

FUNCTION	REQUIRED CHANNELS	ACTION D.1
10. Containment Area Radiation (High Range)	2	F

5.6.5 Post Accident Monitoring Report

When a report is required by Condition B or F of LCO 3.3.[3], "Post Accident Monitoring (PAM) Instrumentation," a report shall be submitted within the following 14 days. The report shall outline the preplanned alternate method of monitoring, the cause of the inoperability, and the plans and schedule for restoring the instrumentation channels of the Function to OPERABLE status.

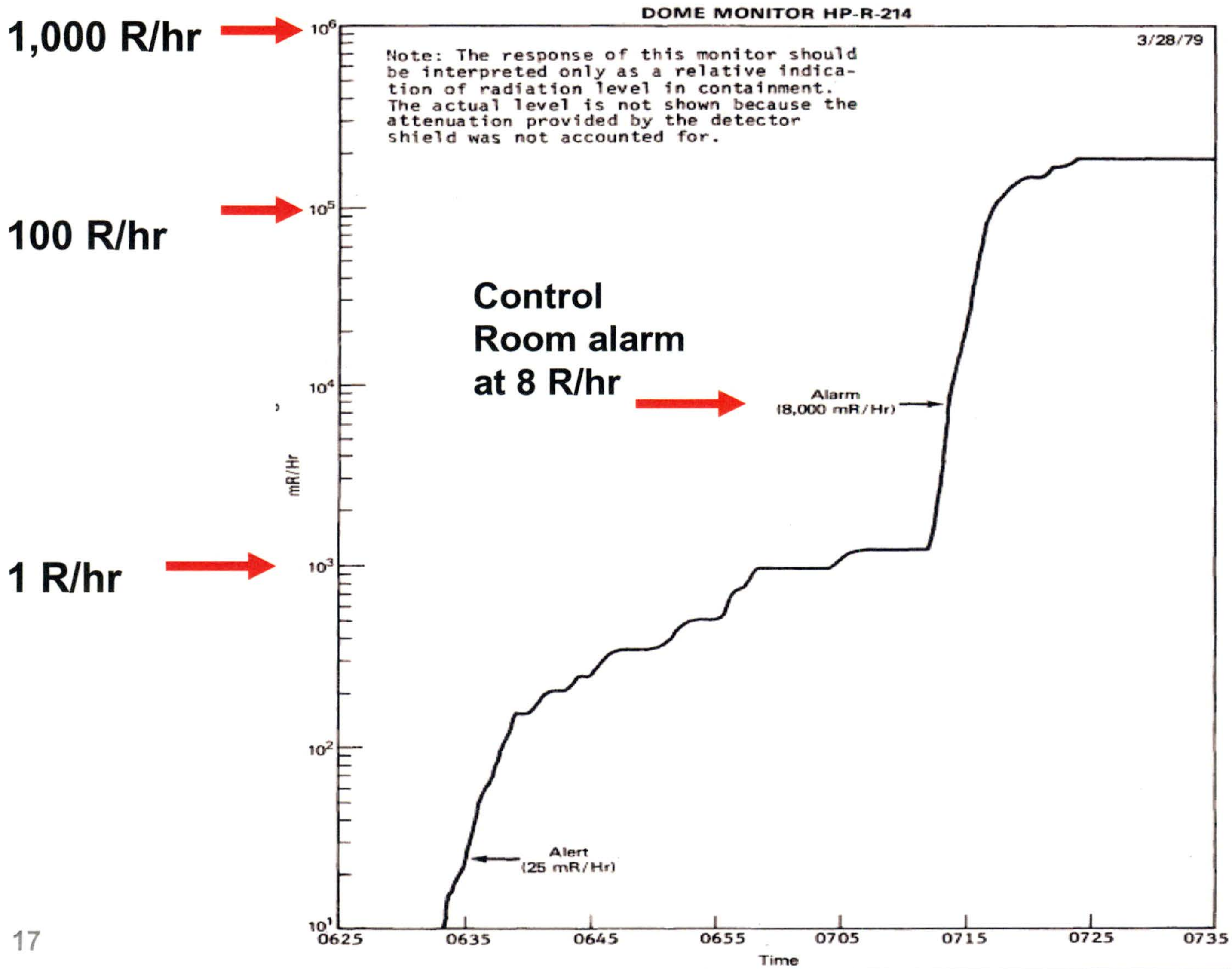
RTM-96 and RASCAL NUREG-1940 (2012) Rev. 4

- NRC Response Technical Manual (RTM) - 96
- NUREG-1940, RASCAL, Section 1.2.4
- Provides estimated core damage as a function of containment radiation levels (see next slides)

Containment / Drywell Dose Rates (per RTM-96)

- CHRMs will detect RCS leakage into containment
- Approximate (nominal) thresholds values for CHRMs:
  - ~ 1 R/hr
    → Minimum steady state value during normal operations
  - ~ 200 R/hr
    → Approx. max TMI-2 reading (even with loss of RCS and core melt)
  - ~ 1 R/hr – 10,000 R/hr
    → Some fuel failure with loss of RCS barrier
  - ~ 10,000 R/hr – 100,000 R/hr
    → Loss of fuel cladding & loss of RCS barrier
  - ~ 100,000 R/hr – 10,000,000 R/hr
    → Core melt with loss of RCS barrier

TMI-2 CHRMs Readings (NUREG-0600)



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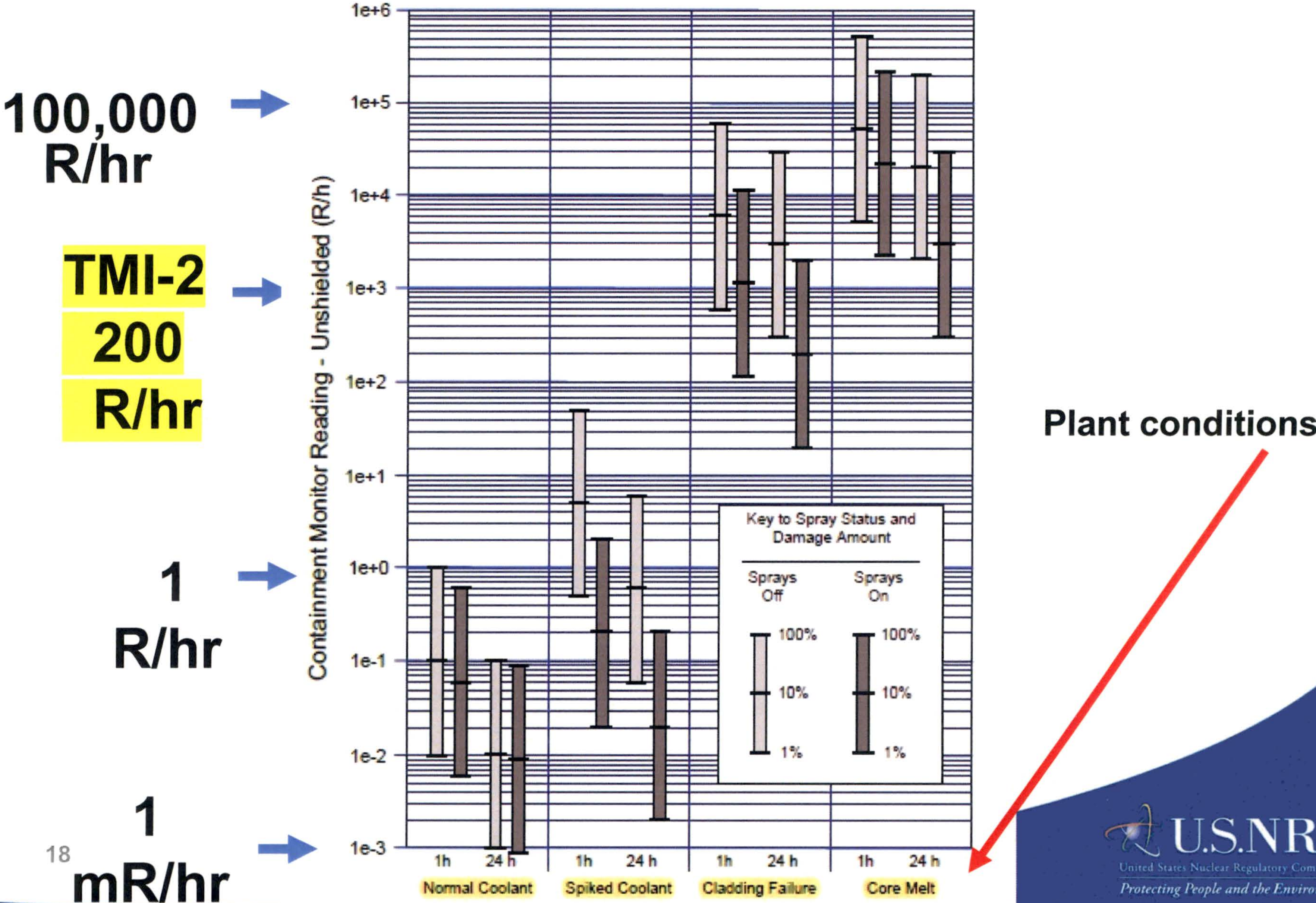
PWR Containment

RTM-96/ NUREG-1940



BWR Mark I and II

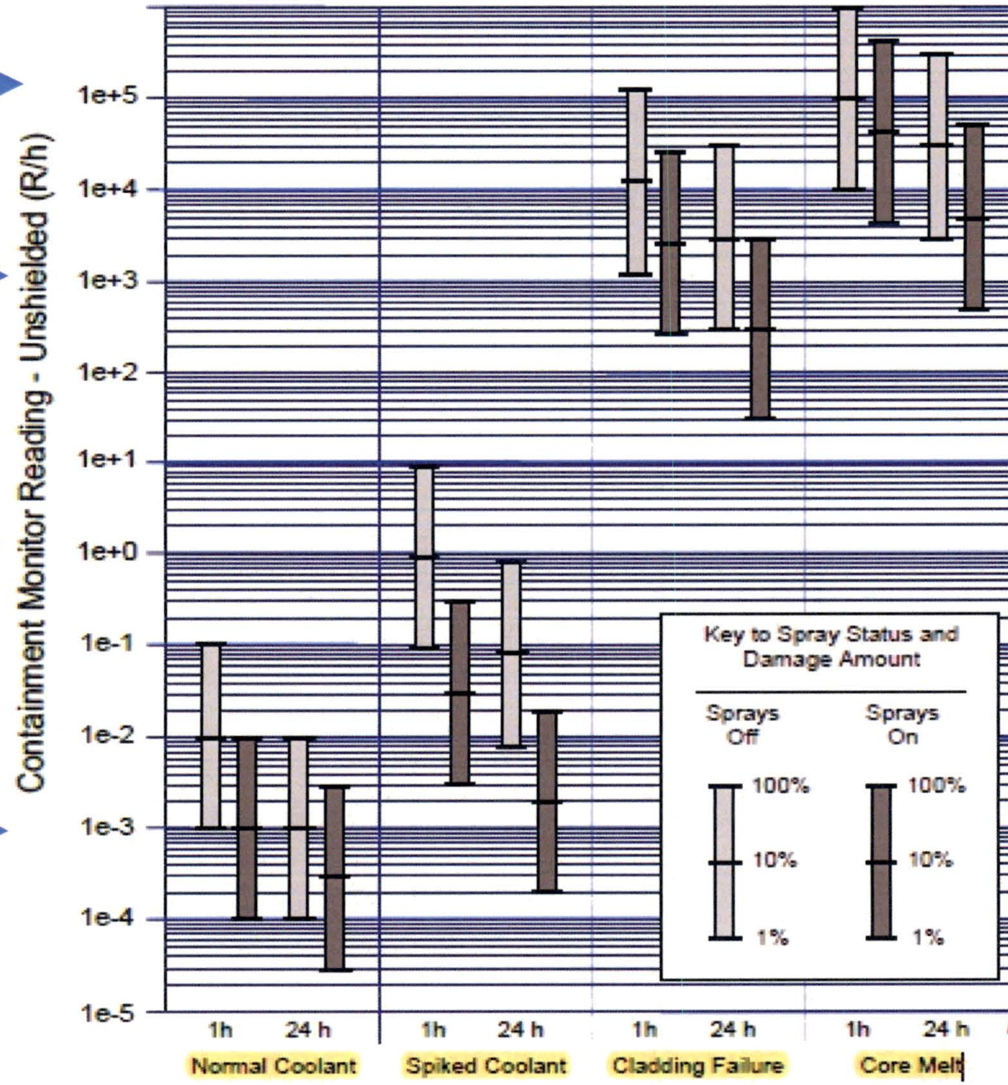
RTM-96/ NUREG-1940

100,000 R/hr

1,000 R/hr

1 R/hr

1 mR/hr



Plant conditions

BWR Mark III

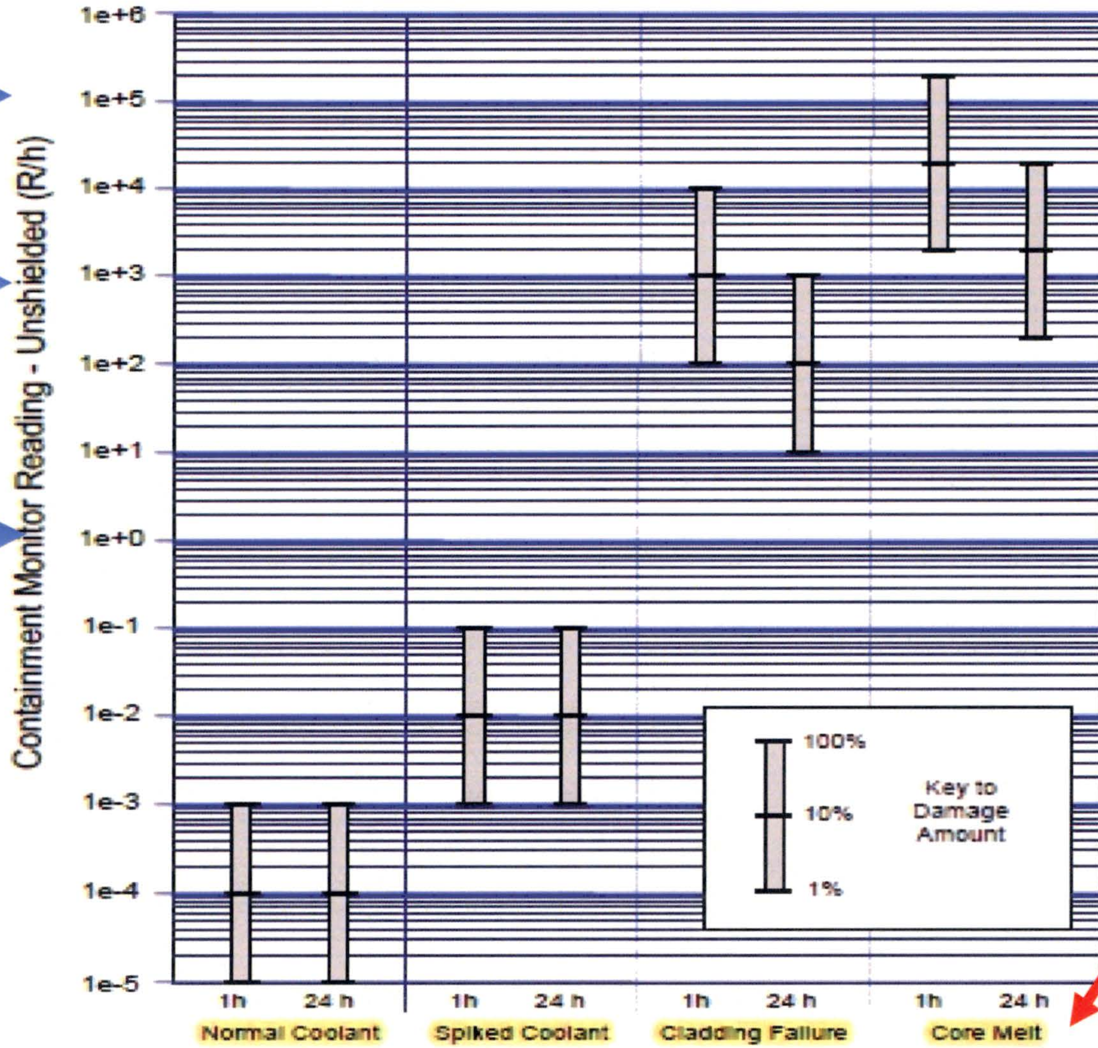
RTM-96/ NUREG-1940

100,000 R/hr

1,000 R/hr

1 R/hr

1 mR/hr



Plant conditions

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ANSI Standards

- ANSI calibration standards are not NRC requirements, but are good practices
- 5 broad categories of ANSI standards
  - Portable survey instruments
  - Fixed instrumentation
  - Air sampling
  - Effluent monitoring
  - Emergency instrumentation

Partial List of Current ANSI Standards

- ANSI N13.10 -1974 – Instrumentation for Monitoring Routine Effluents (replaced by ANSI N42.18-1980)
- **ANSI N323-1978 – Calibration of Portable Instruments**
- **ANSI N320-1979 – Emergency Instrumentation (R1993, draft 2019)**
- ANSI N323D-2002 – Installed routine instrumentation
- ANSI N42.18-2004 – Effluent Monitoring (replaced by N42.54)
- ANSI N323C-2009 – All air monitoring instruments
- ANSI N13.1-2011 – Air Sampling (1969, 1999, 2011, draft 2021)
- ANSI N42.54-2018– Instrumentation for Monitoring Airborne RAM (combines N42.17B, N42.18, N42.30 and N323C)
- ANSI N42.33-2019 – Portable Exposure Rate Meters

Transfer Instrument

- ANSI terminology uses the term a “Transfer Instrument” and “Transfer Standard”
- A Transfer Instrument is basically called a “Field Calibrator” or a “Calibration Jig,”
- Field Calibrator is used to expose the detector in a fixed geometry to a standard radioactive source

ANSI N323-1978 Portable Instruments

Section 5.1 Calibration Standards

– ANSI N323-1978 generally applies to portable instrumentation

– ANSI N323-1978 principles are also applicable to fixed instrumentation (such as CHRMs)

Transfer Instrument
ANSI N323-1978 Portable Instruments

- Section 5.1 Transfer calibrations
    - Instruments should be calibrated against a national or derived source
- Section 5.2 Transfer (Field Calibrator) Precision
    - (Geometry) positioning errors should be less than ± 2%

ANSI N320-1978
Emergency Instrumentation

- Section 5.7 Overall System Accuracy ± 40%
  - Accuracy – how close the measurement is to the right answer (conventionally true value)
    - Overall system accuracy shall be within ± 40%
    - Note: "Calibration" criteria should not be confused with the "design" criteria
    - The factor of 2 in RG 1.97 is a design criteria for detector response from 60 keV to 3 MeV

IEEE Std 497-2017

Criteria for accident monitoring instrumentation

- Annex A - Accident monitoring instrument channel accuracy

- Logarithmic scales – required accuracy ± 50%

ANSI N320-1978
Emergency Instrumentation

- Section 5.7, Overall System "Precision"
  - Precision (repeatability) – repetitive measurements give "similar" answers within one or two standard deviations
  - Small changes in calibration geometry can make large changes in detector output and a decrease in precision

Exposure Geometry

- There are two different exposure geometries, (each has a specific purpose)
  1. Initial calibration is a uniform exposure geometry (similar to the exposure geometry in containment or dry well), used to establish the CHRMs calibration constant
     - The calibration constant is used in the microprocessor to convert output (amps) into a dose rate R/hr

  2. Plant calibration "check"
     1. Geometry is a non-uniform exposure geometry,
     2. Calibration check is used to make sure the CHRMs are working properly

Exposure Geometry

1. Uniform exposure geometry occurs when measuring actual dose rates in containment/drywell during an accident

2. Non-uniform exposure geometry occurs during in-plant calibrations, when there is a short distance between source and detector
   - Short distances are needed in order to get on-scale "high" dose rates from 1- 10 R/hr
   - Non-uniform geometry is acceptable for use in a Field Calibrator

Uniform Radiation Field

ANSI N323-1978 Portable Instruments

- Section 6.1 - Uniform radiation field
  - The distance between a source and the radioactive source must be 7 times the largest dimension of detector
    - An ion chamber detector with an 8-inch length would require the point source to be located 4.7 feet away!!
    - The dose rate throughout the detector is then 99.5% of dose rate at the detector center
    - However, the dose rate at a distance of 7X would be very small, unless the source activity is very high

Uniform Exposure Geometry

- NCRP-112, §§ 4.3.3
  - radiation field (for determining the initial calibration constant) should be uniform over the cross-section or depth of the detector
  - Note: CHRM manufacturer performs the original calibrations using uniform broad beam geometry, in units of $\frac{amps}{R/hr}$

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Non-Uniform Exposure Geometry

- "Field Calibrators" do not provide uniform dose rates over the volume of the detector
- That is acceptable because
  - the purpose is to determine if the CHRM is working properly by comparison to original Transfer calibration
  - The CHRM is measuring a reproducible, repeatable, non-uniform radiation field
  - The idea is to ensure the CHRM is working the same as it was first calibrated by the vendor/manufacturer

NCRP-112, §2.7.1
Common Causes of Error (Uncertainty)

- Erroneous measurement in the Field Calibrator
  - **Geometry errors – i.e., source-to-detector measurement (especially at small distances)**
  - Inability to read a distance scale or an instrument scale
  - Parallax reading error
- Half-life decay corrections

"Overall" Uncertainty NCRP-112, §2.7.1

- The likely uncertainty which combines statistical treatments and systemic error (NCRP-58 (1985)
- NRC notes:
  - **Geometry / positioning errors (using home-made field calibrators) is the most likely source of error and errors can be large**
  - Statistical (counting) error is insignificant with high dose rates
  - Instrument display / reading error

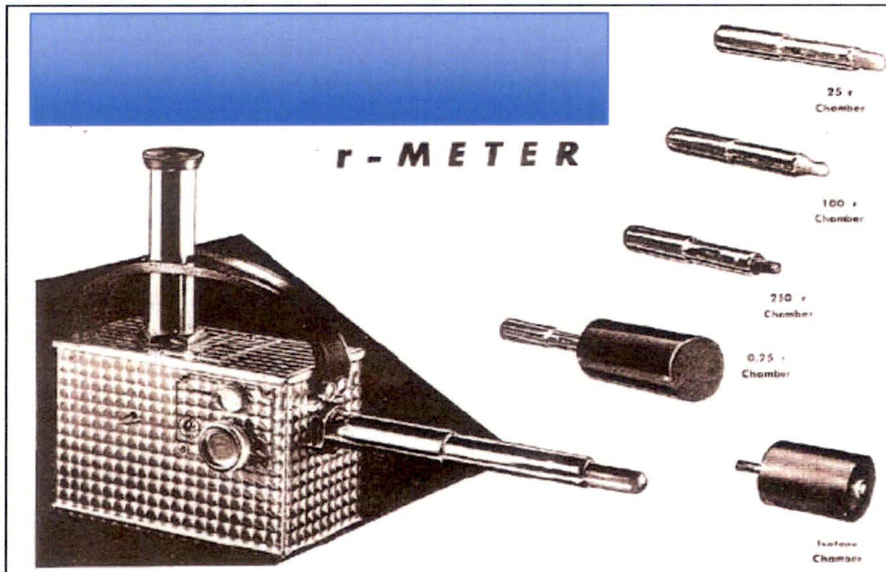
Example: Uncertainty/Error Analysis

- Typical uncertainty
  - Field Calibrator accuracy ± 5%
  - Pico-amp measuring error ± 2%
  - Detector precision ± 20%
  - Nuclide / Isotope accuracy ± 20%
- Total uncertainty = SQRT of sum of squares
- $= 5^2 + 2^2 + 20^2 + 20^2 = 829\%$
- SQRT of 829% = 28.8% total uncertainty
- ANSI N320-1980 criteria ± 40%
- IEEE 497-2017 criteria is ± 50%

NIST Traceability

- NIST/NBS Measurement Assurance Program (MAP) certification process
  - Supplier submits a calibrated source to NIST/NBS, or
  - NIST/NBS provides calibrated blind test sources

Typical Condenser R meter Used for NIST Traceability



. . . with a chamber for YOUR application

For twenty years, the Condenser r-meter with modifications and refinements has been accepted as a secondary standard for accurate measurement of x-radiation.

