LUDLUM MODEL 42-41 & 42-41L 'PRESCILA' NEUTRON PROBE

December 2021

Serial Number 232558 and Succeeding Serial Numbers

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Section 1

Introduction

The Ludlum Model 42-41 & Model 42-41L PRESCILA Neutron Detectors (also referred to as PRESCILA) are viable and ergonomically superior alternatives to traditional rem-ball designs for hand-held radiation surveys, proven through extensive performance and field testing by the Health, Safety, and Radiation Protection Division of Los Alamos National Laboratory. The Model 42-41 and Model 42-41L are designed to detect and measure neutron radiation. The PRESCILA features a low-weight probe (the Model 42-41 weighs 2.0 kg {4.5 lb}; the Model 42-41L weighs 2.3 kg {5.0 lb}) capable of excellent sensitivity of 35 cpm per μSvh^{-1} for ^{241}AmBe) and extended energy response to over 20 MeV. Directional response is uniform (±15%) over a wide range of energies. Response linearity has been characterized to a dose rate exceeding 20 $mSvh^{-1}$. Gamma rejection is effective in gamma fields up to about 1 $mSvh^{-1}$, and can be extended to 2 $mSvh^{-1}$ when using dynamic gamma compensation. For complete details on the Los Alamos testing of PRESCILA, see Section 4 of this manual.

The Model 42-41L has internal lead shields on each of the five faces of the detector. The lead shields, only 0.043 cm (0.017 in.) thick, reduce the gamma interference of low energy photons.

Note:

The detector does not contain any consumable materials.

Note:

If the detector is used in a manner not intended by the manufacturer, the detector may not function properly.

Section 2

Unpacking and Repacking

Remove the calibration certificate and place it in a secure location. Remove the instrument and any accessories, and ensure that all of the items listed on the packing list are in the carton. Check individual item serial numbers and ensure calibration certificates match. The serial number for the Model 42-41 or Model 42-41L is located on the side of the detector.

Important!

If multiple shipments are received, ensure that the detectors and instruments are not interchanged. Each instrument is calibrated to a specific detector; therefore, the instruments are not interchangeable.

To return an instrument for repair or calibration, provide sufficient packing material to prevent damage during shipment. Also, provide appropriate warning labels to ensure careful handling. Include detector(s) and related cable(s) for calibration. Include brief information as to the reason for return, as well as return shipping instructions:

- **Return shipping address**
- **Customer name or contact**
- **Telephone number**
- **Description of service requested and all other necessary information**

Section 3

Specifications

Photomultiplier Tube: 2.9 cm (1.1 in.) diameter

Scintillator: PRESCILA Proton Recoil Scintillator

Sensitivity: approximately 350 cpm per mrem/hr

Neutron Energy Response: thermal to 100 MeV

Angular Dependence: within 15% over a wide range of energies

Gamma Rejection: approximately 450 cpm at 100 mR/hr with ^{137}Cs for the Model 42-41 and 400 cpm at 100 mR/hr with ^{137}Cs for the Model 42-41L

Typical Background: ≈ 12 cpm (0.05 mrem/hr)

Operating Voltage: typically 500-700 volts

Connector: Series ˝C˝ (others available upon request)

Construction: aluminum housing with black powder-coat finish

Temperature Range: -10 to 50 °C (14 to 122 °F); see Figure 10 and Table 5, pages 6-26 and 6-27

Size: 25.7 x 10.8 x 10.8 cm (10.1 x 4.3 x 4.3 in.) (H x W x L)

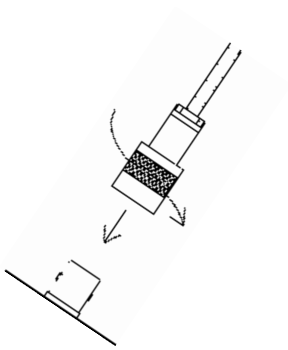
Weight: Model 42-41: 2.0 kg (4.5 lb); Model 42-41L: 2.3 kg (5.0 lb)

Drop Resistance: survives 100g drops in three orientations

Section 4

Operating Procedures

Connecting To an Instrument



Caution!!!