ANSI N42.22-1995 (R2002)
NIST Traceable Sources

- Manufacturer's can get qualified by NIST, and then establish NIST-traceable source activities

- ANSI Std N42.22 provides a description of the criteria necessary for manufacturers (or any organization) to get qualified (to establish traceability of radionuclides to NIST)

ANSI N42.22
Definitions

- Section 3.3 Manufacturer – any commercial organization approved by NIST (through a MAP) to produce or distribute certified NIST-traceable sources
- Section 3.4 MAP – A NIST "Measurement Assurance Program" allowing manufacturers to produce certified sources

ANSI N42.22
Definitions

- 3.4 Measurement Assurance Program (MAP)
  - manufacturers must demonstrate their capability to produce accurate standardized sources by participation in a NIST

- 3.8 NIST traceability
  - the process of relating the accuracy of sources to national physical standards

ANSI N42.22
Definitions

- Section 3.6 NIST source verification
  - Process of verifying that manufacturers are qualified to create NIST traceable sources
  - process of qualifying manufacturers to create NIST traceable sources
- Section 3.7 Product verification – manufacturer submits a (calibrated) source to NIST for verification
- Section 4.7 and 4.9 NIST Traceable Certificates – are provided by manufacturers to its customers

ANSI N42.22 NIST

- Section 6. Measurement Assurance Program (MAP)
  - Requires vendors/manufacturers to perform annual verification tests for each calibration techniques and instrument type
  - Manufacturers analyze blind samples supplied by NIST

NIST-traceable Sources

- Provides data on Radionuclide, Activity, Date of Assay, Dose rate
- The dose rate given on source certificates is not useful information for CHRMs calibrations; i.e.,
  - Certificates provide dose rate at a "point" (narrow beam geometry)
  - Detectors have volume, CHRMs have a ~3-inch diameter, 8-inch length
  - At close distances, a point source, placed 2 inches from an 8" detector does not provide a uniform radiation field
  - Makes a big difference in the detector output

TMI-2 Accident

- **During TMI-2 accident, NRC and plant staff did not know:**
  - **status of reactor core and threat level to the public**
  - **what to recommend for Protective Action Recommendations**
- **NRC Immediate Response**
  - Accident started at 4 am, March 28, 1979
  - NRC staff arrived at 10 am, set up in conference room with glass window looking into Control Room (no Technical Support Center or EOF)
  - Control Room air monitor alarmed, Operators & Chemists wore respirators
  - Chemists pulled samples;
    - 90 R/hr sample line valve
    - 400 R/hr at 1 foot on a 300 ml RCS sample
    - 2 or 3 overexposures (of quarterly limits)

TMI-2 Report on Radiological Aspects

- NRC staff (I&E) prepared a comprehensive technical report on radiological aspects
  - Contained in NUREG-0600 (ML090050311)

- **Radiological Aspects in NUREG-0600**
  - Summary - pgs 13 – 21 (pdf pgs 31 – 39)
  - Appendix II "Details"
    - Document pages pg II -1 to II-E-6)
    - Pdf pgs 436 - 779

Post-TMI Requirements

- **<u>NRC issued new recommendations and requirements:</u>**
  - NUREG-0578 (July 1979) – Post-TMI Short Term Recommendations (Item 2.1.8) (ML090060030)
  - NUREG-0660 (May 1980) – NRC Action Plan, Vol. 1 and 2 (ML072470526 and ML072470524)
  - NUREG-0737 (Nov 1980) – Clarification of NRC Action Plan (ML051400209)
  - New equipment requirements included:
    - **Containment High Range Monitors (CHRMs)**
    - **Post Accident Sampling Systems (PASS)**

NRC's Emergency Response Data System (ERDS)

- 10 CFR 50, Appendix E, Section VI
- NUREG-1394, ERDS Implementation (ML080790038)
  - A real-time electronic data link between licensee's computer systems and NRC Ops Center
  - Software provided by NRC to collect accident data
  - Data on 4 categories of plant conditions
    - Rx core and coolant systems
    - Rx containment
    - Radioactivity Release Rates
    - Met tower data

ERDS Data
NUREG-1394

2. ERDS Information

2.1 ERDS Design Concept

The system selected to fulfill the data collection needs of the NRC is the Emergency Response Data System (ERDS). The Emergency Response Data System concept is a direct electronic transmission of selected parameters (Figures 1 and 2) from the electronic data systems that are currently installed at licensee facilities.

Radiation Monitoring System	Reactor Coolant Radioactivity Level Primary Containment Radiation Level Condenser Off-Gas Radiation Level Effluent Radiation Monitor Process Radiation Levels
Meteorological	Wind Speed Wind Direction Atmospheric Stability

Post-TMI Requirements

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    - **Post Accident Sampling Systems (PASS)**

NRC Communications following TMI-2 accident

1 - September 13, 1979 Letter to Operating Licensees (ML073520999).pdf
2 - October 30, 1979 Letter to Licensees WITH ENCLOSURES (ML031320403).pdf
3 - GL 79-40 September 13, 1979 Letter to Operating Licensees WITH ENCLOSURES (ML031320328).pdf
4 - GL 79-40 September 13, 1979 Letter to Operating Licensees WITHOUT ENCLOSURES).pdf
5 - GL 79-56 October 30, 1979 Letter to Licensees WITH ENCLOSURES (ML031320403).pdf
6 - GL 79-56 October 30, 1979 Letter to Operating Licensees (rad excerpts) (ML031320403).pdf
7 - GL 79-60 November 9, 1979 Letter to pending Operating Licensees with no Enclosures (ML073521000).pdf
8 - GL 79-61 Nov 9, 1979 Letter to pending Construction Permit applicants with no Enclosures.pdf
NUREG-0578 Excerpts - Rad Monitoring.pdf
NUREG-0578 Excerpts - Rad Monitoring.pdf
NUREG-0737 1980 Excerpts II.F.1 Hilites Effluent Monitoring ML051400209 .pdf

NRC Letters, Commitments, Orders

- **The September 13, 1979,** letter (ML073520999) to licensees gave operating plants 30 days to review and make commitments to meet these NUREG-0578 requirements or to take exception and provide a justification

- **The October 30, 1979,** letter (ML031320403) gave operating licensees, when not in complete agreement with the post-TMI action plans, 15 days to figure out how to comply or take exception to the action items, and to respond to the NRC

- Licensees made commitments to NRC

- NRC followed with Orders issued to each licensee to implement their commitments

NUREGs and Letters to Licensees

- September and October 1979 letters instructed licensees to **review** the NRC staff recommendations in NUREG-0578 (dated July 1979) and to make **commitments** to the NRC within 30 days to implement the NUREG-0578 items
- May 1980 - NUREG-0578 items had not yet been reviewed and approved by the NRC Commission. Subsequently, NUREG-0578 items were modified and expanded by NRC staff to a comprehensive list, which were published as NUREG-0660.
- November 1980 - NUREG-0660 items were reviewed by the Commission and a subset of items were approved by the Commission and published in NUREG-0737.
- NUREG-0737 included Item II.F.1 with expanded guidance on the design of monitoring and calibration requirements.

NUREG-0737
(NRC ADAMS No. ML051400209)

Item II.F.1

Additional Radiation Monitoring Requirements

NRC Letters, Commitments, Orders

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NUREG-0737 Item II.F.1

II.F.1 ADDITIONAL ACCIDENT-MONITORING INSTRUMENTATION

Introduction

Item II.F.1 of NUREG-0660 contains the following subparts:

(1) Noble gas effluent radiological monitor;

(2) Provisions for continuous sampling of plant effluents for postaccident releases of radioactive iodines and particulates and onsite laboratory capabilities (this requirement was inadvertently omitted from NUREG-0660; see Attachment 2 that follows, for position);

(3) Containment high-range radiation monitor;

(4) Containment pressure monitor;

(5) Containment water level monitor; and

(6) Containment hydrogen concentration monitor.

NUREG-0578 provided the basic requirements associated with items (1) through (3) above. Letters issued to all operating nuclear power plants dated September 13, 1979 and October 30, 1979 provided clarification of staff requirements associated with items (1) through (6) above. Attachments 1 through 6 present the NRC position on these matters.

NUREG-0737 Table II.F.1-3

TABLE II.F.1-3

CONTAINMENT HIGH-RANGE RADIATION MONITOR

REQUIREMENT	-	The capability to detect and measure the radiation level within the reactor containment during and following an accident.
RANGE	-	1 rad/hr to 10^8 rads/hr (beta and gamma) or alternatively 1 R/hr to 10^7 R/hr (gamma only).
RESPONSE	-	60 keV to 3 MeV photons, with linear energy response $\pm$ 20%) for photons of 0.1 MeV to 3 MeV. Instruments must be accurate enough to provide usable information.
REDUNDANT	-	A minimum of two physically separated monitors (i.e., monitoring widely separated spaces within containment).
DESIGN AND QUALIFICATION	-	Category 1 instruments as described in Appendix A, except as listed below.
SPECIAL CALIBRATION		In situ calibration by electronic signal substitution is acceptable for all range decades above 10 R/hr. In situ calibration for at least one decade below 10 R/hr shall be by means of calibrated radiation source. The original laboratory calibration is not an acceptable position due to the possible differences after in situ installation. For high-range calibration, no adequate sources exist, so an alternate was provided.
SPECIAL ENVIRONMENTAL QUALIFICATIONS	-	Calibrate and type-test representative specimens of detectors at sufficient points to demonstrate linearity through all scales up to 10^6 R/hr. Prior to initial use, certify calibration of each detector for at least one point per decade of range between 1 R/hr and 10^3 R/hr.

NUREG-0737, Item II.B.3

PASS – Post Accident Sampling Systems

Post Accident Sampling Equipment

NUREG-0737, Item II.B.3
Post-Accident Sampling Equipment

Position

A design and operational review of the reactor coolant and containment atmosphere sampling line systems shall be performed to determine the capability of personnel to promptly obtain (less than 1 hour) a sample under accident conditions without incurring a radiation exposure to any individual in excess of 3 and 18-3/4 rem to the whole body or extremities, respectively. Accident conditions should assume a Regulatory Guide 1.3 or 1.4 release of fission products. If the review indicates that personnel could not promptly and safely obtain the samples, additional design features or shielding should be provided to meet the criteria.

A design and operational review of the radiological spectrum analysis facilities shall be performed to determine the capability to promptly quantify (in less than 2 hours) certain radionuclides that are indicators of the degree of core damage. Such radionuclides are noble gases (which indicate cladding failure), iodines and cesiums (which indicate high fuel temperatures), and nonvolatile isotopes (which indicate fuel melting). The initial reactor coolant spectrum should correspond to a Regulatory Guide 1.3 or 1.4 release. The review should also consider the effects of direct radiation from piping and components in the auxiliary building and possible contamination and direct radiation from airborne effluents. If the review indicates that the analyses required cannot be performed in a prompt manner with existing equipment, then design modifications or equipment procurement shall be undertaken to meet the criteria.

Post-Accident Sampling Systems (PASS)

- NUREG-0737 (ADAMS No. ML051400209)
- Item II.B.3 PASS Sampling Capability
- Requirements for:
  - Reactor coolant sampling
  - Containment atmosphere sampling
  - Obtain samples within 1 hour, under accident conditions, without exceeding personnel dose limits (3 rem whole body and 18.75 rem extremities)

PASS Analysis Requirements

- Plants were required to develop capability:
  - Within 2 hours to perform radiological spectrum analysis of RCS samples and containment atmosphere for, noble gases, iodines and cesium, and non-volatile isotopes indicating fuel melt
  - Consider interference from direct radiation
- If existing equipment is inadequate, perform design modifications and procure equipment
- Include a capability to perform chemical analyses for boron and chlorides on a highly radioactive sample

PASS Systems

- PASS systems were installed in NPPs
- Plants had difficulty in meeting regulatory criteria
- In ~1984, licensees/vendors proposed an alternative to PASS using the concept of a Core Damage Assessment Model (CDAM)
- CDAMs were submitted to NRC and approved as a replacement for some of the PASS requirements

Core Damage Assessment Models (CDAMs)

- CDAMs are primarily based on:
  - Core Exit Thermocouple (CET) temperatures
  - RCS pressure and water level
  - Containment hydrogen concentrations
  - Containment High Radiation Monitor (CHRMs) readings

NUREG-0737
Radiation Monitoring During Accidents

- Item II.F.1 Additional Accident-Monitoring Instrumentation – 3 main criteria:
  - II.F.1-1 Noble Gas Effluent Monitoring
  - II.F.1-2 Iodine and Particulate Monitoring
  - II.F.1-3 Containment High Range Monitoring

Radiation Monitoring Design Criteria

- NUREG-0737, pg II.F.1-11, Item 5, and RG 1.97, footnote 7 are instrument **"Design Criteria" (not "instrument calibration" criteria)**

- Detectors should respond to gamma radiation in the range from 60 keV – 100 keV within a factor of 2

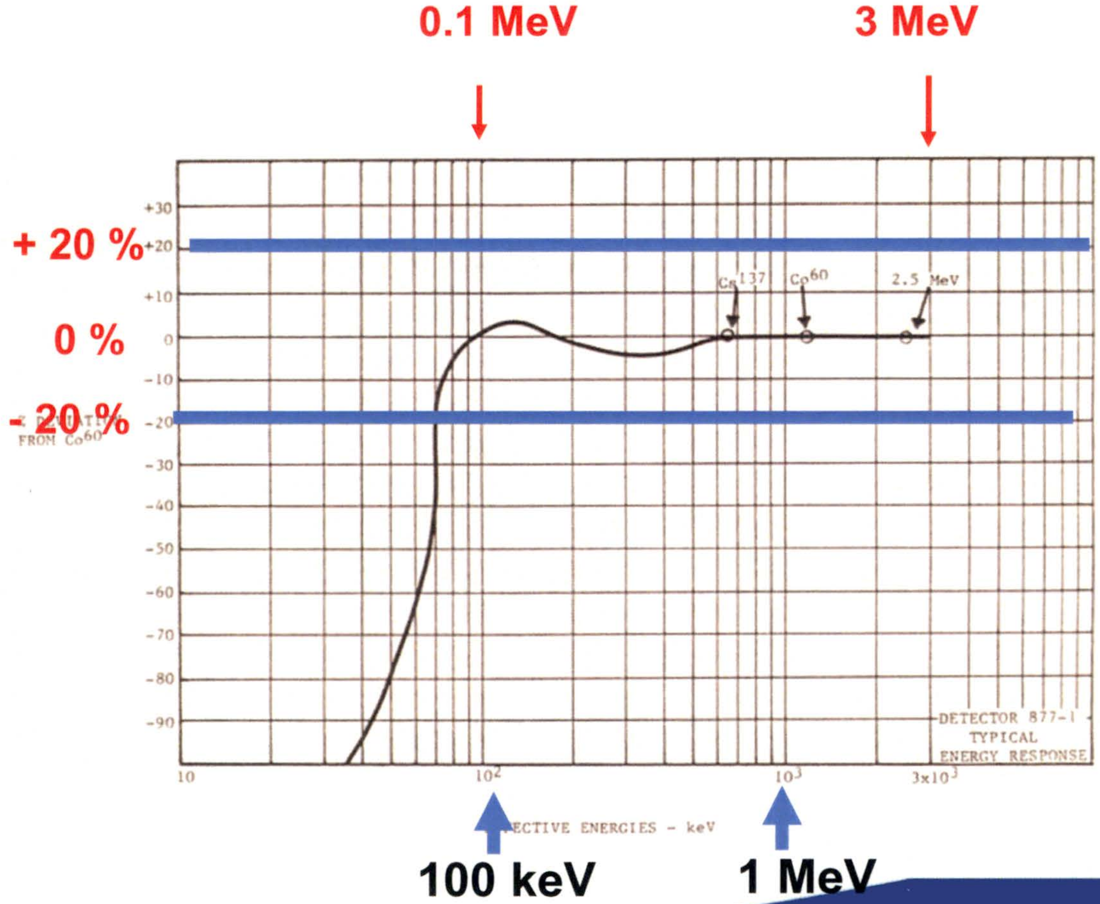
- Detectors should have an energy response accuracy of ± 20% from 100 keV – 3 MeV

[7] Detectors should respond to gamma radiation photons within any energy range from 60 keV to 3 MeV with an energy response accuracy of ±20 percent at any specific photon energy from 0.1 MeV to 3 MeV. Overall system accuracy should be within a factor of 2 over the entire range.