The detector operating voltage (HV) is supplied to the detector via the detector input connector. A mild electric shock may occur if you make contact with the center pin of the input connector.

Connect one end of a detector cable to the detector by firmly pushing the connectors together while twisting clockwise a quarter of a turn. Repeat the process in the same manner with the other end of the cable and the instrument.

Testing the Detector

If a check source is available, expose the detector to the check source and verify that the instrument indicates within 20% of the check source reading from the last calibration. Alternatively, expose the detector to a source of known value and verify that the detector detects greater than or equal to the efficiency listed in the specification section of this manual.

Instruments and detectors that meet these criteria are ready for use. Failure to meet these criteria may indicate a malfunction in the detector.

Section

5

Safety Considerations

Environmental Conditions for Normal Use

Indoor or outdoor use (in a dry environment only)

No maximum altitude

Temperature Range for readings within 30% from -10 to 50 °C (14 to 122 °F)

Maximum relative humidity of less than 95% (non-condensing)

Pollution Degree 3 (as defined by EIC 664) Occurs when conductive pollution or dry nonconductive pollution becomes conductive due to condensation. This is typical of industrial or construction sites.)

Cleaning Instructions and Precautions

The detectors specified in this manual may be cleaned externally with a damp cloth, using only water as the wetting agent. Do not immerse the detector in any liquid. Do not attempt to clean a detector that is attached to an instrument providing high voltage. Disconnect the detector cable before cleaning.

Section 6

Los Alamos National Lab Report

PRESCILA: A NEW, LIGHTWEIGHT, NEUTRON REM METER
LA-UR-03-2638

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ABSTRACT

Conventional neutron rem meters currently in use are based on 1960s technology that relies on a large neutron moderator assembly surrounding a thermal detector to achieve a rem-like response function over a limited energy range. Such rem meters present an ergonomic challenge, being heavy and bulky, and have caused injuries during radiation protection surveys. Another defect of traditional rem meters is a poor high-energy response above 10 MeV, which makes them unsuitable for applications at high-energy accelerator facilities. Proton Recoil Scintillator – Los Alamos (PRESCILA) was developed as a low-weight (2 kg) alternative capable of extended energy response, high sensitivity, and moderate gamma rejection. An array of ZnS(Ag) based scintillators is located inside and around a Lucite™ light guide, which couples the scintillation light to a sideview bialkali photomultiplier tube (PMT). The use of both fast and thermal scintillators allows the energy response function to be optimized for a wide range of operational spectra. The light guide and the borated polyethylene frame provide moderation for the thermal scintillator element. The scintillators represent greatly improved versions of the Hornyak and Stedman designs from the 1950s, and were developed in collaboration with Eljen Technology.[1] The inherent pulse height advantage of proton recoils over electron tracks in the phosphor grains eliminates the need for pulse shape discrimination and makes it possible to use the PRESCILA probe with standard pulse height discrimination provided by off-the-shelf health physics counters. PRESCILA prototype probes have been extensively tested at both Los Alamos and the German Bureau of Standards, Physikalisch-Technische Bundesanstalt (PTB). Test results are presented for energy response, directional dependence, linearity, sensitivity, and gamma rejection. Initial field tests have been conducted at Los Alamos and these results are also given. It is concluded that PRESCILA offers a viable, ergonomically superior, alternative to traditional rem meters that is effective for a wide range of neutron fields. The probe is capable of excellent sensitivity (40 counts per minute (cpm) per µSvh-1 for 241AmBe) and extended energy response to beyond 20 MeV. Directional response is uniform (+/-15%) over a wide range of energies. Response linearity has been characterized to over 20 mSvh-1. Gamma rejection is effective in gamma fields up to 2 mSvh-1. The PRESCILA technology has been commercialized and is now offered under license by Ludlum Measurements, Inc.[2]

INTRODUCTION

Bramblett et al. (1960) set the stage for conventional rem meter design when they pointed out that the response of a 12-inch diameter polyethylene sphere surrounding a small $Li^6I(Eu)$ scintillator could be used for neutron dose equivalent measurement – at least over a limited energy range. Andersson and Braun (1963), Leake (1966), and Hankins (1967) introduced popular variations on this theme, using BF_3 and ^3He thermal detectors. In all of these cases, it was necessary to surround the thermal detector with a large polyethylene moderator to enhance fast neutron sensitivity. A recent iteration on this type of design, with improved sensitivity, is the Berthold model LB 6411[3] which uses a 9.2 kg moderator assembly. Because of the

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requirement for a large moderator assembly, traditional rem meters are heavy and bulky instruments that are difficult to maneuver under field conditions. Several cases of injury from lifting of heavy rem meters have been reported within the U.S. Department of Energy complex. A lightweight instrument would reduce the incidence of back strain injuries.

Traditional rem meter designs also have the defect of monotonically decreasing response above a neutron energy of 10 MeV, which renders them inappropriate for high-energy applications. An under response on the order of a factor of 10 is possible in high-energy accelerator neutron fields. A recent design trend has been to add heavy metal inserts to the polyethylene moderator to improve the meter's high-energy response via spallation neutron generation. LINUS, a modified Andersson-Braun rem meter, (Birattari et al. 1990) was the first design to use a lead insert to enhance neutron response above the (n,2n) threshold of 8 MeV. Tungsten powder is used in the Los Alamos design, WENDI (Olsher et al, 2000), as both an absorber and neutron generator to extend the response function to 5 GeV. In both cases, there is a serious weight penalty, as the moderator assembly's weight exceeds 13.5 kg.

Several novel and lightweight rem meter designs have been commercialized in the past decade. Three such designs have undergone field testing at the Los Alamos National Laboratory: HPI REM 500[4], Canberra Dineutron[5], and Apfel Enterprises REMbrandt, which is now defunct. The REM 500 features admirably low weight (2.2 kg), but its poor sensitivity (0.8 cpm per μSvh^{-1}) makes it extremely difficult to measure low-level fields in real-time. The Dineutron is based on a dual moderating sphere design, with each sphere incorporating a compact ^3He detector. It features good accuracy over its operating energy range (thermal to 15 MeV) and a total weight of only 3.5 kg. However, it is not suitable for applications in high-energy neutron fields.

Our goal was to develop a practical low-weight (2 kg) rem meter with good sensitivity, directional response, gamma rejection, and enhanced high-energy response. PRESCILA is the result of research and development funded by the Health, Safety, and Radiation Protection Division at the Los Alamos National Laboratory.

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[5] Canberra Industries 800 Research Parkway, Meriden, CT 06450

DESIGN OVERVIEW

In order to eliminate the heavy moderator assembly associated with conventional rem meters, it was vital to utilize a detector element with excellent fast neutron response. Both plastic and ZnS(Ag) scintillators were considered and evaluated. Plastic was rejected early on because its proton recoil scintillations are of lower pulse height relative to electrons, making pulse height based gamma rejection impossible. It was also critical to incorporate a thermal detector element to extend the energy response of the meter down to the epithermal and thermal range. A dual-scintillator design, using both fast and thermal types, made it possible to balance the overall energy response and provide adequate response in the crossover region between the thermal and fast elements. Uniform directional response was another challenge. Much engineering effort was spent in determining the optimum fast scintillator arrangement required for angular independence. An exploded view of the PRESCILA probe assembly is shown in Figure 1. Light produced in the scintillators is collected by the Lucite™ light guide and transmitted to the PMT, where it is converted into an electrical current. An ADIT sideview bialkali 1-inch PMT is positioned in a cylindrical cutout in the light guide. The light guide itself - as well as a borated polyethylene frame - are used as moderating material for the thermal scintillator, which is located below the PMT.