Typical CHRMs Ion Chamber

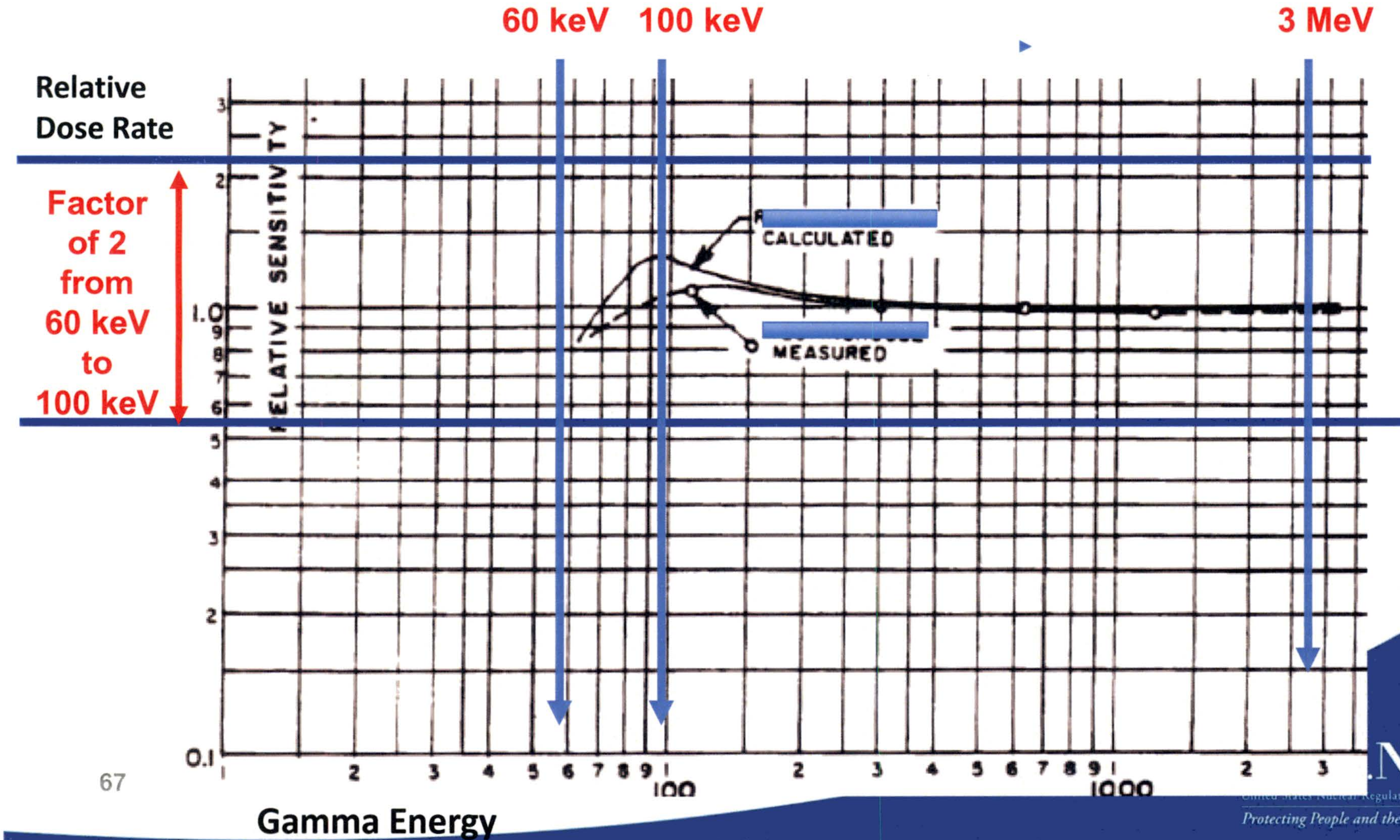
Design Criteria: Dose Rate vs Gamma Energy

RG 1.97, footnote 7: ± 20% from 100 keV to 3 MeV



Dose Rate Linearity vs. Energy

RG 1.97 design criteria
a factor of ± 2 from 60 keV to 100 keV



Module 3

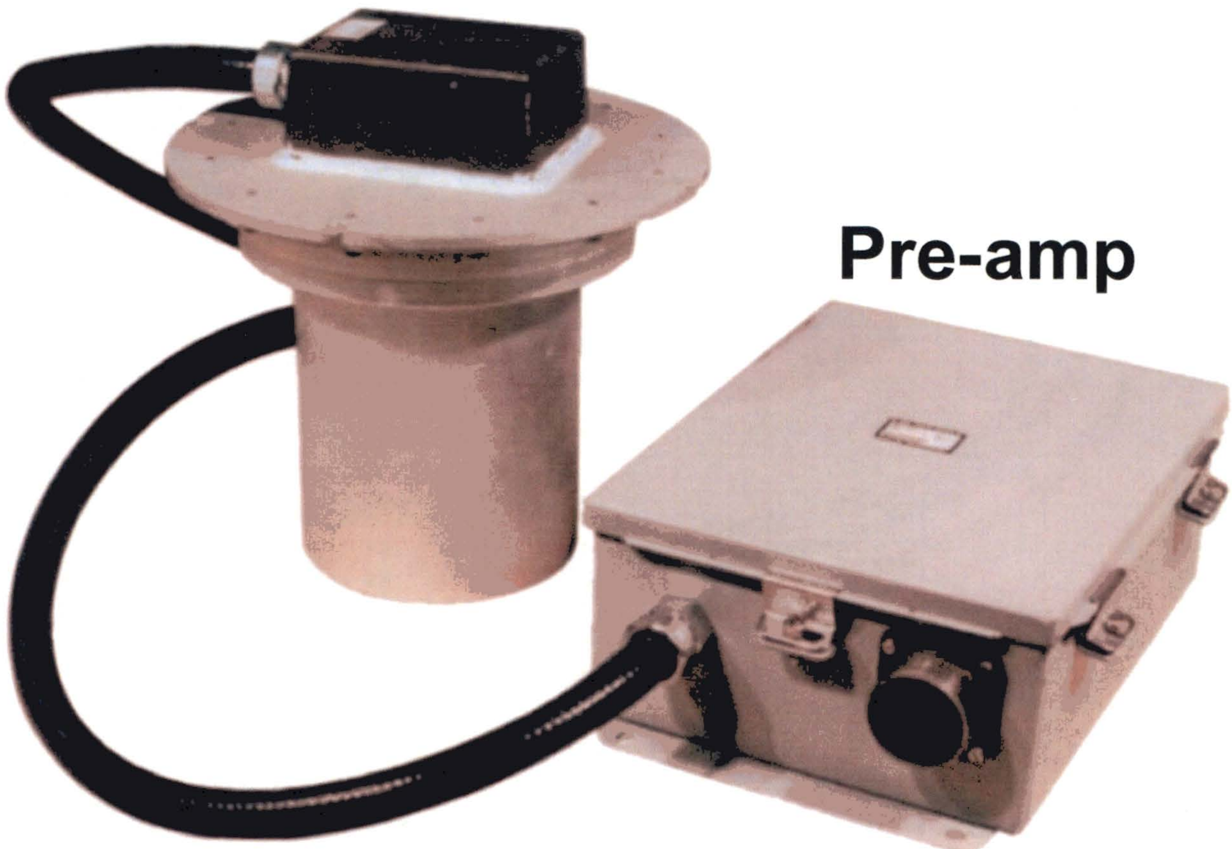
CHRMs Equipment

Typical CHRM Detector

~ 3 inch diameter

~ 8 inch length

Wide Range Ion Chamber



Typical CHRMs

- Ion Chamber detectors are similar to capacitors, with two electrodes separated by a volume of air/gas
- Dose rate measurement
  - in the range of 1 R/h to 10,000,000 R/h,
  - energy dependence within ± 20% from 100 keV to 3 MeV, and
  - energy dependence within a factor of 2 from 60 keV to 100 keV
- The preamp is housed in a gasket sealed enclosure
- Interconnection between the detector and preamplifier is accomplished via two five-foot cables, encased in a flexible conduit

Terminology

- Prototype or Design detector
  - The original detector that is fully-tested
  - Establishes a generic calibration constant in a uniform, broad beam radiation field
  - $(\frac{amps}{R/hr})$, approx. (1E-11 amps // R/hr)
- Production detectors
  - Replica detectors of the Design detector
  - Vendors made several (~200 - ~300) production detectors for sale to power plants
- Field Calibrators – calibration jigs

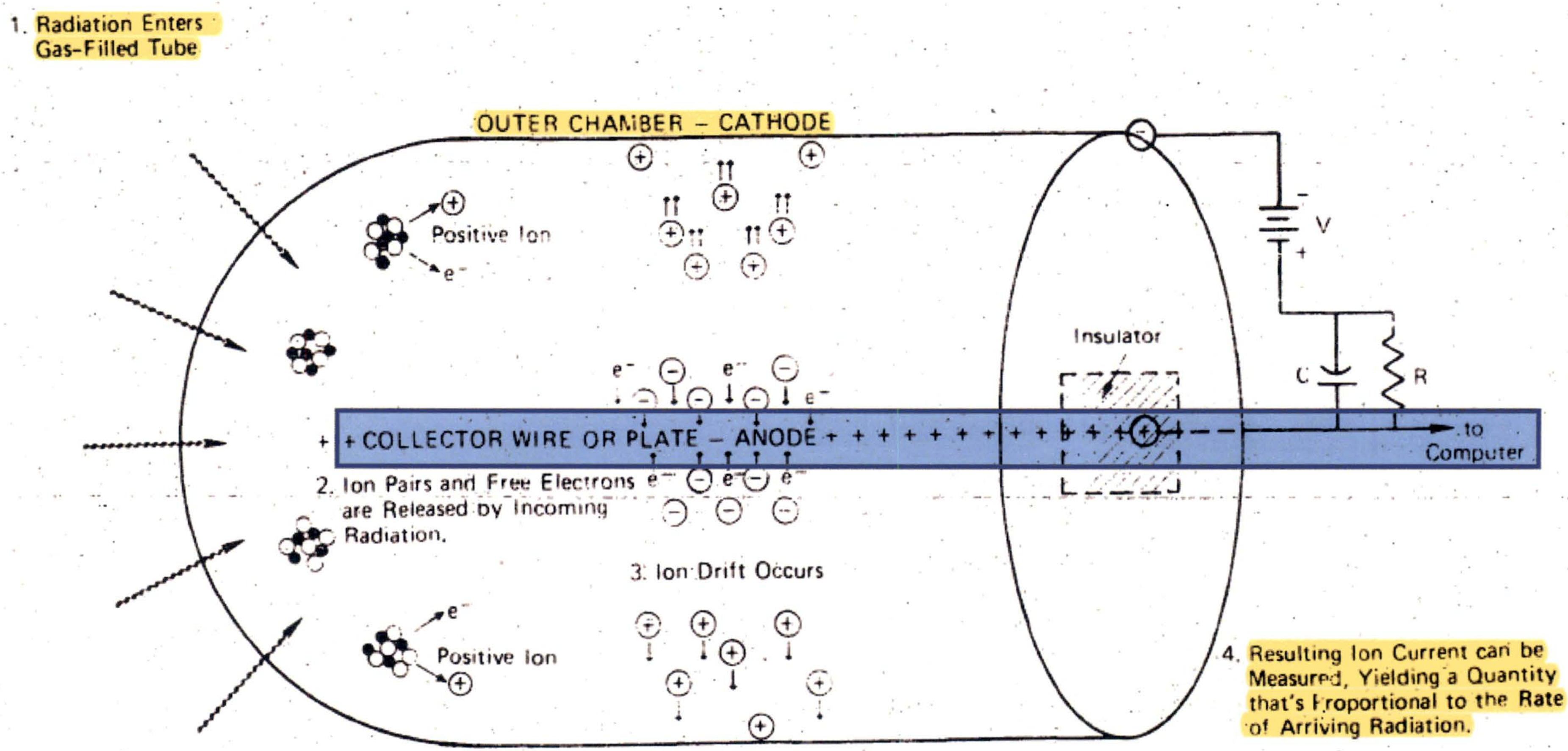
Production (Replica) Detector

- A "for-sale" (replica) of the design detector
- Some manufacturers install an internal radioactive source to produce a "Keep-Alive" current equivalent to ~ 1 R/hr (Am-241 or U-234)
- Is tested by manufacturer in a uniform radiation field to 3 dose rate decades (~1 R/hr to 1,000 R/hr)
- Is calibrated to determine its detector-specific calibration constant $(\frac{amps}{R/hr})$

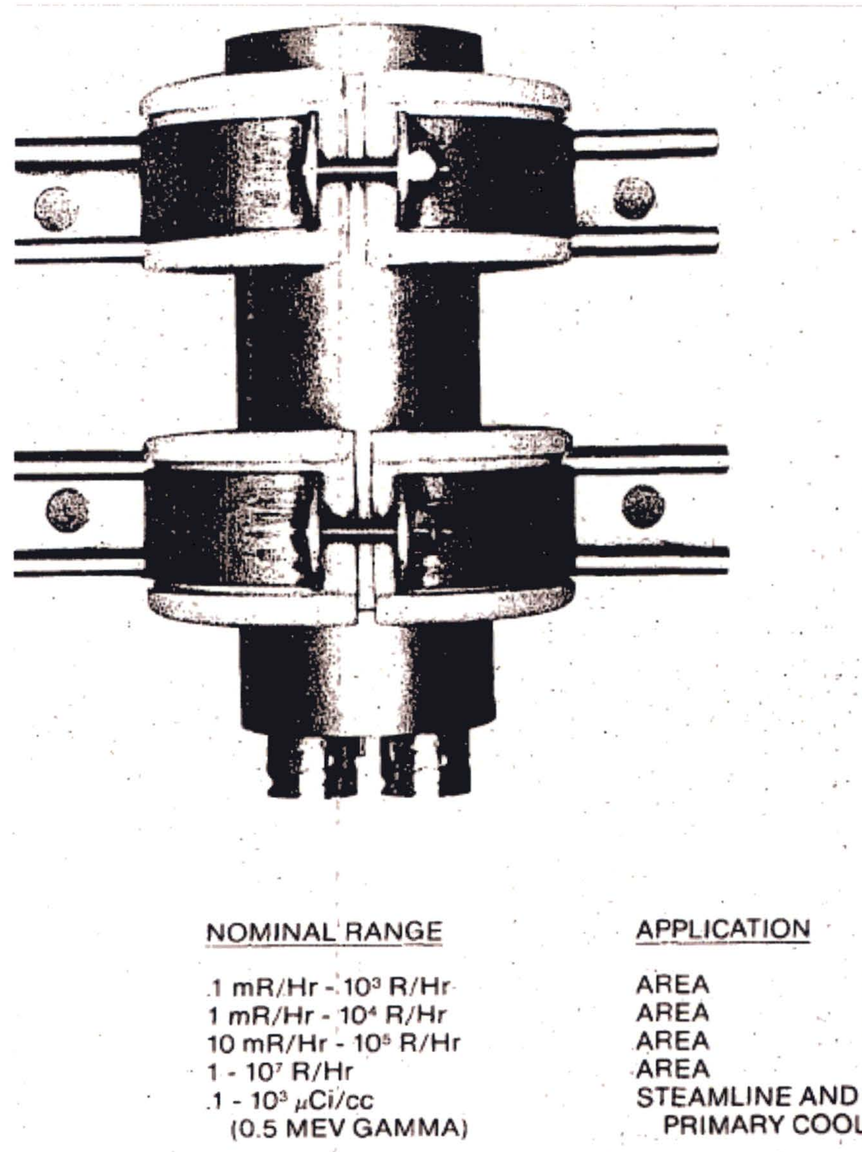
Typical CHRM

- Ion Chamber - ceramic detector, 3-inch diameter, 8-inch length
- Central electrode is + 800 V anode collecting negative ions
- Chamber wall is the cathode collecting positive charges

Typical Ion Chamber



- Typical Mounting Brackets



Typical CHRMs specs

- Ion chamber is loaded with an internal Am-241 keep-alive source, then filled with nitrogen at atmospheric pressure, and hermetically sealed
- Keep-alive source is 0.1 Ci Am-241 (433 yrs $T_{1/2}$) or U-234 (245,000 yr $T_{1/2}$)
- Only variables affecting ion chambers are collection voltage, fill pressure, and the condition of its connectors' insulation.
- Example: Ion chambers exposed to 3 decades between 1 R/hr and 1,000 R/hr.
- The average response of the ion chambers, is referred to as the calibration constant, was 1.02E-11 ± 5.5 E-12 $\left(\frac{amps}{\frac{R}{hr}}\right)$
- ~ 46% variation in calibration constant

Typical Ion Chamber

- Contains an internal Am-241 “Keep-Alive” alpha source
- Continuous dose rate ~ 1 - 9 R/hr, depending on how much Am-241 is installed

Typical Ion Chambers

- Failure modes
  - Gradual loss of internal gas pressure (from 1 atm)
  - Dirty connectors (dust & humidity)
  - Mineral cable insulation - Loss of resistance
  - Continuity can only be checked when there is access to both ends of the cable
- Spare parts
  - No spare parts are needed
  - Replace entire assembly as needed

Typical Ion Chamber Maintenance

- Preventative Maintenance
  - Connectors are sensitive to dust and moisture
  - Use "caps" to protect connectors
  - Clean cables with freon or alcohol and dry with heat gun
  - Verify ~1E+11 ohm insulation resistance from conductor to sheath
  - V = I*R (1 volt is one amp current through 1 ohm resistance)

Other CHRMs Designs

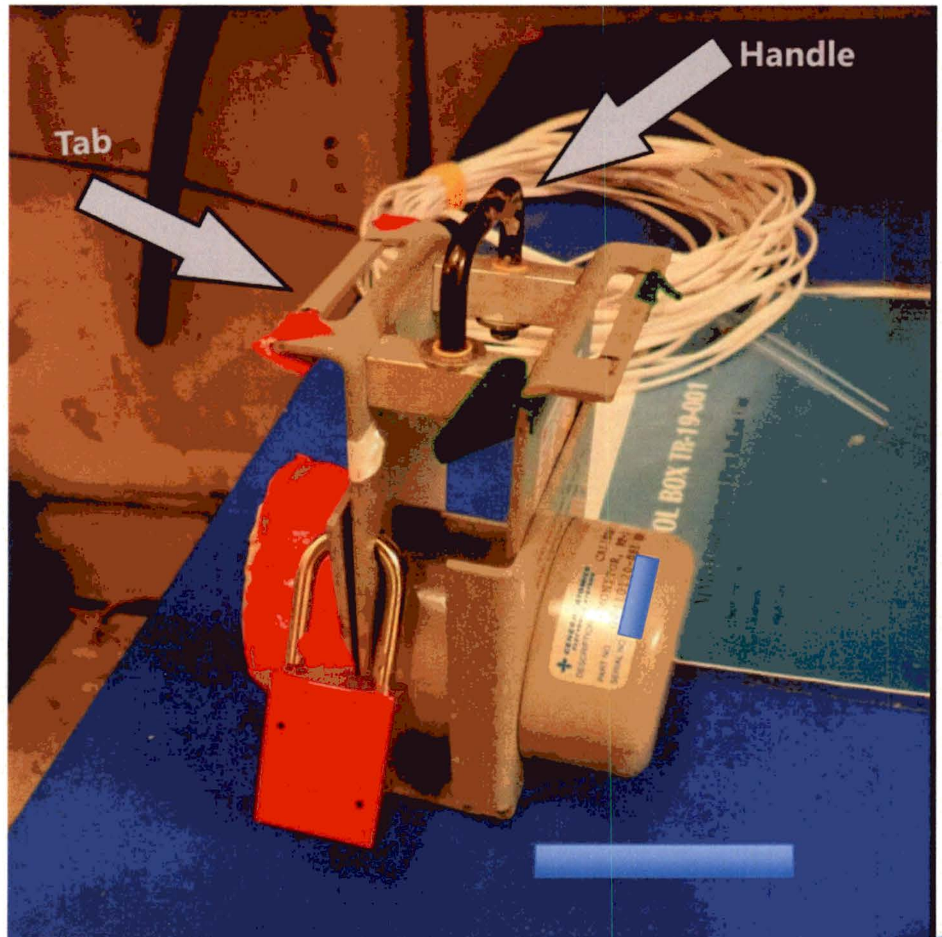
- Some Ion Chamber's do not have an internal Keep-Alive source
- Instead, they use an electronic signal to continuously display a minimum of ~ 1 R/hr

Field Calibrator

- The manufacturer builds a device to be used for in-plant calibration called a "Field Calibrator"
- Field Calibrator provides a narrow-beam exposure, but in precise exposure geometry within ± 2% - 5%
- Manufacturer determines the "expected dose-rate value" in the Field Calibrator for a specific Cs-137 source and a specific CHRMs
- Manufacturer provides the Field Calibrator and a Cs-137 source to the power plants for use in in-plant calibration checks

Field Calibrator with source

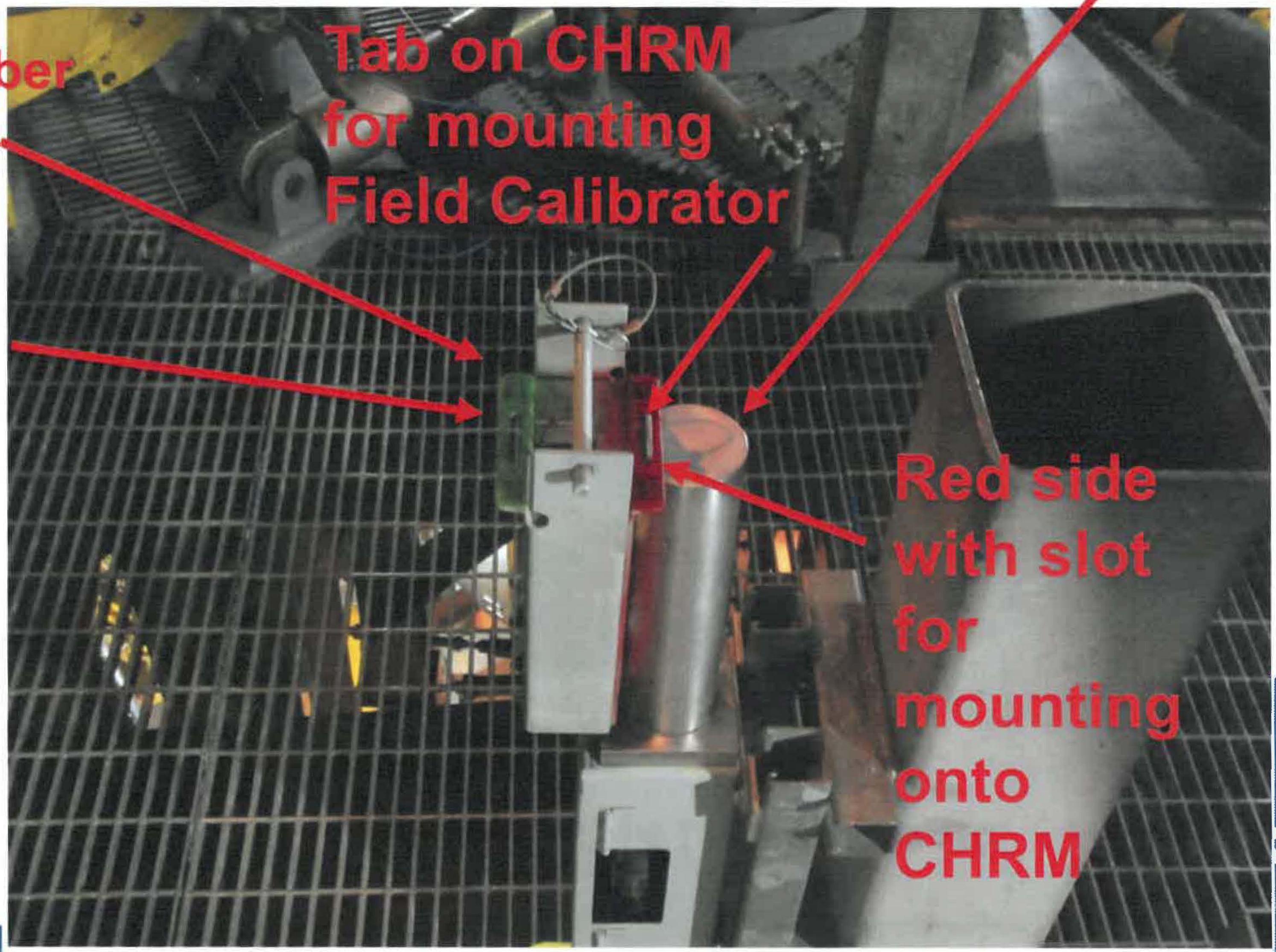
Photo shows hanger mounting slots to mount device onto detector tabs