The fast neutron signal is derived primarily from proton recoils in the hydrogenous matrix of the fast scintillator elements. The phosphor is a ZnS(Ag) powder, Sylvania type 1330 or equivalent, which is produced in quantity primarily as a blue-light phosphor coating for cathode ray tubes. PRESCILA's fast scintillator (Eljen EJ-410P) is based on the work of Hornyak (Hornyak, 1952) and Emmerich (Emmerich, 1954) in the 1950s. The original Hornyak detector was made by molding together a blended mixture of ZnS(Ag) and Lucite™ powders. The original design suffered from poor efficiency because ZnS(Ag) absorbs its own light and limits the active phosphor volume that can transmit light to the PMT. Emmerich improved the light collection efficiency by embedding sections of 0.32 cm thick Lucite™ sheet into the detector. These sections acted as a light guide for pulses originating inside the scintillator, increasing collection efficiency by about a factor of three relative to the standard Hornyak button. This principle was taken to the extreme in the Eljen Technology EJ-410P design (see Figure 2), which is the result of a collaborative effort with Eljen Technology. The strategy was to increase the surface area from which scintillation light may be emitted and also to minimize self-absorption in the phosphor. A total of five phosphor rings are used, the thickness of each ring being approximately 2.5 mm.

The grooves are filled with a mixture of epoxy glue and ZnS(Ag) powder. This geometry minimizes light self-absorption and maximizes the phosphor surface area that can communicate light to the PMT. Some of the proton recoils reach and deposit energy in nearby grains of ZnS(Ag) phosphor. The phosphor grain size is on the order of 8 microns, which gives protons an advantage over secondary electrons as far as being able to deposit significantly more energy per grain due to their higher stopping power (dE/dx). The resultant voltage pulse height due to proton tracks is of sufficient magnitude to allow gamma pulse height discrimination. In contrast, plastic scintillators require pulse shape discrimination for effective gamma discrimination. Since standard health physics counters, such as the Eberline (now Thermo RMP) model E-600, only provide pulse height discrimination, PRESCILA is compatible with existing off-the-shelf commercial counters.

Thermal and epithermal neutron energy response is generated by the thermal scintillator (Eljen EJ-420P), an improved form of the Stedman scintillator (Stedman, 1956). A mixture of ^{6}LiF and ZnS(Ag) powders is hot pressed onto the back of a Lucite™ disc, with the active phosphor layer being convoluted to maximize light output. The $^{6}Li(n, \alpha)^{3}H$ reaction produces the ionizing tracks responsible for excitation of the phosphor. Both the triton and alpha particle have sufficient range to ionize nearby grains of phosphor.

The mass of the ^{6}Li loading was optimized on the basis of Monte Carlo simulations and measurements. A couple of design iterations were required to provide the best overall energy response relative to NCRP-38 dose equivalent. The trouble spot in any dual scintillator design is the transition region between the thermal and fast detector elements. The need to limit the gamma response of the proton recoil scintillator imposes a gradual drop off in the fast scintillator's neutron response below about 2 MeV. It is possible to fill in this gap – at least up to an energy of about 0.5 MeV - by increasing the thermal detector's output. However, this must be done judiciously or else the over response in the thermal and epithermal energy ranges becomes too extreme. The design goal was to balance the under response in the range from about 0.1 MeV to 2 MeV by an over response below 0.1 MeV that would give the most accurate results for a range of practical field spectra.

A filter assembly is located directly below the thermal scintillator, and consists of lead and cadmium discs. The lead disc (2.84 cm diameter, 0.038-cm nominal thickness) is used to reduce the scintillator's sensitivity to low-energy photons, while the cadmium disc (1.91 cm diameter, 0.038 cm thick) is used to reduce the thermal neutron response below the cadmium cutoff energy. The diameter of the cadmium filter was optimized on the basis of Monte Carlo calculations and measurements in a D_2O-moderated ^{252}Cf field.

PERFORMANCE TESTING RESULTS AND DISCUSSION

Energy Response

The energy response of the final PRESCILA prototype was investigated at the German Bureau of Standards (PTB) during July 2001. Irradiations were performed using a series of monoenergetic neutron beams at the PTB Accelerator Facility, as well as bare and D_2O moderated ^{252}Cf sources.