Typical CHRM Field Calibrator

Field Calibrator mounted on side of ion chamber

Ion chamber



Green is the low dose side ~ 3 R/hr

Red is high dose side ~ 10 R/hr

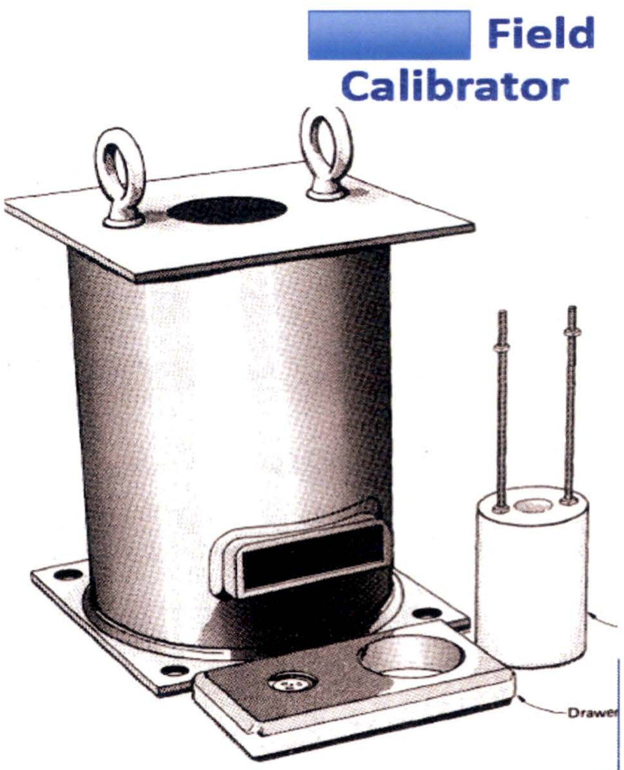
Field Calibrator Description

The field calibrator consists of a right circular cylinder made of steel encased lead. It has a circular opening at one end, concentric with its axis, which extends approximately two-thirds its length, and which accommodates the detector (or detector and fixture). At the end of the circular opening, and at right angles to it, is a rectangular channel which accommodates the drawer.

The drawer has three recesses in it to accommodate different size sources, and to position them immediately below the detector, and center them on the detector axis.

Different Style Field Calibrator

CHRM is unmounted from installed location, and inserted into the Field Calibrator



Field Calibrator Description

4.2 The Field calibrator and its drawer affords a stable, reproducible reference geometry between the secondary transfer source and the detector.

4.2.1 The field calibrator consists of a right circular cylinder made of steel encased lead. It has a circular opening at one end, concentric with its axis, which extends approximately two thirds its length, and which accommodates the detector (or detector and fixture). At the end of the circular opening, and at right angles to it, is a rectangular channel which accommodates the drawer.

4.2.2 The drawer has three recesses in it to accommodate different size sources, and to position them immediately below the detector, and center them on the detector axis. The small recess is generally used for the calibration source. The large recess is generally used for linearity sources. And the larger, cylindrical opening is used for counting particulate or iodine cartridges in a reproducible geometry.

Field Calibrator

4.3 Transfer Sources

4.3.1 The secondary transfer calibration sources supplied as a standard part of a system are one inch in diameter, and should be placed in the one inch diameter recess in the drawer. Also, two inch diameter sources may be supplied for linearity sources. This source is placed in the two inch diameter recess.

4.3.2 Sources used will be individually serialized, and that number written on applicable data sheets along with the count data.

4.3.3 Sources shall be placed in the proper drawer recess with only the source inserted and the assay information facing away from the detector. **(Do not place the planchet in the drawer with the source. It is only used for source storage.)**

4.3.4 Two sets of disc sources are used in the secondary transfer calibration. ASI standard calibration source set will be permanently kept by the ASI Radiation Lab. The customer's standard calibration source set will be transferred to customers for field calibration. All the secondary sources have NIST traceability through the ASI primary isotopic calibration which is performed with NIST traceable isotopic sources.

Transfer source in Field Calibrator

1.5 The secondary transfer calibration sources supplied as a standard part of a system are one inch in diameter, and should be placed in the one inch diameter recess in the drawer. Also a two inch diameter area source may be supplied for linearity sources. This source is placed in the two inch diameter recess.

1.5.1 Sources used will be individually serialized, and that number written on the manufacturer's source activity certification, as well as applicable data sheets and/or log books, along with the count data.

NBS Traceable Sources

Two sets of disc sources are used in the secondary transfer calibration. [redacted] standard calibration source set will be permanently kept by the [redacted] Radiation Lab. The customer's standard calibration source set will be transferred to customer for field calibration. All the secondary sources have N.B.S. traceability through the [redacted] primary isotopic calibration which is performed with N.B.S. traceable isotopic sources.

Typical Transfer Source Certificate

CERTIFICATE OF CALIBRATION
SEALED SOURCE GAMMA RADIATION DOSE RATE
FOR

The Gamma Ray Air Absorbtion Dose Rate resulting from radiation emission of the subject source was determined to be 30.84 milliroentgens per hour at an exposure point 1.0 meter (39.4") distant, approximately perpendicular to the capsule longitudinal axis center line.

The measurement was performed using a Precision Ionization Chamber/ Electrometer System for which the dose equivalent response of the subject source was developed by comparison with ___ N.B.S. Cobalt-60 Dose Rate Source Standard #47342 X N.B.S. Cesium-137 Dose Rate Source Standard #47455. The overall uncertainty of the measurement value is estimated to be ± 4%.

= 30 mR/hr at 1 meter, or using inverse square law

~ 77 R/hr at a point at ~2 cm (~ 1 inch)

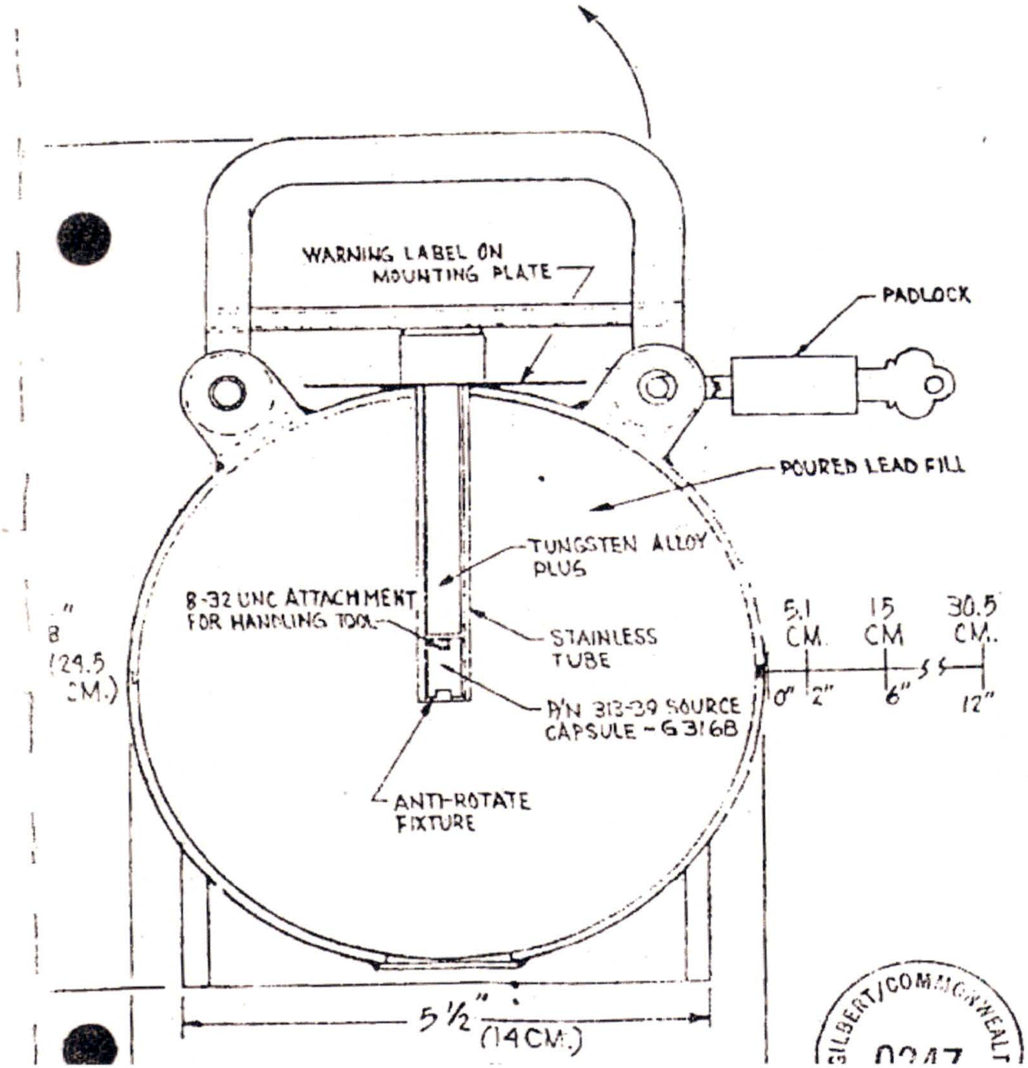
~12 R/hr at a point at ~5 cm (~ 2 inches)

Calibration Source Lead Shield

[redacted]

The [redacted] calibrated source and shield sets are designed and constructed for easy use and minimum radiation exposure. The shield and source weight of 27 kg (~60 lbs) can easily be transported using the handle. The padlock prevents any unauthorized use of the calibrated source. Pictured below is the shield and source in the storage mode with approximate dose rates given in the table.

Drawing for a Source Shield



STORAGE-RADIATION DOSE RATES
(mR/hr/mCi)

Source Nuclide	Co-60	Cs-137
At Shield Surface	2.8	0.01
2" (5.1cm) From Surface	1.0	<0.01
6" (15cm) From Surface	0.31	<0.01
12" (30.5cm) From Surface	0.11	<0.01

Dose rates measured using TLD LiF chips 1.25 cm² (1/2" dia.)

Cs-137

1 mR/hr

(100 mCi)

Serial No. CS1498

Activity 96.4 mCi

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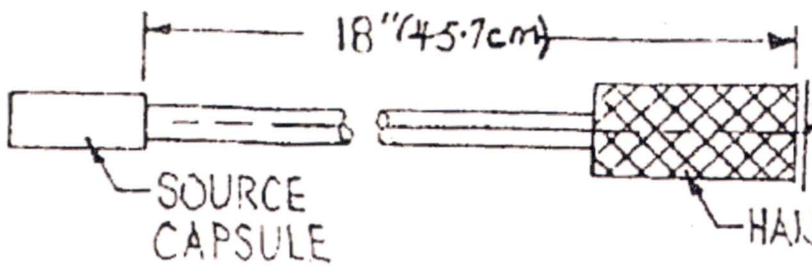
Protecting People and the Environment

Typical Source Shield

To remove source from storage shield, first, place shield skirt on horizon surface. Then unlock padlook and remove it from padlock hasp. After lifting the shield handle, pull out the tungsten plug. Insert source handling tool, thread side first, into the tube and thread it into the source capsule. (NOTE: The anti-rotate fixture will prevent rotating the source capsule.) You may now remove the source.

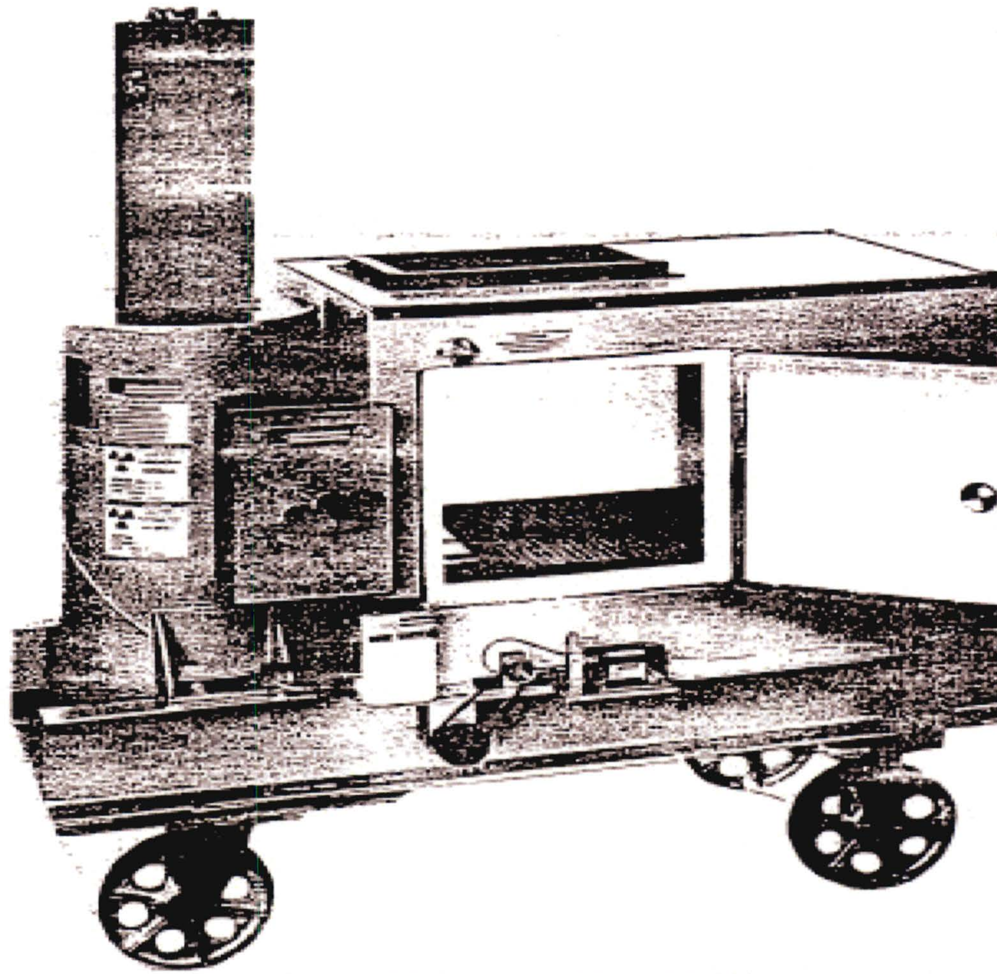
Reverse the above procedure to return the source into the storage shield.



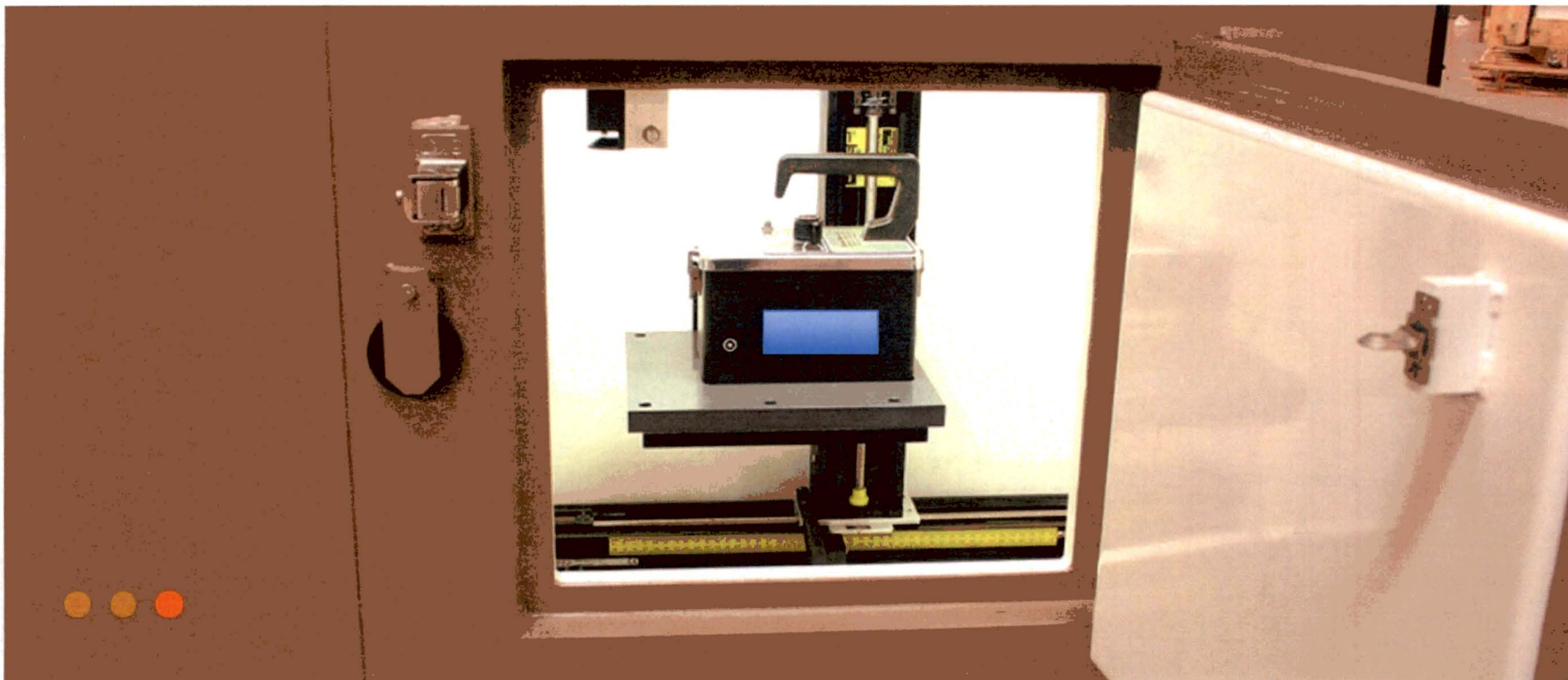
calculated dose rate:

60Co	~6.2 mR/hr/mCi
137Cs	~1.5 mR/hr/mCi

Box Calibrator



Box Calibrator



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Module 4

CHRMs Calibration Process

Calibration

- What is a "Calibration?"
- What is a "Calibration Check?"
- The terms are used interchangeably
- Basically:
  - A calibration check evaluates if the instrument is working properly, and if not, then
  - A calibration is the adjustment of the instrument output

Manufacturer's Primary Calibration

- What is a "primary calibration?"
- Plain language: The manufacturer's measurement of the detector's response to a uniform exposure geometry (similar to the radiation field in containment during an accident)

$$\sim 1E\text{-}11 \left(\frac{amps}{R/hr}\right)$$

- Ion chambers are very stable – normally no need to adjust the "calibration constant"

In-Plant Calibration Check

- **Purpose** – to demonstrate that CHRMs are working properly – i.e., the CHRM is functioning the same as it was when calibrated at the manufacturer's facility
- The calibration does **NOT** require the exposure geometry to be a uniform exposure geometry – instead, use non-uniform exposure geometry in a fixed geometry
- Manufacturers establish a **repeatable geometry** for the non-uniform exposure using a Field Calibrator
- The non-uniform exposure geometry must be the same as the geometry when the detector was known to be working properly

In-plant Calibration Check

- What is an "in-plant calibration check?"
- Plain language: Two parts: Electronic and Rad Calibration
  - Electronics Calibration Check
  - Radiation Exposure Calibration Check
    - A check to determine if the CHRMs are still working properly
    - Make a comparison of the CHRMs instrument response (R/hr) to the manufacturer's expected value (R/hr)
    - The expected value was determined by the manufacturer in a non-uniform, fixed geometry Field Calibrator
    - The expected value is decay corrected

In-Plant Calibration Components

- 1) Radiological calibration
  - Compare detector dose rate (R/hr) response to an expected dose rate response (R/hr) in the Field Calibrator
  - Requires a fixed geometry and **knowledge of the dose rate** when the manufacturer established the Transfer dose rate in its Field Calibrator (in a non-uniform geometry standard with a Cs-137 source)
- 2) Electronic calibration
  - Injection of a simulated signal as close to the detector/sensor as possible
  - Test upper ranges 10 R/hr to 10M R/hr

Exposure Geometry

- During an accident, the exposure geometry is a **uniform, broad beam geometry**
  - Ideally, CHRMs mounted in a 4 π (360 ° geometry)
  - CHRMs are mounted onto a concrete wall is a 2π geometry
- Uniform exposure geometry is used when determining the calibration constant, $(\frac{amps}{R/hr})$, to simulate exposure conditions during an accident
- During periodic in-plant calibrations, **a non-uniform exposure geometry is OK**

Manufacturer's Primary Calibration

- The manufacturer's <u>primary</u> calibration determines the "calibration constant" $\frac{amps}{R/hr}$
  - The primary calibration uses a <u>uniform exposure geometry</u> (similar to a containment radiation field during an accident)
  - the manufacturer exposes the detectors to various dose rates and various gamma energies
  - They measure the detector amperage for each dose rate
  - They average the output and determine the "calibration constant" (amperage per R/hr) (~ 1E-11 $\frac{amps}{R/hr}$)

Example
Energy Response Testing

HIGH RANGE RADIATION MONITOR
TYPE CALIBRATION REPORT SUMMARY
ABSTRACT FROM E-115-939 (PRELIMINARY)

SOURCE	ENERGY	DOSE RATE (R/HR)	RESPONSE (A/R/HR)
Co-60 (RADCAL)		.66	1.06×10^{-11}
Co-60 (R-S)	1.17+1.33MEV	10^2	1.16×10^{-11}
Co-60 (SALK)		4×10^3	1.1×10^{-11}
		3×10^4	1.03×10^{-11}
Cs-137	662 KEV	1	1.13×10^{-11}
		2	1.08×10^{-11}
		5	1.07×10^{-11}
		2×10^1	1.01×10^{-11}
XRAY	70 KEV (EFF)	3.7	9.14×10^{-12}
	117 KEV (EFF)	1.5	1.39×10^{-11}
	167 KEV (EFF)	1.9	1.019×10^{-11}
	210 KEV (EFF)	1.4	1.013×10^{-11}
LINEAR ACCELERATOR	4.5 MEV (AV)	5×10^6	1.13×10^{-11}

$\overline{A/R/hr} = 1.073 \times 10^{-11}$

NUREG-0737 criteria (CHRMs)

- “Design” detectors – dose rate tested to 10 million R/hr
- “Production” (replica – for sale) detectors
  - Every production detector is tested in first 3 decades
    - 1 – 10 R/hr, 10 – 100 R/hr, 100 -1,000 R/hr
  - Electronic calibration above 10 R/hr
  - In-plant calibration at one point below 10 R/hr

Replacement Calibration Sources

- Cs-137 sources in Field Calibrators (calibration jigs) are ~30 – 40 years old
- Source strength has decayed ~40% to ~60%
- Source certificates give activity and assay date
- Dose rates from replacement sources in Field Calibrators can be obtained by ratio of source activities (new source activity vs. original source activity

Typical Source Certificate

CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cs-137 Half-Life: 30.0 y 2

Source No.: 81623

Was assayed as containing: 114 mCi

As of: 11-1-81

METHOD OF CALIBRATION:

( ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the MeV peak (a value of gamma rays per decay was used in the calculations), against standard No. , in the same geometrical arrangement.

(X) The source was assayed in a ~~windowless internal~~ pressurized ion chamber proportional counter against Cs-137 standard No. 47484 .

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. , in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in µCi/gm was determined by the method indicated above.

Typical Source Certificate (Cont.)

Page 2 of 2

ERROR CALCULATION:

a) Systematic errors (SE)
   1. Accuracy of the standard: ±.95%
   2.

b) Random errors (RE)
   1. Precision of source count, e_1:
   2. Precision of standard count, e_2:
   3. Error due to background, e_3:

$$RE = \sqrt{e_1^2 + e_2^2 + e_3^2} \pm 4.1\%$$

c) Total Error

$$TE = SE + RE \pm 5.0\%$$

NOTES

(X) The error given is calculated at the 99 % confidence level.

(   ) This calibration is directly/indirectly based on NBS Standard Reference Material No.

[redacted]

Title: Health Physicist

CERTIFICATE OF CALIBRATION

Standard Reference Source

SRS Number: 111308A

Source Description: 12 cm x 12 cm Plate Source

Product Code: CO0-LDS-100MM

Customer: [redacted]

P.O. Number: 02389833, Item 1

This standard radionuclide source was prepared gravimetrically from a master solution calibrated with an ionization chamber. The ionization chamber was calibrated by the National Physical Laboratory (NPL), Teddington, U.K., and is traceable to national standards. Radionuclide calibration and purity were checked by germanium gamma-ray spectrometry, liquid scintillation counting, and/or alpha spectrometry, as applicable. The nuclear decay rate and reference date for this source are given below. Eckert & Ziegler Analytics (EZA) maintains traceability to the National Institute of Standards and Technology (NIST) through a Measurements Assurance Program as described in USNRC Regulatory Guide 4.15, Revision 2, July 2007, and compliance with ANSI N42.22-1995, "Traceability of Radioactive Sources to NIST."

Reference Date: 22-January-2019 12:00 PM EST

Isotope	Half-Life, d	Activity, Bq	Uncertainty u_A, %	Uncertainty u_B, %	Uncertainty U, %*	Calibration Method**
Co-60	1.925E+03	8.995E+03	0.1	1.6	3.3	IC

***Uncertainty:** U - Relative expanded uncertainty, k = 2. See NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." ****Calibration Methods:** 4π LS - 4π Liquid Scintillation Counting, HPGe - High Purity Germanium Gamma-Ray Spectrometer, IC - Ionization Chamber.

Foreign Sources

- NIST-Traceability may be established by conformance with a foreign National Standardizing Laboratory (NSL)

- The NSL must provide NIST with documentation that guidelines from the International Committee for Radionuclide Metrology (ICRM) have been met

Four Basic Calibration Steps

- Step 1 – Manufacturer calibrates the **Prototype (Design) detector** (determine its energy response, linearity, and determine its **calibration constant** $\left(\frac{amps}{R/hr}\right)$
  Step 2 – Manufacturer calibrates the **Production Detector** (i.e., prove the production detector's performance is equivalent to the Prototype (design detector)

- Step 3 – Manufacturer calibrates the **Field Calibrator** (calibration jig) to its **Production Detector**– i.e., determine the CHRMs expected response to a specific Cs-137 source in a fixed geometry

- Step 4 – Licensees perform **In-Plant Calibrations using the Field Calibrator to determine if the CHRM is still working properly**

Step 1
Primary Calibration

- Determine detector's energy response characteristics (~80 keV to 3 MeV).
- Verify dose rate linearity check to 10 million R/hr.
- Determine **calibration constant** (efficiency factor) in a uniform external beam $\left(\frac{amps}{R/hr}\right)$
  - Ion chambers produce amperage (amps)
  - Microprocessor converts amps to R/hr by dividing the amps by the calibration constant $\left(\frac{amps}{R/hr}\right)$ = R/hr

Example: Primary Calibration of Prototype (Design) Detector Calibration

TABLE 1
PROTOTYPE CALIBRATION DATA

Nuclide | Energy | Amps | Amps / R/hr

Source	Energy	Reference Data	True Dose Rate, R/hr	Detector Response	Measured Sensitivity, A/R/hr
1. Co-60 0.5 Ci Radcal Corp.	1.17 MeV, 1.33 MeV	Air ion chamber	0.6625 (av of two tests)	7.015×10^{-12} A (av of two tests)	1.06×10^{-11}
2. Co-60 Reuter-Stokes	1.17 MeV, 1.33 MeV	RS-C4-1606-203 calibrated by NBS	109.7	1.262×10^{-9} A	1.15×10^{-11}
3. Co-60 1000 Ci	1.17 MeV, 1.33 MeV	Landsverk L64 roentgen meter	3.9×10^{4}	4.46×10^{-7} A	1.14×10^{-11}
4. Cs-137 GA	662 keV	RS-C4-1606-203 calibrated by NBS	1.0[a]	1.13×10^{-11} A	1.13×10^{-11}
			2.0[a]	2.17×10^{-11} A	1.08×10^{-11}
			5.0[a]	5.37×10^{-11} A	1.07×10^{-11}
			20.0[a]	2.03×10^{-10} A	1.02×10^{-11}

[a] These readings should not be averaged. A collimating geometry error at 2 R/hr and above is inherent in the source holder and is insignificant in smaller detectors.

Example Primary Calibration Data CHRMs

X-ray	Energy		Dose Rate	Amps	Amps / R/hr
5. X ray	70 keV (eff)	Air ion chamber	3.72	1.01×10^{-9} C	9.14×10^{-12}
	117 keV (eff)	Air ion chamber	1.55	1.28×10^{-9} C	1.39×10^{-11}
	167 keV (eff)	Air ion chamber	1.91	1.16×10^{-9} C	1.19×10^{-11}
	210 keV (eff)	Air ion chamber	1.39	1.24×10^{-9} C	1.13×10^{-11}
6. X ray GA	43.5 keV[(b)] 60 keV[(b)]	Landsverk L64 roentgen meter	19.5 24.2	1.27×10^{-10} A 2.40×10^{-10} A	6.5×10^{-12} 9.9×10^{-12}
7. Linear accelerator IRT Corp.	4.5 MeV (av)	Photochromic dye dosimetry	5.17×10^{6}	5.17×10^{-5} A	1.13×10^{-11}

[(a)] These readings should not be averaged. A collimating geometry error at 2 R/hr and above is inherent in the source holder and is insignificant in smaller detectors.

[(b)] See Section 3.1.

Energy Response Testing

TABLE B-8-4. SENSITIVITY MEASUREMENT RESULTS USING THE [redacted] ION CHAMBER

Source	Energy Level (MeV)	Average Current (10^{-11}A)	Incremental Current (10^{-11}A)	Radiation Field (mR/hr)	Sensitivity (10^{-11}A/R/hr)
^{57}Co	0.122	1.2114 ± 0.0011	0.0124 ± 0.0017	11.3	1.09 ± 0.13
^{133}Ba	0.356	1.457 ± 0.0014	0.258 ± 0.002	245.0	1.05 ± 0.008
^{137}Cs	0.662	1.245 ± 0.002	0.046 ± 0.0024	45.2	1.02 ± 0.053
^{60}Co	1.17 1.33	1.279 ± 0.0014	0.080 ± 0.002	77.3	1.03 ± 0.025
No Source		1.199 ± 0.0014			

Energy Response Testing

B-8-5-1 Field Response

The overall response of the ion chamber is 1.05×10^{-11} A/R/hr between 10^0 and 10^7 R/hr.

B-8-5-2 Energy Response

The response to energies between 0.10 and 3.0 MeV is ±20% of the nominal 1.05×10^{-11} A/R/hr.

B-8-5-3 Test Accuracy

The calibration accuracy is 7%.

B-8-5-4 Detector Accuracy

The detector accuracy is 29%.

Typical Radiation Detectors

Containment High Range Monitor

- In 1981 and 1983, a manufacturer performed the Design detector's primary calibration and provided:
  - A 408 page Instrumentation Manual
  - Only data available is from the Calibration Summary Report
    - the calibration constant was 1.02E-11 $(\frac{amps}{R/hr})$
  - Difficult to find the data on the energy response testing or dose-rate linearity up to 10 million R/hr

Typical Design Detector Primary Calibration

[redacted]	DOCUMENT STANDARD PRACTICE PROCEDURE	[redacted] Exhibit A	REV. A

ION CHAMBER AREA
SUMMARY OF CALIBRATION

Detector Type Ion Chamber
Model [redacted]
P/N 824636-002
S/N 21511

I. DESIGN CALIBRATION

A. Primary Isotope Efficiency (Ref. report no. K-82-70-U(R))
0.99 (10^{-11}) amps/mR/hr [redacted]

B. Isotopic Calibration Constant (default program value)
1.01 (10^{11}) mR/hr/amp [redacted]

C. Absolute Efficiency ([redacted] Source S/N N/A)
N/A amps/uCi

Typical Ion Chamber Specs

~ 1E-11 Amps per R/hr

	KDI-.1	KDI-1	KDI-10	KDI-1000	KDI-F
Insulators:	Ceramic	Ceramic	Ceramic	Ceramic	Ceramic
Outershell:	Same	Same	Same	Same	Stainless Steel
Electrodes:	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Fill Gas:	Argon/Nitron	Argon/Nitron	Argon/Nitron	Nitron	Xenon
Fill Pressure:	20 Atm	20 Atm	40 Atm	1 Atm	Approx 25 Atm
Diameter:	7.0 in.	7.0 in.	3.5 in.	3.0 in.	3.5 in.
Active Volume:	5200 cc	5200 cc	400 cc	160 cc	Approx 400 cc
Overall Length:	18 in.	18 in.	8.0 in.	8.0 in.	Approx 8 in.
Sensitivity:	6.5E-9A/R/hr	6.5E-9A/R/hr	1.2E-9A/R/hr	1E-11A/R/hr	6×10^{-9} A/R/hr±35%
Nominal Range:	.1mR/Hr-10^3R/Hr	1mR/Hr-10^4R/Hr	10mR/Hr-10^5R/Hr	1-10^7R/Hr	.1-10^3 micro-Ci/cc (0.5MEVgamma)
Internal Test Source:	None	.1 micro-Ci Am-241	.1 micro-Ci Am-241	.1 micro-Ci Am-241	0.1 micro-Ci/ Americanium 241 to produce 1 to 5×10^{-11} Amps

Typical Ion Chamber Energy Response Tests

B-8-1-3 Measurements

Two basic measurements were made. The first measurement was to determine the response of the detector between energy levels of 0.080 and 3 MeV. This measurement was performed with four isotopes (^{57}Co, ^{60}Co, ^{137}Cs, and ^{133}Ba). Where actual isotope testing was not done, vendor-typical

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Step 2
Production (replica) Detector's Calibration

- Objective: Verify the Production (replica) detector's response is equivalent to the Design Detector
- Perform a 3-decade dose rate check (NUREG-0737)
  - e.g., 3 R/hr, 30 R/hr, 300 R/hr
  - Verify the calibration constant ($\frac{amps}{R/hr}$) is the same as the Design Detector
  - Answer is ~ 1.0E-11 $\frac{amps}{R/hr}$

CHRMs Calibration

B-8-1-1 <u>Requirements</u>

The [redacted] high-range in-containment area (HRICA) detectors (drawing 6092096) calibrated at the [redacted] detect activity in the range of 10^0 to 10^7 R/hr over an energy range of 80 KeV to 3 MeV. The detectors are qualified to function during and after a loss-of-coolant accident (LOCA). Maximum accident temperature is 400°F, and maximum accident pressure is 50 psig.

Typical Production Detectors
Linearity Tests

Low level field intensity tests are required on each individual ion chamber; these tests are not included in this report, but were conducted as follows. Using an NBS-traceable condenser R-meter [redacted], the hot cell at [redacted] was calibrated to location field strengths of approximately 8, 80, and 800 R/hr. Each ion chamber was placed at these locations, the output current was recorded, and a linear plot was calculated. If the ion chamber was within a linearity tolerance factor of 2, it was accepted; otherwise, the ion chamber was rejected.

Typical “Production” Detector Calibration

TEST DATA

High Voltage Setting +800 v

Other Instrument Settings (if applicable)

Acceptance Criteria .8 to 1.2 (10^{-11}) A/R/hr

Check Source/Live Zero Reading 1.40 E-11 Keep-alive (K.A.) amps

	Measured Field: Dose Rate	Instrument Reading: GROSS (amps)	NET (amps)	A/R/HR
698 mR/hr	.698 (10^3)mR/hr	2.03 E-11	.63 E-11	.90 E-11
5.60 R/hr	.560 (10^4)mR/hr	6.12 E-11	4.72 E-11	.84 E-11
57.8 R/hr	.578 (10^5)mR/hr	5.13 E-10	4.99 E-10	.86 E-11
748 R/hr	.748 (10^6)mR/hr	6.29 E-9	6.28 E-9	.84 E-11

Example: Gross amps (2.03E-11) minus K.A. amps (1.40E-11) = 0.63E-11 amps

Calibration constant = 0.63E-11 amps / 0.698 R/hr = 0.90 E-11 $\frac{amps}{R/hr}$

Typical Production Detector

Production Detector's Calibration

II. FACTORY CALIBRATION (data sheet attached)

D. Transfer Efficiency (Kaman Source S/N N/A dated N/A)
N/A amps/uCi

E. Factory Correction Factor (age and Kaman Source relative strength) N/A

F. Factory Calibration Constant (C/D times B/E) (User-program)
1.03 E11 [redacted]R/hr/amp
[redacted]

G. Factory Efficiency (Customer Source S/N 82058-2 dated 1/14/83)
7.51 E-11 net amps[redacted]i on 9/30/83
[redacted]

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

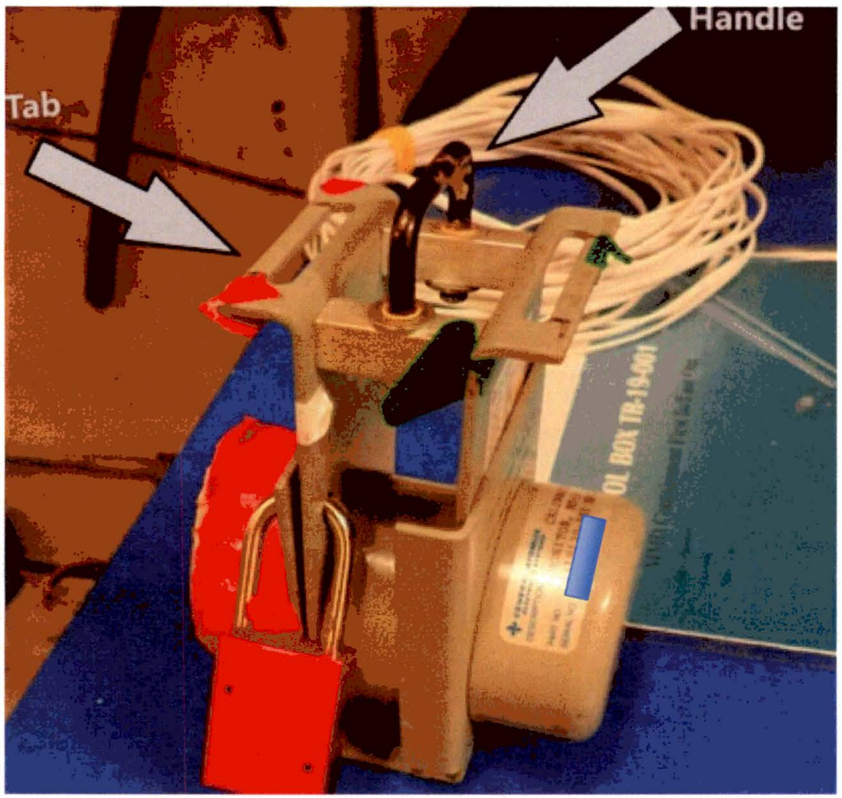
Step 3
Transfer Calibration of the Field Calibrator

- The purpose of a transfer calibration of the Field Calibrator is to develop a method for the nuclear power plants to verify CHRMs are operating properly
- One method is to design a Field Calibrator and then measure the CHRMs response to a Cs-137 source in a fixed non-uniform geometry
- The exposure geometry is NOT a uniform radiation field across the detector because the source is too close!
- The vendor measures the CHRMs response (dose rate) to a specific Cs-137 source loaded into the Field Calibrator; e.g., a previous example was ~ 7 R/hr at ~2 inches

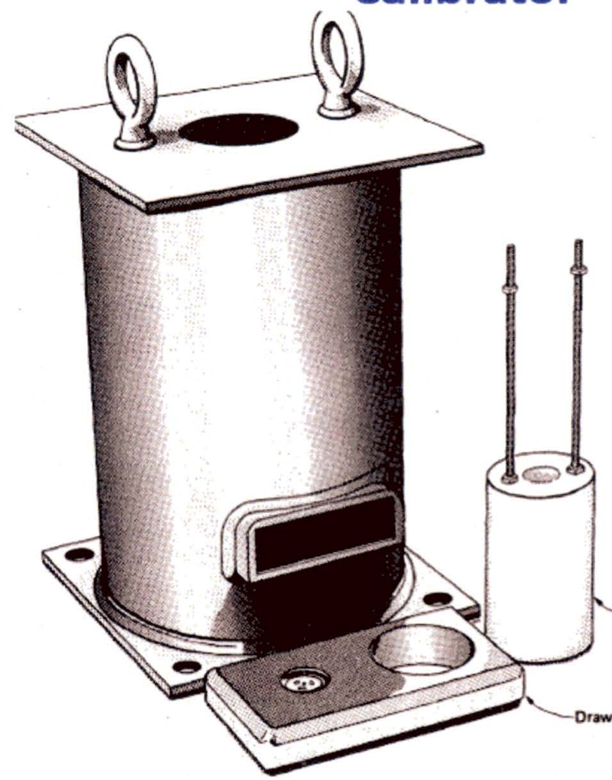
Summary
Transfer Calibration of the Field Calibrator

- Manufacturer builds a field calibrator
- Loads a Cs-137 source into the field calibrator
- Exposes the CHRM to the source in the field calibrator
- CHRM detector produces amperage
- CHRM microprocessor divides the amperage (amps) by the calibration factor ($\frac{amps}{R/hr}$) and displays (R/hr)
- Document the result in a Calibration Summary Report and send it to the plant for their use in periodic calibration check