Monoenergetic neutron beams were produced by accelerating protons or deuterons onto ^{7}Li, tritium, and deuterium targets. Beam energies were as follows: 24 keV, 144 keV, 250 keV, 565 keV, 1.2 MeV, 2.5 MeV, 5.0 MeV, 8.0 MeV, 14.8 MeV, and 19 MeV. These beams have been well characterized by the Neutron Dosimetry staff of the PTB using spectral measurements including time of flight techniques. The irradiations were performed in a low-scatter geometry within a large experimental hall (24 m x 30 m x 14 m). The contribution of room return and background was subtracted for each technique by performing an additional measurement using an appropriate shadow cone between the detector and neutron source. In the case of the 19 MeV technique, a large unwanted neutron contribution is generated due to (d,n) reactions in the target structural materials (Ti and Ag). An additional measurement was performed with a blank (untritiated) target. The blank target count rate was then subtracted from the primary measurement to correct for this source of background neutrons.

Figure 3 shows the response function for PRESCILA, per unit fluence (counts-cm^2), over the energy range from thermal to 19 MeV. Also shown are the calculated response functions for the Eberline NRD, Eberline WENDI, and the Andersson-Braun (AB) rem meters. Despite their age, the Eberline NRD and AB rem meters are still widely used worldwide for neutron field surveys. Hence, is was deemed important to compare their performance with that of PRESCILA. Folding in a given field neutron spectrum with one of the response functions shown in Figure 3 will yield the predicted instrument response in counts per unit fluence for that field.

The PRESCILA energy response function is a composite of measurements and calculations. Below 0.144 MeV, the PRESCILA response function is supplemented with Monte Carlo calculations using the Los Alamos code MCNP4C (Briesmeister, 1997). This is an energy range where only the thermal element has any useful response. Therefore, the relative response of the thermal detector may be determined on the basis of the total number of capture reactions in ^{6}Li. Neutrons were transported through a detailed model of the PRESCILA probe. The fluence averaged over the volume of the thermal scintillator was folded in with the capture cross section to determine the number of capture events. The simulation result was then normalized to the experimental result at 0.144 MeV. The normalized MCNP model was able to accurately predict the experimentally derived response at 24 keV, the agreement being within 1.5%.

The conventional health physics representation of energy response is in terms of instrument response per unit dose equivalent. To modify the response functions for PRESCILA, NRD, and AB rem meters, given in Figure 3, to a dose equivalent basis, the delivered fluence at each energy point was converted to H*(10). In the case of PRESCILA, a conversion was also made to NCRP-38 dose equivalent. Since the scaling of the energy response function, and hence the degree of over and under response to various operational spectra, is affected by the choice of calibration field, the response was normalized to a bare ^{252}Cf calibration factor. Bare ^{252}Cf is a commonly used field for rem meter calibrations, and it represents the best choice for most applications of the PRESCILA rem meter. A calibration factor (counts per unit dose equivalent) was calculated for each rem meter on the basis of H*(10), and also relative to NCRP-38 dose equivalent for PRESCILA. Calibration factors were determined by folding each individual response function (counts per unit fluence) with a bare ^{252}Cf source spectrum to obtain the response in counts, and then dividing the response by the delivered dose equivalent. These factors were used to normalize the energy response functions, which are shown in Figures 4 and 5 for PRESCILA [both NCRP-38 and H*(10) dose equivalent], and relative to H*(10) for the Eberline NRD and the Andersson-Braun (AB) or Snoopy rem meters. Figure 5 provides an expanded view of the energy range from 0.1 MeV to 20 MeV.

The ideal normalized response per unit dose equivalent is, of course, a uniform response of 1.0 at all neutron energies. All rem meters deviate from the ideal significantly. Below 0.1 MeV, PRESCILA's energy response exhibits an over response similar to that of current commercial models. In the range from 0.1 MeV to 1.0 MeV, the probe under responds with the response minima of 0.35 being at energy of 0.565 MeV. PRESCILA was designed so that for most field spectra, the over response balances out the under response to provide a reasonably uniform dose equivalent response.

The sensitivity of PRESCILA is almost on par with that of the Eberline WENDI rem meter, and is up to a factor of 10 greater than that of the Eberline NRD rem meter. Sensitivity measurements for a gamma rejection setting of 1 $mSvh^{-1}$ are summarized in Table 1 for standard isotopic fields of importance in rem meter calibration.