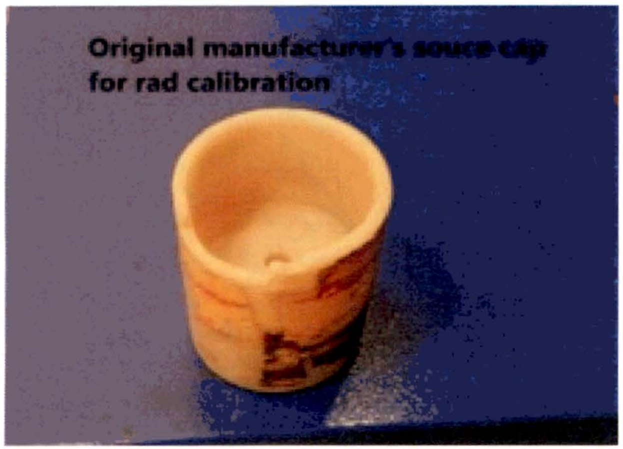
Field Calibrators



[redacted] Field Calibrator



Cap Field Calibrator for an Area Rad Monitor (ARM)

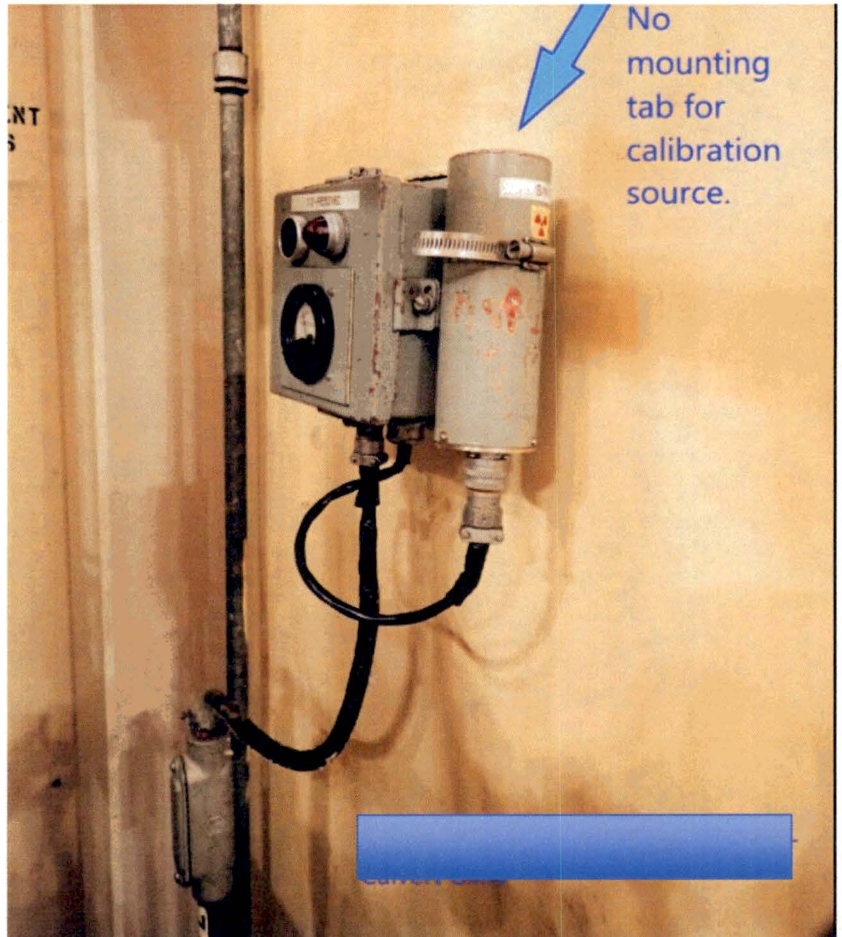


Source holding cap fits over detector to establish a fixed geometry

Issue of Concern: The Cs-137 source had decayed. Instead of buying a new source, the plant used a Field Calibrator designed for a different detector.

The ARM did not have a mounting tab, so the plant used a stanchion to mount to the detector without having an equivalency evaluation.

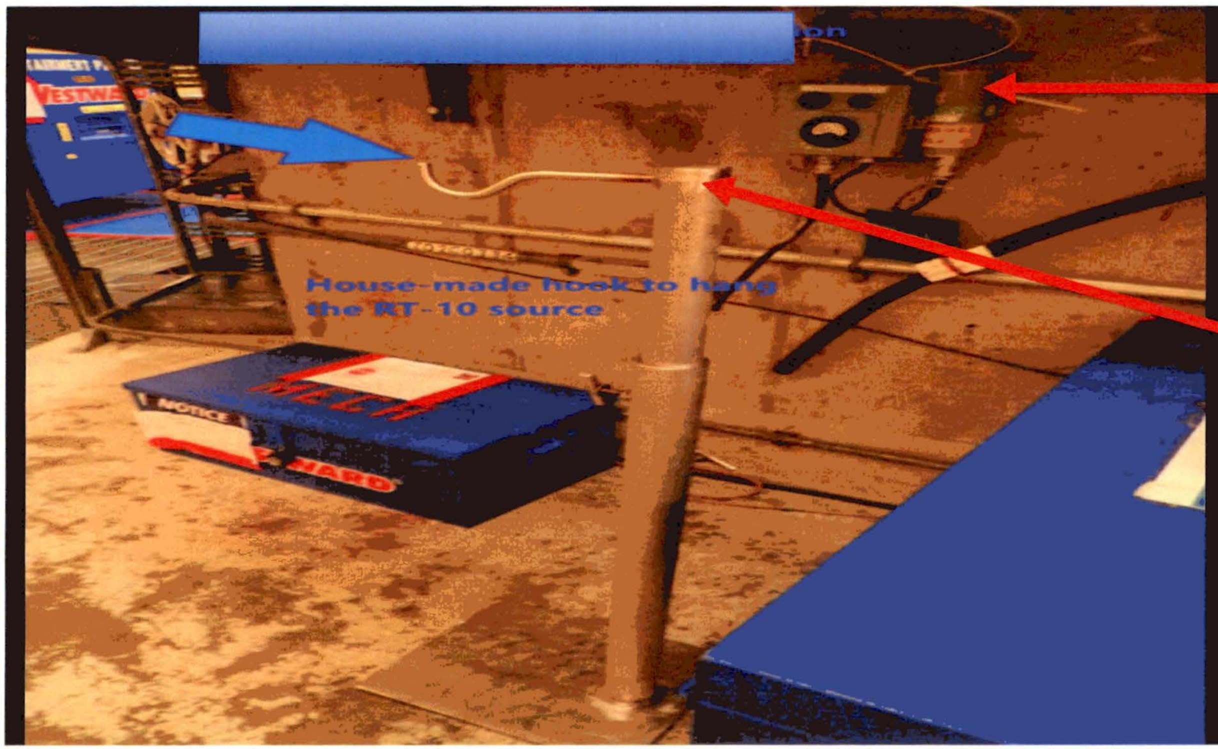
Containment AREA monitor (no mounting tab for Field Calibrator)



Home-made Field Calibrator

stanchion for mounting calibration source

Mounting Hook



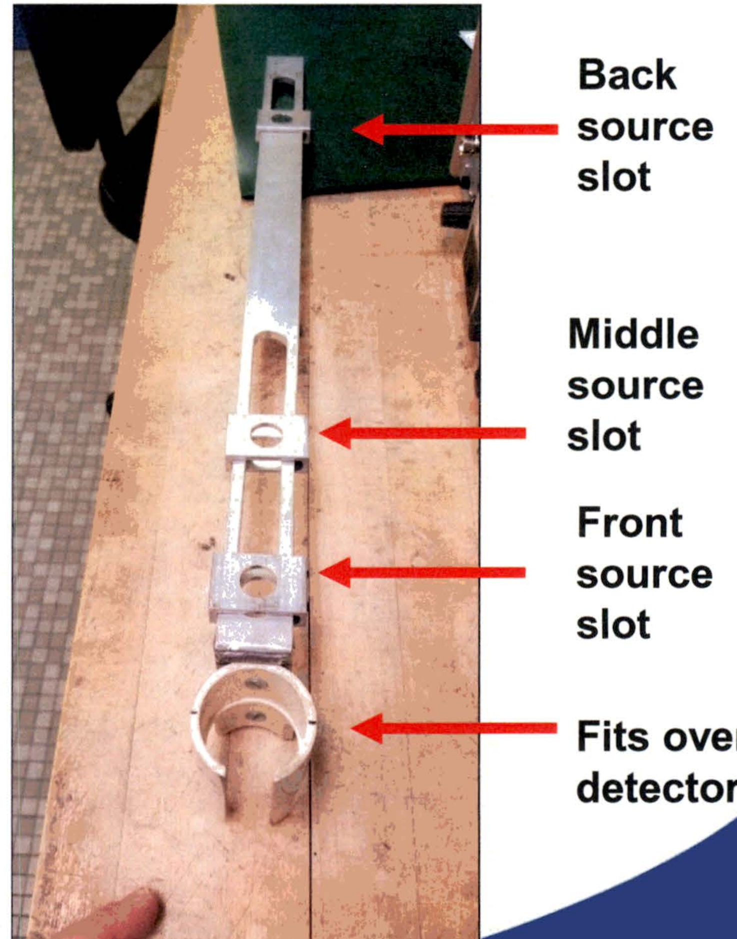
Area Radiation Monitor

Stanchion

Issue of Concern: Is there an evaluation showing this geometry is reproducible and meets accuracy criteria (±40% or ±50%?)

Home-made Bar Field Calibrator

- Three source slots
- The back slot is for the source when used for low dose rate calibrations
- The front slot is used for high dose rate calibrations
- Is there an evaluation of accuracy and reproducibility?



Manufacturer's Transfer Calibration Report

CALIBRATION REPORT

HIGH RANGE RADIATION MONITOR CALIBRATOR [redacted]

The [redacted] High Range Radiation Monitor Calibrator, Serial No. 006 was calibrated on 11-1-81, at [redacted]. This calibrator was found to produce the following effective dose rates:

on [redacted]	Low Side	3.10 R/HR
	High Side	10.8 R/HR
at 1 foot	In Housing	15 mr/hr

Typical Field Calibrator (pg 1)

[redacted]

CALIBRATION REPORT

HIGH RANGE RADIATION MONITOR CALIBRATOR RT-11

The [redacted] High Range Radiation Monitor Calibrator, Serial No. 012 was calibrated on 11-1-81, at [redacted]. This calibrator was found to produce the following effective dose rates:

on [redacted]	Low Side	3.23 R/HR
	High Side	11.2 R/HR
at 1 foot	In Housing	15 mr/hr

Transfer Field Calibrator (pg 2)

The following procedure was used to obtain the above values:

A detection channel consisting of a [redacted] detector calibrated with traceability to N.B.S., a [redacted] electrometer, and a [redacted] high voltage power supply adjusted to 875 volts DC was connected to determine the signal current resulting from the dose rate applied. The signal current obtained was divided by the calibrated detector sensitivity to obtain the effective dose rate. This measurement was performed for each side of the calibrator to provide levels for a two point calibration.

The 1 foot reading was made using an [redacted] Ion Chamber survey meter.

Data Submitted By ______________________ ______________ ______________
Signature Date

Data Reviewed By ______________________________________ ______________
Signature Date

Transfer Field Calibrator (pg 1)
QA certificate

SUPPLIER QUALITY ASSURANCE CERTIFICATION

of Supplier [redacted] | Date 2-18-82

ess of Supplier Plant [redacted]y Court | Mill Power Order No. [redacted]

[redacted] | Duke Item or Req. No. 1

Spec. No. N/A | Rev. N/

lier ID Nos. [redacted]0615, Rev. A

ription of Component(s) or Material(s) [redacted] Calibrator (1 ea.) Serial No. 006.

_ Attached Documentation covers all Components/Materials on Mill Power Order.

_ Attached Documentation covers partial shipment of Components/Materials on Mill Power Order.

following listed tests, inspections and reports have been completed as required by the ification:

Certification Data Sheet [redacted]

Leak Test Certificate

Certificate of Radioactivity Calibration

[redacted]

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Transfer Field Calibrator (pg 2)

CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cs-137 Half-Life: 30.0y 2

Source No.: 81617

Was assayed as containing: 107 mCi

As of: 11-1-81

METHOD OF CALIBRATION:

( ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the MeV peak (a value of gamma rays per decay was used in the calculations), against standard No. , in the same geometrical arrangement.

(X) The source was assayed in a ~~windowless internal~~ pressurized ion chamber proportional counter against Cs-137 standard No. 47484 .

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. , in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in μCi/gm was determined by the method indicated above.

ERROR CALCULATION:

a) Systematic errors (SE)
   1. Accuracy of the standard: ± .95%
   2.

b) Random errors (RE)
   1. Precision of source count, e_1 :
   2. Precision of standard count, e_2 :
   3. Error due to background, e_3 :

$$RE = \sqrt{e_1^2 + e_2^2 + e_3^2} \pm 4.1\%$$

c) Total Error

TE = SE + RE ± 5.0%

Transfer Calibration

1.2 The secondary transfer calibration has the following characteristics

a. Use of a Standard Field calibrator to perform calibration.

b. Use of a Standard Drawer to fix exact repeatable position of sealed secondary transfer source, in the standard field calibrator. (±3%)

1.4 The field calibrator and its drawer affords a stable, reproducible reference geometry between the secondary transfer source and the detector. (Reference section 1.2.b)

Transfer Calibration

1.6 The general procedure for a [redacted] supplied detector is to:

1.6.1 Count [redacted] standard sources in the field calibrator (to obtain the individual detector absolute efficiency).

1.6.2 Count the customer's reference sources in the field calibrator.

- Provide the customer the expected response: i.e., the customer's source (decay corrected) results in a specific detector readout; e.g., how many R/hr

MCAM S/N 82211-4
P/N 451336-001
CHC

DATA SHEET, DETECTOR CALIBRATION

Customer Tag No. 1D19N800AB

Part No. 824636-002

Serial No. 14624

A. Date of Field Calibrator Calibration 9-30-83

B. Date of Field Calibration 10-14-83

C. Time interval (yrs) B-A = .04

D. Radioactive decay = $e^{-.693\ C/30.17}$

E. Field Calibrator R/hr 7.72

F. Present Field Calibrator R/hr = DE = 7.72

G. Present Detector [redacted] current (microprocessor in Calibrate mode) (including significant background) 1.06×10^{-11}

H. Present detector gross Field Calibrator current 9.52×10^{-11}

I. Present Calibration Constant to be entered into microprocessor = F/(H-G) = 9.13×10^{10} R/hr/A

Field Calibrator's Calibration Data

A. Date of Field Calibrator Calibration 9-30-83

B. Date of Field Calibration 10-14-83

C. Time interval (yrs) B-A = .04

D. Radioactive decay = $e^{-.693\ C/30.17}$

E. Field Calibrator R/hr 2.22

F. Present Field Calibrator R/hr = DE = 2.22

G. Present Detector [redacted] current (microprocessor in Calibrate mode) (including significant background) 1.40×10^{-11}

H. Present detector gross Field Calibrator current 8.91×10^{-11}

I. Present Calibration Constant to be entered into microprocessor = F/(H-G) = 1.03×10^{11} R/hr/A

TEST EQUIPMENT

ITEM	MFGR	MODEL	S/N	CALIBRATED
Field Calib.	[redacted]	[redacted]	82058-2	9-30-83

Field Calibrator

CERTIFICATE OF CALIBRATION

It is hereby certified that the equipment listed below has been calibrated, per internal [redacted] procedures, and is traceable to the National Bureau of Standards. This documentation is on file at [redacted] and is available for your review.

Model No. [redacted] Calibrator

Serial Number 118

Field Value 10.0 R/h on May 8, 1986

Sincerely,

[redacted]

Manager, Quality Assurance

Field Calibrator
Calibration Summary Report

– Determined by measurement of the transfer value for the detector in its Field Calibrator jig was 7.72 R/hr

– Cs-137 source was ~ 100 mCi Cs-137

Source Certificates

CERTIFICATION

DATA SHEET

CUSTOMER: [redacted] P.O.# 772 702 DATE: 10/31/81

CATALOG # Special line QUANTITY: 11

CAPSULE TYPE: line configuration [redacted]

NATURE OF ACTIVE DEPOSIT: CsCl in silver wire element

ACTIVE DIAMETER: 0.03"

BACKING: —

COVER: —

Sources Purchased by Manufacturer from Source Supplier

R+11 S/n

ISOTOPE	SOURCE #	ACTIVITY	CALIB. DATE	UNCERTAINTY
Cs-137	81613 002	114 mCi	11-1-81	± 5.0%
	4 003	104	'	'
	5 004	114	'	'
	6 005	106	'	'
	7 006	107	'	'
	8 007	116	'	'
	9 008	113	'	'
	20 009	106	'	'
	1 010	111	'	'
	2 011	127	'	'
	[illegible] 012	[illegible]	'	'

REMARKS:
I[illegible] described herein are in compliance with all applicable specifications.

Source Certificate

Page 1 of 2

CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cs-137 Half-Life: 30.0 y 2

Source No.: 81623

Was assayed as containing: 114 mCi

As of: 11-1-81

METHOD OF CALIBRATION:

( ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the MeV peak (a value of gamma rays per decay was used in the calculations), against standard No. , in the same geometrical arrangement.

(X) The source was assayed in a ~~windowless internal~~ pressurized ion chamber proportional counter against Cs-137 standard No. 47484 .

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. , in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in µCi/gm was determined by the method indicated above.

Source Certificate

ERROR CALCULATION:

a) Systematic errors (SE)

1. Accuracy of the standard: ± .9%
2.

b) Random errors (RE)

1. Precision of source count, e_1 :
2. Precision of standard count, e_2 :
3. Error due to background, e_3 :

$$RE = \sqrt{e_1^2 + e_2^2 + e_3^2} \pm 4.1\%$$

c) Total Error

$$TE = SE + RE \pm 5.0\%$$

NOTES

(X) The error given is calculated at the 99 % confidence level.

(   ) This calibration is directly/indirectly based on NBS Standard Reference Material No.

[redacted]

Title: Health Physicist

Calibration records

– Manufacturer provided licensees a "Calibration Summary Report" on both:

- the "ProtoType" detector calibration, and
- the "Production" detector's calibration

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Calibration Summary Report

- Report Number [redacted] Summary Report of Area Radiation Monitoring System Detector Calibration

- Report Number [redacted] Corporation Report of Calibration, Model KDA-HR, High Range Area Monitor Ion Chamber Detector.

- Master Material Equipment List and Shipping Documentation, dated 7/3/85, with one Cs-137 source of 96.4 mCi, with traceability Numbers 7605-1, Cs-1498.

- [redacted] Certificate of Calibration for Source with Serial Number CS1498, dated 1/14/83.

Step 4

In-Plant Calibrations

Calibration Check

- Objective
  - Determine if the CHRM is operating correctly
- Method:
  - Perform electronic calibration check
  - Perform radiation detector check
    - by comparing detector response to manufacturer's decay corrected, expected value

Example:
Plant's Acceptance Test

- 1986 – Manufacturer shipped the CHRM and field calibrator with Cs-137 source with NBS traceable certificate
- Ideally, upon receipt of CHRMs equipment from the vendor, the licensees should do an acceptance test.
  - Licensees first use the Field Calibrator and perform a calibration check and compare dose rate reading to a known "expected" value given by the manufacturer (decay corrected)
  - Licensees may have documentation on the initial acceptance test (before installation)

Experience with Typical Radiation Detectors

- Plant staff performed an in-plant calibration check on the CHRM and verified proper operation by:

  - Exposing the CHRM to the calibration source in the Field Calibrator and verifying the transfer dose-rate value of 7.72 R/hr (as decayed to current date)

  - Plant staff concerns were raised about integrity of the mineral insulation cabling while removing the CHRM from its wall mount

In-plant Calibration

- In-plant licensee calibrations then use the Field Calibrator and compare the CHRMs readings to the expected response value (e.g., ~7.72 R/hr) (after decay correction)

- The ANSI N323-1979 accuracy criteria is ± 40%, i.e., the acceptable range = 7.72 R/hr ± 40% = 4.6 R/hr to 10.8 R/hr

- The IEEE 497-2017 accuracy criteria is ± 50% = 3.86 R/hr to 11.6 R/hr

Example of Documentation of Installation of CHRM

High Range Containment Radiation
Monitors

This design change calls for the installation of Class IE redundant safety high range, 10^0 to 10^8 R/hr, containment area radiation monitors as required by NUREG 0578. The system consists of a detector, readout module and cabling for each train. The system meets all the requirements of NUREG 0578 and subsequent requirements.

<u>Trains</u>

Train A monitors use containment

NUREG-0578 (July 1979) TMI-2 LLTF
Short Term Recommendations

Documentation of Installation of CHRM

penetrations A10 with the readout modules for 2R-49 and 1R-49 being installed in positions M and N of RMS Rack 2RM-2 respectively. Train B monitors, 1R-48 and 2R-48, use penetration D11 with the readout modules being housed in positions M and N of RMS Rack 1RM-2 respectively.

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Documentation of Installation of

Detector Assemby

The detector assembly, [redacted], is a gamma sensitive ion chamber encased in stainless steel. The detector part of the assembly is a cylinder with a three inch diameter and nine inch height. The pull box section of the detector assembly is nine inches high by four inches wide by four inches deep. The detector cable, Rockbestos Model RSS-6104, is hard wired in the pull box and is routed to the containment penetration.

Documentation of Installation of CHRM

All four detector~~s~~ assemblies are mounted on 22½ inch high stands manufactured from QA Type 1 steel. Unit 1 Train A detector, 1R-49, is located on the 755 elevation of the containment at coordinates 45° and 56' from containment center. Unit 1 Train B detector, 1R-48, is located on elevation 755 of the containment at co-ordinates 282° and 56 feet from containment center. Unit 2 Train A detector, 2R-49 is located on elevation 755 of the containment at coordinates 350° and 56 feet from containment center. Unit 2 Train B detector, 2R-48, is located on elevation 755 of the containment at coordinates 80° and 56 feet from the containment center.

Documentation of Installation of CHRM

Cabling

The high voltage and signal cables, [redacted] are routed from the containment penetrations to the RD Racks in the Control Room via the Relay Room.

Documentation of Installation of CHRM

Electronic calibration can be checked via a current source corresponding to 10^5 R/hr. An internally generated signal in the detector corresponding to 1R/hr is generated to provide an onscale indication. Therefore if the signal is lost or the

detector should fail a DOWNSCALE FAILURE alarm will be actuated in the Control Room.

Documentation of Installation of CHRM

High Range Containment Area Monitor

The High Range Containment Area Monitors need to be added to Table 7.7-2 "Post Accident Instrumentation Available to the Operator" The monitors will be available for all three types of Accidents and all accidents listed.

FSAR Table 7.7-2

Documentation of Installation of CHRM

<u>Readout-Control Units</u>

The readout-control, hence forth referred to as readout unit, are installed in Rack 2 of the NSSS, [redacted], racks in the Control Room. The readout units [redacted] Model RP-2C, are mounted in a 19 inch NIM bin with outputs to HIGH ALARMS and DOWNSCALE FAILURE via terminal strips in the RD Racks. High voltage and signal connections to each channel are accomplished with MHV connectors. The readout unit is 8¾" high by 2¾ inches wide and 10 inches deep.

Electronic Calibration

- Electronic Calibration
  - The detector (ion chamber) output is electrical current; measured in amps (an analog signal)
  - The electronic calibration tests the Analog to Digital Converter by using a pico-amp generator and observing the microprocessor readouts

Alarm Setpoints

- Each detector has 2 or more electronic "Channels"
- Plant staff choose Alarm Setpoints:
- Setpoints are normally set well below Emergency Action Level thresholds. Examples are:
  - ALERT Alarms
    - Channel 1 at 100 R/hr
    - Channel 2 at 10 R/hr
  - HIGH Alarm
    - Channel 1 at 1,000 R/hr
    - Channel 2 at 2,000 R/hr

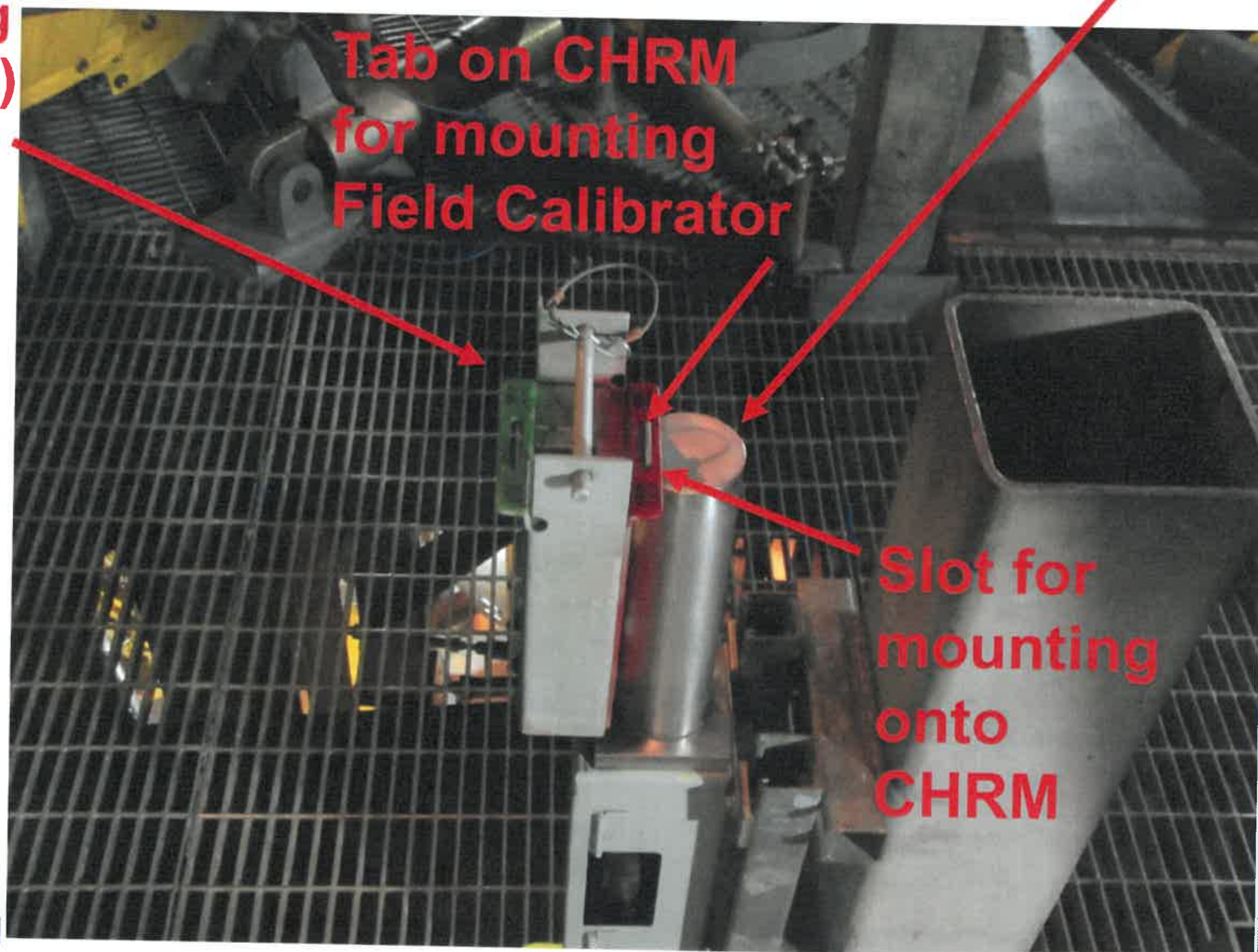
Example
Field Calibration Method

- Take the Field Calibrator to the CHRMs
- Mount the Field Calibrator onto the CHRMs (see photo on next slide)
- Take readings and compare to decayed corrected expected readings

CHRM Field Calibrator

Field Calibrator (with lead shielding removed)

Ion Chamber



Green is the low dose side ~ 3 R/hr

High dose side ~ 10 R/hr

CHRMs

B-8-1-1 Requirements

The [redacted] high-range in-containment area (HRICA) detectors (drawing 6092096) calibrated at the [redacted] detect activity in the range of 10^0 to 10^7 R/hr over an energy range of 80 KeV to 3 MeV. The detectors are qualified to function during and after a loss-of-coolant accident (LOCA). Maximum accident temperature is 400°F, and maximum accident pressure is 50 psig.

B-8-2 TRACEABILITY AND STANDARDIZATION

The high level field strength tests were run at Argonne National Laboratory using its ^{60}Co multipoint field. This field has a standardized strength as determined by an NBS gamma ion chamber (model RS-C4-1606-203). Table B-8-1 lists the standardized fields and locations.

TABLE B-8-1. STANDARDIZED FIELD AS A FUNCTION OF LOCATION

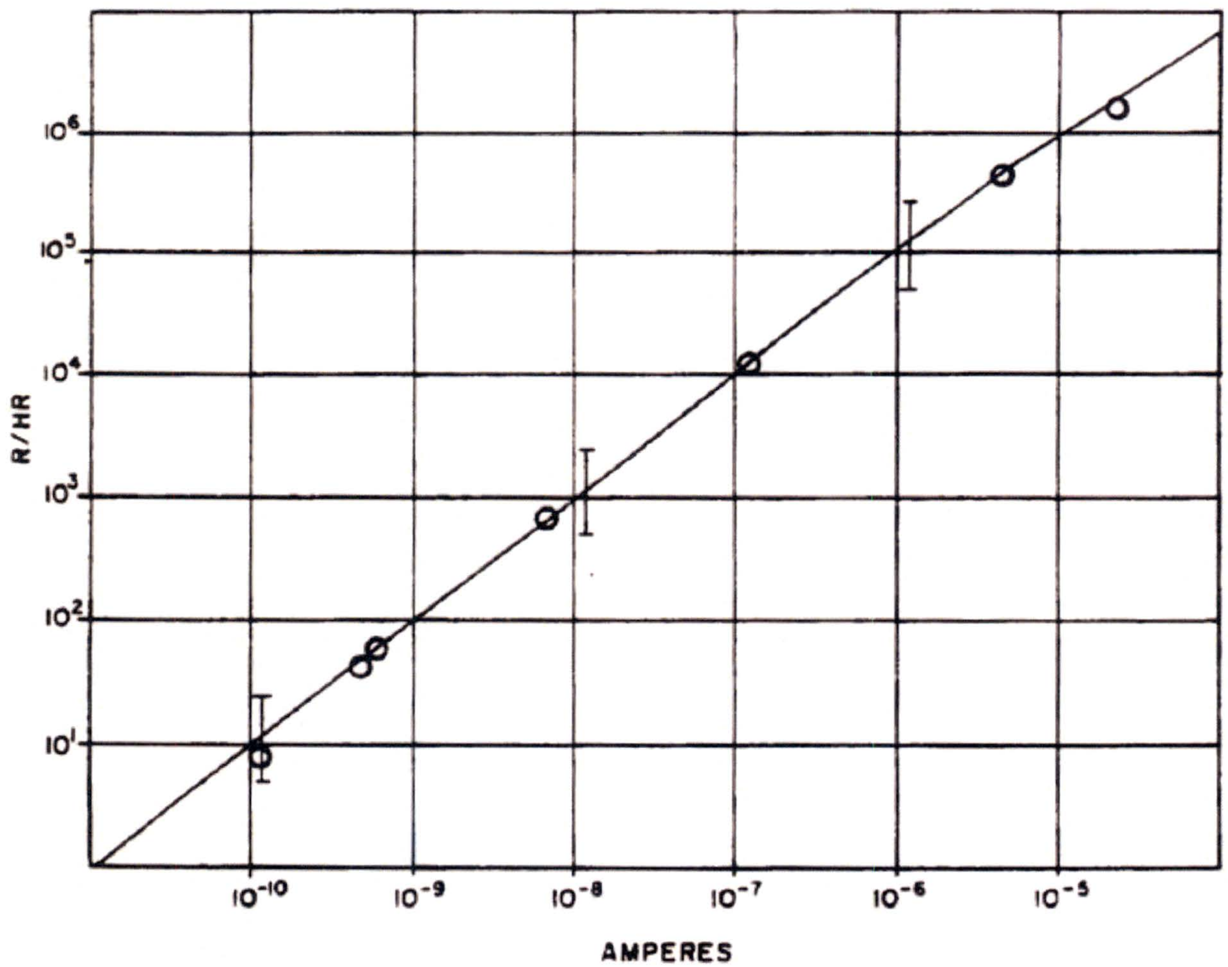
Run	Location	Dose Rate (R/hr)
1	61' East	1.09×10^4
2	Center	1.34×10^6
3	10' East	6.20×10^5

B-8-3-2 Detector Energy Response

To cover as wide an energy range as possible, measurements were made with four isotopes (^{57}Co, ^{133}Ba, ^{137}Cs, and ^{60}Co). These isotopes cover energies between 0.122 and 1.25 MeV. These sources were of low field

Dose Rate Linearity Test

CALIBRATION DATA



CHRM Sensitivity & Accuracy

CALIBRATION DATA

TABLE B-8-4. SENSITIVITY MEASUREMENT RESULTS USING THE [redacted] ION CHAMBER

Source	Energy Level (MeV)	Average Current (10^{-11}A)	Incremental Current (10^{-11}A)	Radiation Field (mR/hr)	Sensitivity (10^{-11}A/R/hr)
^{57}Co	0.122	1.2114 ± 0.0011	0.0124 ± 0.0017	11.3	1.09 ± 0.13
^{133}Ba	0.356	1.457 ± 0.0014	0.258 ± 0.002	245.0	1.05 ± 0.008
^{137}Cs	0.662	1.245 ± 0.002	0.046 ± 0.0024	45.2	1.02 ± 0.053
^{60}Co	1.17 1.33	1.279 ± 0.0014	0.080 ± 0.002	77.3	1.03 ± 0.025
No Source		1.199 ± 0.0014			

B-8-4 ACCURACY

The accuracy components of the high-range in-containment area detector were as follows:

1. Calibration accuracy
2. Current-measuring accuracy
3. Detector repeatability
4. Isotope response accuracy.

Assuming a calibration field accuracy of 5% and current-measuring accuracies of 2%, the total calibration accuracy is 7%. With the detector repeatability at 20% and isotope accuracy of 20%, the overall detector accuracy is 28%.

Example: FSAR

G. Containment High Range Area Monitors RE-0005 and RE-0006

To indicate, along with RE-0002 and RE-0003, the radiation levels inside the containment building at the operating deck following a design basis accident.

[redacted]-FSAR-12

TABLE 12.3.4-2 (SHEET 1 OF 2)

RANGE AND CONTROL FUNCTIONS FOR AREA RADIATION MONITORS

Monitor	Range (mR/h)	Sensitivity (mR/h)	Control Function	Accuracy
RE-0005, RE-0006 (A and B) containment high range	10^3 to 10^{11} (both)	10^3	No	± 20 percent of actual radiation field

Violation - White Finding

- NRC issued a White finding for invalid calibration and invalid adjustment of CHRMs output
- Apparent cause: A CHRMs system was manufactured and sold without supplying a Field Calibrator
- The plant purchased a Field Calibrator from a different vendor
- The Field Calibrator was not designed for CHRM calibration
- Plant incorrectly developed their own calibration method
- Then used a tripod mount to hold the Cs-137 source closer to the detector

White Finding (cont.)

- Plant calibration method was based on a calibration laboratory measurements using a Condenser R chamber to determine the “expected value” at a “point” at a specific distance
- The “expected value” was determined incorrectly, with 3 sources of error (see next slide):

White Finding (cont.)

Three sources of error occurred:

1. Detector "volume" errors in determining the "expected value" (i.e., dose rate)
   - A Condenser R chamber (0.6 cm^3 small volume) (~ essentially a point measurement)
   - CHRMs ion chamber has a 130 cm^3 (large volume) (~ a volumetric measurement)
2. Geometry errors
   - As the source decayed, the source was pushed closer to the detector to achieve the desired "expected value"

White Finding (cont.) (third error)

3. Plant staff error:
   - As the source was moved closer to the CHRMs, the CHRMs did not display the “correct” expected value, so plant staff incorrectly adjusted the gain on the CHRMs to achieve the expected value

Other Inspection Experiences

- A Field Calibrator was not locked properly when stored, source could have been removed
- Locking pins were found to be missing from the Field Calibrator and were replaced with pieces of wire

Other Considerations

- The Field Calibrator with Cs-137 source was licensed under 10 CFR 30
- The Field Calibrator must be used and maintained in that licensed configuration
- Repairs must be made by the original vendor or someone authorized under the 10 CFR 30 license to work on these sources.
- The vendor might authorize these, by letter, since repairs could be very simple.

Inspection Experiences

- A Field Calibrator was replaced with different model (but retained the old model number)
- New calibration data was provided by vendor applicable to a different model of rad monitor (i.e., for the post-Fukushima hardened vent monitor)
- Calibration data was not applicable to CHRMs, resulting in calibration error

Example: In-Plant Calibration Procedure

5.2 Calibration

The monitoring systems require calibration before placing them into service. In addition, they should be recalibrated at regular intervals during routine service. The length of time between calibration intervals should be determined by operations personnel. For further calibration information, refer to the applicable calibration procedure provided in Appendix A.

The high-range containment area monitor underwent a complete electronic and isotopic calibration prior to leaving the [redacted] plant. The same electronic calibration procedure is supplied in this manual. Prior to primary isotopic calibration, the detector's hermetically must be verified. Primary isotopic calibration requires a highly radioactive source (greater than 400 curies) with National Bureau of Standards (NBS) traceability. As this is beyond the capability of most facilities to perform, the following method of verifying detector calibration is used:

> Detectors shall either be returned to [redacted] at a five (5) year interval from the date of delivery or the owner must establish a procedure to determine that the average A/R/h output current does not deviate from original factory calibration by more than ± 10%.
>
> To encompass Nureg-0737 guidelines, on-site in-situ calibration checks can be performed with the [redacted] High-Range Field Calibrator that is capable of producing a 10 R/h indication on the channel under test.

Field Calibrator
CHRMs

[redacted]

DATE: JULY 24, 1984

[redacted] ORDER: 0 358831

[redacted] S. O. 750005

[redacted] P/N 878-10

CERTIFICATE OF CALIBRATION

It is hereby certified that the equipment listed below has been calibrated, per internal [redacted] procedures, and is traceable to the National Bureau of Standards. This documentation is on file at [redacted] and is available for your review.

Model Number 878-10 Calibrator Serial Number 106

Field Value 9.0 R/h on July 24, 1984

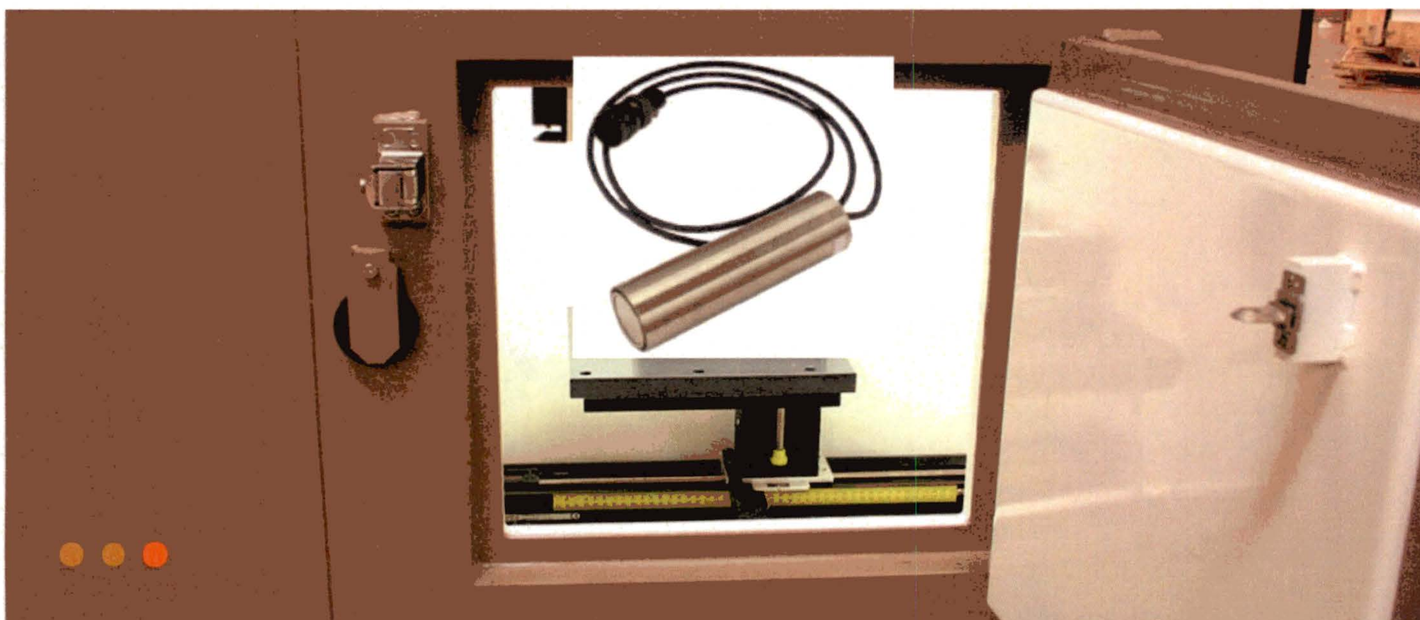
Sincerely,

[redacted]

Manager, Quality Assurance

Unmounting CHRMs for calibration

- Some plants physically unmount (remove) CHRMs from installed locations
- Then perform a calibration in a box calibrator



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Module 5

Inspector Preparations

And

Experiences

Inspector Preparations

- **FSAR** – Review the FSAR to obtain plant-specific description of CHRMs
- **Tech Specs** –
  - Review plant-specific STS for definitions of Channel Check and Channel Calibration
  - Review Post-Accident Monitoring Instrumentation (e.g., TS 3.3.3)
  - Review TS 5.4.1 for Emergency Operating Procedure criteria

Inspector Preparation

- Review EPRI proprietary report, "Calibration of Radiation Monitors," Rev. 2, (ML21146A265)
- Review licensee Emergency Planning documents to determine which Radiation Monitors are tied to EOPs and EALs
- Review licensee's Post-TMI commitments and Orders
- Review work orders/surveillance procedures for most recent CHRMs calibrations

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Inspector Preparation

- Request and review CHRMs system manuals
- Request and review licensee calibration procedures
- Determine the calibration method
  - Vendor Field Calibrator?
  - Home Made Field Calibrator?
- If home-made calibrator, review the technical bases for the new Field Calibrator method

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Inspector Preparations

- Review most recent radiological calibration checks
- Review electronic calibrations
- **Determine if the licensee adjusted any CHRMs calibration constants, and if so, determine why?**

Calibration Acceptance Criteria

– Determine calibration accuracy criteria, should be either:

- ± 40% per ANSI N320-1979, or
- ± 50% per IEEE 497-2017

– Some sites may be incorrectly using an accuracy criteria of a "factor of 2," based on the footnote in RG 1.97, Rev. 2 or Rev. 3

– Note: The "factor of 2" is not a calibration criteria. It is an "instrument design criteria" for detector's energy response from 80 keV to 3 MeV

Inspector Preparation

- Maintenance history
  - Review the maintenance history on the CHRMs
  - Review any component failures and replacements
  - Determine if there has there been failures of cabling mineral insulation, and if so, has it been replaced or is it a continuing problem?