The predicted response of PRESCILA in a variety of benchmark and operational neutron fields was calculated by folding its fluence response function (Fig. 3) with published neutron spectra. Almost all of the spectra, including a representative selection of pressurized water reactor fields (PWR) were derived from the IAEA's Technical Report 318 (IAEA, 1990). The calculations are summarized in Table 2 and provide an indication of PRESCILA's expected field performance. The nomenclature for the neutron fields is identical to that given in the IAEA report. The stated relative response is referenced to a bare ^{252}Cf calibration.

For many operational spectra, a bare ^{252}Cf calibration is optimum and gives the most conservative response. For fields dominated by a high-energy component, as well as for highly moderated fields, a calibration to ^{241}AmBe works well. Unlike both the NRD and AB meters, whose response decreases monotonically above 7 MeV, PRESCILA's response was measured to be quite uniform from 2 MeV to 19 MeV, the high-energy limit of the PTB facility.

Above a neutron energy of 20 MeV, additional charged particle production channels become available that compensate for the decreasing elastic scatter cross section and are likely to extend PRESCILA's useful energy response to several hundred MeV. Spallation products (protons, deuterons, tritons, and alpha particles) from reactions on carbon and oxygen target nuclei provide a means of phosphor excitation. In addition, the probability of high-energy neutron interactions in either the front or back fast scintillators increases the response efficiency. During July 2003, the PRESCILA rem meter was irradiated at the Cyclone cyclotron facility, Catholic University of Louvain (UCL), Louvain-la-Neuve, Belgium. The UCL irradiations were to quasi-monoenergetic neutron beams at nominal energies of 33 MeV and 60 MeV. PTB staff were on hand to characterize the spectral fluence by means of time-of-flight methods using a NE213 detector and a ^{238}U ionization chamber. An overview of the measurement protocol used for several years at UCL for neutron beam characterization has been given by Schumacher et al. (1998). Data analysis is still in progress, however, preliminary results indicate excellent response for these two spectra.

Field Measurements

Field testing of two pre-production prototypes has been completed at Los Alamos during 2001. Both probes were mated to Eberline E-600 counters. One probe, calibrated to ^{241}AmBe neutrons, participated in a survey of Flight Path 15L, Target 4, WNR facility south yard, at the Los Alamos Neutron Science Center (LANSCE). Target 4 is a tungsten target, which is irradiated by an 800 MeV proton beam for spallation neutron production. PRESCILA and several other neutron rem meters were used to obtain dose rate data at several distances from the flight path beam tube. Since the neutron beam is highly collimated, the measurements represent scatter due primarily to interactions in the beam tube's walls and air fill. The results are summarized in Figure 6. SWENDI refers to Eberline's Smart WENDI (SWENDI) rem meter, and REMbrandt refers to Apfel Enterprises' neutron survey meter Model AP2001. The Dineutron rem meter is currently distributed by Canberra Industries. The EAGLE was developed at Los Alamos and is offered commercially by Health Physics Instruments (HPI). It represents a modified version of the HPI 2080 pulsed neutron rem meter, and features a tungsten powder loaded moderator assembly for extended high-energy response to 5 GeV. Conventional rem meters (e.g., Eberline NRD) under responded relative to the results of PRESCILA and the EAGLE. At the majority of the measurement locations, the PRESCILA results agreed closely with those obtained with the EAGLE.

The second PRESCILA rem meter, calibrated to ^{252}Cf neutrons, was used at a plutonium processing facility at Los Alamos in conjunction with other instruments to map out the neutron dose rates in several rooms (see photograph 2). The results are summarized in Table 4. Under the instrument list, ROSPEC refers to BTI Inc.'s Rotational Spectrometer (Ing et al 1997). The ROSPEC was used to measure the neutron spectrum at the locations indicated, which it then converts to dose equivalent by folding in an appropriate fluence to dose conversion function. Based on previous studies, ROSPEC dose measurements are believed to be accurate to within 10%. Where ROSPEC results were available, the PRESCILA measurements, in general, agreed with ROSPEC within 21%.