Home-made Field Calibration Jigs
What's the problem?

- Normally, the manufacturer does a calibration of its CHRM in its own Field Calibrator using a NIST traceable source
- Home-made Field Calibrators – what's the problem?
  - How was the expected response determined?
  - How does the plant know if the CHRM detector was operating properly when the expected response measurement was made?
  - Does the plant have an evaluation of the calibration of its own home-made field calibrator?

Home-Made Field Calibrators

- Plants should have a documented evaluation of the expected dose rate from the source in a home-made Field Calibrator
- Dose rates obtained from NIST-source certificates cannot be used directly by inverse square law, since these are dose rates at "point" locations vs a "volumetric" detector's geometry
- The inverse square law does not work because of geometry differences

Replacement Sources

- Most original Cs-137 sources have now decayed over 50%
- Dose rates have declined toward the lower end of the 1 R/hr to 10 R/hr scale
- Some plants may have replaced their sources
- A NIST traceable source can be used
- How was "expected value" determined?
- Review EPRI proprietary report, "Calibration of Radiation Monitors," Rev. 2, (ML21146A265)

Example 1 - Source Replacement

How to determine "expected response"

- The "expected response" can be based on the ratio of the activity of the NIST traceable Cs-137 sources
- Example: The original NIST source was 110 mCi producing a 7.72 R/hr dose rate in the Field Calibrator Jig
- Replacement source is 120 mCi.
- By ratio, the new "expected response" is
  = 120 / 110 x 7.72 R/hr = 8.42 R/hr

Example 2: Home-made Field Calibrator

Developing a new expected response value

- First, verify the CHRM was operating properly (e.g., by using the original Field Calibrator)
- Expose the CHRM to the replacement source in the home-made Field Calibrator jig to determine its new "expected response"
- Use the new "expected response" value (decayed for future calibration checks)

Example #3
Transfer Standard using Cutie Pie

- A Field Calibrator was no longer used
- A licensee developed their own Transfer Standard using a Cutie Pie dose rate meter
- Issue of Concern: Was an evaluation of equivalency performed?

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Example #3 (continued)
Transfer Standard using Cutie Pie

- Used a 2nd Transfer detector that has been recently calibrated (e.g., a Cutie Pie)
- Used the home-made Field Calibrator with its Cs-137 source, measure the dose rate on the Cutie Pie to determine the "Expected Response"
- Exposed the CHRM to the same source in the same geometry
- Determined if the CHRM response was the same as the 2nd transfer detector

Cutie Pie 740F Calibration

- Cutie Pie has decade selector switches
- X1, x10, x100, x1000
- 0 – 25 mR/hr, 0 – 250 mR/hr, 0 – 2,500 mR/hr and 0 – 25,000 mR/hr

8.2 **Calibration of the Cute Pie Mode No. 740F**

8.2.1 From the current Calibration Curves or Exposure Rate Tables, determine the sources, distances and attenuation factors, if applicable, required to deliver dose rates at 20% and 80% of full scale (desired dose rates) for each range or as specified by Supervisor Instrument Calibration (SIC) or

Concerns with Use of Cutie Pie as a Transfer Standard

- Cutie Pie was calibrated to Cs-137 within one week
- Geometry of transfer calibration was not specified
- Possibly calibrated in a box calibrator

Module 6

Licensee Calibration Procedures

Excerpts from Plant Procedures

Example 1

4.0 PERSONNEL AND SPECIAL EQUIPMENT REQUIREMENTS

4.1 Two (2)Radiation Protection Personnel Required

4.2 One (1) Licensed Operator

4.3 200 mCi Cesium 137 Source

4.4 200 mCi Bugging Tool **(i.e., Field Calibrator)**

Add Hand tools

4.5 Long Handled Source Tool

Excerpts from Plant Procedures
Example 1

6.0 PREREQUISITES AND INITIAL CONDITIONS

6/6/19 ✓ 2/24/19 ✓

6.1 **Verify** that SP 1783.4A and Sp 1783.4B have been completed.

6.2 **Obtain** the desired readings from the Radiation Monitoring Database (RADMON.MDB), and enter in the note sections for each monitor.

6.3 **Perform** independent verification of values entered.

6.4 **Conduct** a Pre-Job Brief

6.5 **Notify** the Control Room Operators to expect various Rad Monitor related annunciators to alarm during this test.

6.6 **Obtain** Shift Supervisor's permission to perform test.

Excerpts from Plant Procedures
Example 1 (Detector 1R-48)

7.1 1R-48, Unit 1 Containment High Range Area Radiation Monitor

7.1.1 Note the background level.

7.1.2 When notified by RP in Containment that they are ready to bug **1R-48**, bug the detector and note the date, time, and all meter readings for the two bug points.

Bug = expose

7.1.3 After all bug points have been recorded, **direct** RP in Containment to put the protective cover back in place.

7.1.4 **Rotate** the OPERATE switch to the "CHECK" position.

7.1.5 Note the meter reading in the note section.

NOTES							
Monitor	**Bug Point**	**Background**	**Low Limit**	**Corrected Reading**	**High Limit**	**Date**	**Time**
1R-48	1	$1.5E^0$	7.6e-1	$4E^0$	6.1e0	7/18/19	1410
	2	$1.5E^0$	3.8e0	$1E^1$	3.0e1	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Check Source	$1.5E^0$	2.0e4	$8E^4$	1.6e5	[redacted]	[redacted]

Data Analysis

Example 1 (detector 1R-48)

NOTES							
Monitor	Bug Point	Background	Low Limit	Corrected Reading	High Limit	Date	Time
	1	1.5E0	7.6e-1	4E0	6.1e0	7/18/19	1410

- What is a "corrected reading"? Is that the measured value or the expected value?
- Inspectors should look at the Low and High Limits (acceptance criteria)
- Why are the values typed in?
  - Are the values decay corrected?
  - **Why is the low/high acceptance range so large?**
    - from 0.76 to 6.1 R/hr?
    - vs. 4.0 ± 40% would be a range of 2.4 to 5.6

More Data Analysis

Example 1 (monitor 1R-48)

NOTES							
Monitor	Bug Point	Background	Low Limit	Corrected Reading	High Limit	Date	Time
Low Side?	1	$1.5E^0$	7.6e-1	$4E^0$	6.1e0	7/18/19	1410
High Side?	2	$1.5E^0$	3.8e0	$1E^1$	3.0e1	[redacted]	[redacted]
1R-48	[redacted]						
	Check Source	$1.5E^0$	2.0e4	$8E^4$	1.6e5	[redacted]	[redacted]

- How can the Low Limit be 2.0E4 (20 R/hr?)
- How can the High Limit be 1.6e5 (160 R/hr?)
- Is that on contact with the Field Calibrator?
- How is that measured?
- Is the data for the check source in mR/hr?

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Plant Calibration
Example 2 (monitor 1R-49)

7.3 1R-49, Unit 1 Containment High Range Area Radiation Monitor

7.3.1 Note the background level.

7.3.2 When notified by RP in Containment that they are ready to bug **1R-49**, bug the detector and note the date, time, and all meter readings for the two bug points.

7.3.3 **Rotate** the OPERATE switch to the "CHECK" position.

7.3.4 Note the meter reading in the note section.

NOTES							
Monitor	**Bug Point**	**Background**	**Low Limit**	**Corrected Reading**	**High Limit**	**Date**	**Time**
1R-49	1	$2E^0$	1.1e0	$5E^0$	8.8e0	7/15/19	1002
	2	$2E^0$	1.7e0	$9E^0$	1.4e1	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Check Source	$2E^0$	2.0e4	$9E^4$	1.6e5	[redacted]	[redacted]

Data Analysis

Example 2 (monitor 1R-49)

NOTES							
Monitor	Bug Point	Background	Low Limit	Corrected Reading	High Limit	Date	Time
	1	$2E^0$	1.1e0	$5E^0$	8.8e0	7/15/19	1002
1R-49	2	$2E^0$	1.7e0	$9E^0$	1.4e1	[redacted]	[redacted]
	[redacted]						
	Check Source	$2E^6$	2.0e4	$9E^4$	1.6e5	[redacted]	

- Why are the Low and High Limits different than for the **detector 1R-49** ?
- Possible Answer: Because the internal background on CHRMs # 1R-48 was 1.5 R/hr vs. 1R-49 was 2 R/hr

Plant Calibration Example 3

7.2 2R-48, Unit 2 Containment High Range Area Radiation Monitor

7.2.1 Note the background level.

7.2.2 When notified by RP in Containment that they are ready to bug **2R-48**, bug the detector and note the date, time, and all meter readings for the two bug points.

7.2.3 After all bug points have been recorded, **direct** RP in Containment to put the protective cover back in place.

7.2.4 **Rotate** the OPERATE switch to the "CHECK" position.

7.2.5 Note the meter reading in the note section.

"Bug" means expose

NOTES							
Monitor	**Bug Point**	**Background**	**Low Limit**	**Corrected Reading**	**High Limit**	**Date**	**Time**
2R-48	1	$1.8E^0$	8.9e-1	$5E^0$	7.1e0	7/10/19	1007
	2	$1.8E^0$	3.8e0	$8E^0$	3.0e1	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Check Source	$2.0E^0$	2.0e4	$9E^4$	1.6E+05 ~~1.5e5~~	[redacted]	[redacted]

Calibration Procedure Example 4

1.0 **PURPOSE**

1.1.1 Sections 4.5 and 4.10 can only be performed when plant conditions allow entrance into the Reactor Building such as during an outage. The remainder of the procedure is normally performed pre-outage.

1.1.2 Calibrate RM-G29 and RM-G30 with Pico-Amp source simulating a detector signal.

1.1.3 Calibrate/verify all end point readout locations (recorder, recall points, REDAS points) using Pico-Amp source.

1.1.4 Verify readout monitor alarms and REDAS alarms from loss of power, loss of signal, high radiation, Check switch position, and Trip adjust switch position.

1.1.5 Provide a detector operability check by utilizing a known gamma source at the ionization chamber and verifying equivalent dose rate at the readout module.

2.1.2 Instruction Manuals:

- Manual #506, High Range Gamma Radiation Monitoring System

2.1.3 MARs:

- MAR 86-10-06-01, and 86-10-06-01, MAR Functional Test TP-1B
- MAR 82-05-03-07, FCN 8 and 82-05-03-07 MAR Functional Test TP-3A
- MAR 82-05-03-12, FCN 18, FCN 20, and FCN 21
- MAR 88-06-07-0, New Power Supply Breaker for RM-G29/30

Technical Specifications

2.1.4 Technical Specification References [NOCS 000998]

Applicable References	Surv. Perf. During Modes	LCO/Other Requirements During Modes	Surv. Freq.	Freq. Notes
3.3.17.2(11)	1 thru 6, and NO Mode	1, 2, 3	2Y	*

* 2Y at least once per 24 months

Example Licensee Commitments

2.1.5 NOCS Commitments 000998, 001783, 005825, 060310, and 090210

2.1.6 Calc. I89-0006, IR and Loop Uncertainty Rad Monitors RM-G29 and RM-G30

Example Calibration Procedure

4.0 **INSTRUCTIONS**

> **NOTE**
>
> Pico ammeter input values are based on detector coefficient of 1.04. If a detector is replaced, a procedure revision will be required.

4.1 **RM-G29 Calibration and Functional Test**

4.1.1 NOTIFY SM/CRS **ITS 3.3.17 Condition A** will be entered. .... ☐

4.1.2 NOTIFY Nuclear Operator of alarms during this test:

- Annunciator H-1-1, GAMMA RADIATION HIGH .... ☐
- Annunciator H-1-2, GAMMA MONITOR WARNING .... ☐
- Event Point 1784 .... ☐
- Event Point 1785 .... ☐
- PICS REDAS Points W049 .... ☐
- PICS REDAS Points W050 .... ☐

4.1.3 MEASURE ambient temperature at calibration location and RECORD on Enclosure1, RM-G29 Data Sheet. .... ☐

Example Electronic Calibration

4.2 **Electronic Calibration Adjustment of RM-G29**

4.2.1 **Concurrent Verification Point** OPEN links to deenergize ratemeter:

Ratemeter	Links	Performed by: Initial/Date	Concurrent Verification
RM-G29	TB 17-17		
RM-G29	TB 17-18		

4.2.2 DISCONNECT Pico Amp current source at signal input. .... ☐

4.2.3 CONNECT DMM to input coaxial cable of ratemeter to measure input off-set voltage. .... ☐

4.2.4 **Concurrent Verification Point** ENERGIZE ratemeter by closing links, and WAIT five minutes for warmup:

Ratemeter	Links	Performed by: Initial/Date	Concurrent Verification
RM-G29	TB 17-17		
RM-G29	TB 17-18		

Adjust meter readout to 1 R/hr
(based on pico-amp input)

4.2.9 RECONNECT Pico-Amp source to the input coaxial cable. ☐

4.2.10 ADJUST mechanical meter zero (side of meter) for a reading of 10^0 R/Hr. ☐

4.2.11 **Concurrent Verification Point** CLOSE links to ENERGIZE ratemeter and WAIT five minutes for warmup:

RATEMETER	LINKS	PERFORMED BY: INITIAL/DATE	CONCURRENT VERIFICATION
RM-G29	TB 17-17		
RM-G29	TB 17-18		

4.2.12 ADJUST Pico-Amp source to input 1.04×10^{-5} amps. ☐

4.2.13 ADJUST Slope Adj pot for a TP-3 voltage reading of 7.50 VDC (7.20 to 7.80 VDC). ☐

Adjust meter readout to 1 million R/hr
(based on pico-amp input)

4.2.14 ADJUST Pico-Amp source to 1.04 x 10^{-9} amps.

4.2.15 ADJUST Bias Adj pot for a TP-3 voltage of
2.50 VDC (2.20 to 2.80)........ ☐

4.2.16 REPEAT 4.2.12 through 4.2.15 until readings are in tolerance and
RECORD final values:

RATEMETER	FINAL SLOPE ADJ READING	FINAL BIAS ADJ READING	INITIAL/DATE
RM-G29			

4.2.17 ADJUST Pico-Amp source to apply 1.04 x 10^{-5} amps to ratemeter........ ☐

4.2.18 ADJUST Meter Adj pot for a meter reading of 1 x 10^{6} R/Hr........ ☐

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Example: Check alarm setpoints

4.3 **RM-G29 As-Left Calibration Data**

CAUTION

When power is applied to the readout module, the circuits generate high voltages (up to 1000 V). Failure to de-energize the unit before making connections can result in equipment damage and electrical shock.

4.3.1 INPUT current signals from cal data sheet and RECORD As Left data. ☐

4.3.2 ADJUST Pico-Amp source current input to 0.01 X 10^{-9} and RESET ratemeter alarms. ☐

4.3.3 RAISE input current until the Trip 1 light is ON. ☐

4.3.4 RECORD input current, output voltage, and monitor display for As Left Warning setpoint:

RATEMETER	INPUT CURRENT Amps	OUTPUT @ TP-3 VDC	MONITOR DISPLAY (analog meter) R/HR
DESIRED VALUES	0.832 X 10^{-9} to 1.25 x 10^{-9} Amps	2.2 to 2.8 VDC	80 to 141 R/HR
RM-G29			

Example: Check Alarm Failure

4.4 **Functional Check of RM-G29 Failure and Switch Alarms**

4.4.1 **Concurrent Verification Point** OPEN links to deenergize ratemeter:

RATEMETER	Links	Performed By: Initial/Date	Concurrent Verification
RM-G29	TB 17-17		
RM-G29	TB 17-18		

4.4.2 VERIFY associated REDAS point has failed:

Ratemeter	REDAS point	Condition	Initial/Date
RM-G29	W049 (YES) ☐	FAILED	

Example: Calibration Procedure

- The following slides appear to be I&C procedure
- Where is the Chemistry/HP Procedure?
  - Does the procedure describe how to determine the expected value?
  - Does the procedure describe how to use the Field Calibrator to achieve the correct exposure geometry?

Example: Radiation Calibration Check

Note: This appears to be an I&C procedure

4.5.6 REQUEST HP to EXPOSE detector to a Gamma Field of between 3 and 10 R/Hr:

RATEMETER	KNOWN GAMMA FIELD VALUE	INITIAL/DATE
RM-G29	R/Hr	

4.5.7 RECORD DMM reading at TP-3 when the detector ionization chamber under test is exposed to the source:

RATEMETER	DMM READING VDC	INITIAL/DATE
RM-G29	VDC	

4.5.8 CONVERT DMM reading to an equivalent R/Hr dose rate as follows:

1. DIVIDE voltage reading by 1.25 to determine the log base 10 ....
2. Raise ten (10) to the power of V/1.25 ($10^{v/1.25}$) ....

This will yield equivalent dose rate.
Example: Assume the DMM reading was 0.95 VDC
0.95/1.25 = 0.76
$10.^{0.76}$ = 5.75 R/Hr equivalent dose rate
OR
$10^{v/1.25} = 10^{0.95/1.25} = 10^{0.76}$ = 5.75 R/Hr

Example: Subtract Background

4.5.9 **Independent Verification Point** RECORD voltage converted to R/Hr calculated value:

RATEMETER	EQUIVALENT CALCULATED VALUE R/HR	CALCULATION PERFORMED BY: INITIAL/DATE	INDEPENDENTLY VERIFIED BY INITIAL/DATE
RM-G29			

4.5.10 SUBTRACT the background reading Recorded in step 4.5.5 from the Source reading recorded in step 4.5.9 to determine Calculated Actual Reading and RECORD:

Source Reading – Background Reading = Calculated Actual Reading__________R/Hr

4.5.11 IF Calculated Actual Reading R/Hr dose rate does NOT agree within the following acceptance criteria statement, THEN REFER TO Section 5.2, Contingencies. ....

- Functional Test, with Radiation Source, ACCEPTANCE CRITERIA ....
- Calculated Actual Value is equal to the field strength ±20%:

RATEMETER	ERROR	INITIAL
RM-G29		

Example: Follow-up Questions

4.5.6 REQUEST HP to EXPOSE detector to a Gamma Field of between 3 and 10 R/Hr:

RATEMETER	KNOWN GAMMA FIELD VALUE	INITIAL/DATE
RM-G29	R/Hr	

- What was the calibration geometry?
- Did the vendor specify how the field calibration geometry was to be established?
- What was the expected value?
- Was there a Field Calibrator?
- Was the expected value decay corrected?

Exampe: Self Assessments

- After learning of an industry White finding on mis-calibration of CHRMs, the plant staff did a self-assessment
- Self-assessment was inadequate, i.e., did not recognize or investigate the geometry change
- A Condition Report was written that the dose rate and date used in the calibration procedure did not match the information on the radiation source certificate
- **The inspector reviewed the CR and recognized that there had been an inappropriate change in the calibration geometry**

Other examples: Radiation Detectors

- In order to protect cabling, the calibration geometry was changed
- Instead of removing the detector from its wall mount, the Cs-137 source was placed against the detector in a new geometry
- A new transfer standard was developed of 8.06 R/hr ± 0.364 R/hr
- The acceptance criteria for the calibration check was ± 20% (vs. 40%)

Example: Radiation Detectors

- A Field Change Request was attached to a CAP Condition Report (CR) to change the calibration geometry
- The inspector questioned the change in the geometry for the secondary/transfer calibration method being used
- How was the new transfer standard established?
- Was the new transfer standard NIST traceable?

Module 7

References

Main Reports on TMI-2 Accident

- NRC staff (I&E) technical report
  - NUREG-0600 (ML090050311)
  - **Radiological Aspects of TMI-2 Accident**
    - **pgs 13 – 21 (pdf pgs 31 – 39)**
    - **Appendix II (Details on document pg II -1 to II-E-6 or pdf pgs 438 - 779**
- Rasmussen Reactor Safety Study
  - NUREG-075/014 WASH-1400 (1975)
  - Search on NRC Public Web site search
- Kemeny Report to the President's Commission, Vol. I and II
  - Search for it on Google

NRC Requirements following TMI-2 accident

1 - September 13, 1979 Letter to Operating Licensees (ML073520999).pdf
2 - October 30, 1979 Letter to Licensees WITH ENCLOSURES (ML031320403).pdf
3 - GL 79-40 September 13, 1979 Letter to Operating Licensees WITH ENCLOSURES (ML031320328).pdf
4 - GL 79-40 September 13, 1979 Letter to Operating Licensees WITHOUT ENCLOSURES).pdf
5 - GL 79-56 October 30, 1979 Letter to Licensees WITH ENCLOSURES (ML031320403).pdf
6 - GL 79-56 October 30, 1979 Letter to Operating Licensees (rad excerpts) (ML031320403).pdf
7 - GL 79-60 November 9, 1979 Letter to pending Operating Licensees with no Enclosures (ML073521000).pdf
8 - GL 79-61 Nov 9, 1979 Letter to pending Construction Permit applicants with no Enclosures.pdf
NUREG-0578 Excerpts - Rad Monitoring.pdf
NUREG-0578 Excerpts - Rad Monitoring.pdf
NUREG-0737 1980 Excerpts II.F.1 Hilites Effluent Monitoring ML051400209 .pdf