Angular Dependence

The angular dependence of the PRESCILA probe was investigated at PTB at low (0.144 MeV), intermediate (2.5 MeV), and high (14.8 MeV) neutron energies. Data were collected for both X-Y and X-Z planes of rotation (the

Z-axis being defined along the handle of the probe). The results are presented in Figures 6, 7, and 8.

Typically, response uniformity was within +/15% for all three energies tested and both rotations. The maximum deviation, about 22% over response, was measured during the X-Z rotation at 141 keV for the bottom facet of the probe.

Response Linearity

The dose rate linearity of PRESCILA was investigated at PTB using the Accelerator Facility's cyclotron. The $^{2}H(d,n)^{3}He$ reaction was used to produce an intense 8 MeV neutron beam. In addition, the response linearity below 1 $mSvh^{-1}$ was studied at the PTB Bunker facility using a bare ^{252}Cf source. All of the measurements were conducted with the Eberline E-600 counter. The results are summarized in Figure 9. The response becomes nonlinear at dose rates in excess of 6 $mSvh^{-1}$ due to coincidence counting of small pulse height events. These are proton recoil events that individually would not exceed the upper discriminator setting and trigger a count. However, at high-count rates on the order of 500,000 cpm, coincidence results in increased counting efficiency. As the count rate exceeds about 10^{6} cpm, dead time becomes severe enough to reduce the response per unit dose. At a dose rate of 25 $mSvh^{-1}$, dead time losses amount to 45%.

Gamma Rejection

The scintillator types used in PRESCILA allow for limited gamma rejection (1 to 2 $mSvh^{-1}$) on the basis of pulse height, while still maintaining good sensitivity to neutron radiation. The gamma spillover into the neutron channel was investigated at PTB using a ^{137}Cs field, and at Los Alamos using ^{137}Cs, ^{60}Co, and fluorescent x-ray fields.

The PRESCILA probe may be calibrated with any off-the-shelf counter that, as a minimum, provides a single pulse height discriminator. The neutron channel is defined by setting the counter's discriminator such that the gamma response in the neutron channel is limited to the range of 650 - 750 cpm in a 1 $mSvh^{-1}$ ^{137}Cs gamma field. The PMT is operated at a high voltage in the range of 580 V to 635 V. For typical calibration factors, this results in a neutron dose equivalent indication of 20 to 30 μSvh^{-1} in a 1 $mSvh^{-1}$ ^{137}Cs gamma field. When the neutron channel is defined as described above, the gamma spillover is linear to about 1 $mSvh^{-1}$ in a ^{137}Cs gamma field.

When mated to a dual-discriminator counter such as the Eberline E-600, dynamic gamma spillover correction can be implemented for PRESCILA. The two discriminators are adjusted to define upper and lower channels. A small fraction of the lower channel may be subtracted from the upper channel (neutron channel) to reduce the gamma spillover signal. The optimum setting of the lower channel discriminator was determined to be at about 40% of the upper discriminator value. It is recommended that the discriminator settings be established in a 1 $mSvh^{-1}$ ^{137}Cs gamma field. The ratio of the upper to lower channel count rate is entered as the gamma spillover correction. This correction helps in controlling gamma response to about 2 $mSvh^{-1}$, but it is of limited utility because the count rate in the lower window is a nonlinear function of gamma dose rate.

The gamma-induced neutron response, expressed as a percentage of the incident gamma dose equivalent rate, was also found to be relatively independent of photon energy over the range from 100 keV to 1.2 MeV. In other words, for the same delivered gamma dose rate, the gamma response is fairly uniform over the energy range indicated. In gamma fields exceeding 1 $mSvh^{-1}$, gamma spillover was observed to become nonlinear and excessive due to coincidence counting of photon events.

In mixed gamma-neutron fields, the gamma spillover increases due to coincidence counting. The combination of a 0.58 $mSvh^{-1}$ gamma field with a 0.77 $mSvh^{-1}$ ^{252}Cf neutron field resulted in a 14.6% over response in the neutron channel and an 8% over estimate of the total (neutron plus gamma) dose rate. Such errors, however, are small relative to the measurement uncertainty due to energy response. While clearly not as impressive as the inherent gamma rejection of a gas proportional detector, PRESCILA affords adequate rejection for many field applications involving hand-held surveys of neutron fields.

CONCLUSIONS

Performance and field-testing results have shown the PRESCILA neutron rem meter to be a viable and ergonomically superior alternative to traditional rem meter designs for hand-held radiation surveys. PRESCILA features a low-weight probe (2 kg) capable of excellent sensitivity (40 cpm per μSvh^{-1} for $^{241}AmBe$) and extended energy response to over 20 MeV. Directional response is uniform (+/-15%) over a wide range of energies. Response linearity has been characterized to a dose rate exceeding 20 $mSvh^{-1}$. Gamma rejection is effective in gamma fields up to about 1 $mSvh^{-1}$, and can be extended to 2 $mSvh^{-1}$ when using dynamic gamma compensation.

On March 4, 2003, the University of California was granted a US patent for the PRESCILA neutron rem meter (Olsher and Seagraves, 2003). The technology has been commercialized under license to Ludlum Measurements, Inc., and PRESCILA is now in routine production.

Acknowledgements-The authors are grateful for the support of the Health, Safety, and Radiation Protection Division, Los Alamos National Laboratory, and in particular the encouragement of Senior Scientist, Dr. Thomas E. Buhl. The authors thank Dr. Sigmund Guldbakke of the German Bureau of Standards (PTB) for his warm hospitality and assistance in completing the probe characterization study at the PTB Accelerator Facility.

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TABLE CAPTIONS

FIGURE CAPTIONS

Table 1. Rem Meter Sensitivity (NCRP-38 Dose)

Model	**Bare ^{252}Cf cpm per μSvh^{-1}**	**D_2O moderated ^{252}Cf cpm per μSvh^{-1}**	**^{241}AmBe cpm per μSvh^{-1}**
PRESCILA	26	39	40
NRD	3.9	5.1	3.1

Table 2. Calculated PRESCILA response in various benchmark and operational fields

Neutron Spectrum	**Relative Response** Bare ^{252}Cf Calibration NCRP-38	H*(10)
Bare ^{252}Cf	1.00	1.00
^{252}Cf in 18-inch diameter polyethylene sphere	1.17	1.20
^{252}Cf Skyshine	0.86	0.81
D_2O moderated ^{252}Cf	1.67	1.67
^{241}AmBe	1.49	1.62
Bare $^{238}PuO_2$	1.07	1.06
Cm_2O_3 power source	1.00	1.00
Bare PuF_4 source	0.61	0.58
BWR E/3-X29	0.88	0.77
PWR I/1-IV	1.44	1.25
PWR F/5	1.76	1.54
PWR G/3	1.46	1.30
PWR H/12	1.42	1.26
PWR 1L-1	1.31	1.15
Medical Accelerator: 25 MeV Photons on Tungsten, through 90 cm concrete	1.28	1.30
25 MeV photons on Tungsten, Skyshine	0.93	0.86
Medical Accelerator: U-120 Cyclotron, unshielded	1.68	1.89
Fusion Reactors: Tokamak, First wall	1.13	1.10
Natural Uranium pile (5 ton)	0.97	0.83

Table 3. Survey Results. Los Alamos Neutron Science Center, WNR, Target 4, Flight Path 15L

Instrument	**Dose Rate (μSvh^{-1})**			
	Top – 6"	Top – 12"	Bottom – 12"	Bottom – 6"
PRESCILA	480	380	140	230
EAGLE	470	350	100	100
SWENDI	230	190	90	90
Dineutron	36	240	8	6
REMbrandt	65	--	--	--
HPI Albatross	110	70	20	40
Eberline NRD	60	60	30	30
Eberline RO2	60	32	25	25
(Gamma)	65	30	22	20
HPI Ion Chamber				
(Gamma)				

Table 4. Field Survey Data for Plutonium Processing Facility.

Location	Instrument	Dose Rate (μSvh^{-1})
Vault, Room A	PRESCILA	98
	ROSPEC	81
	SWENDI	103
	REMbrandt	69
Vault, Room C	PRESCILA	662
	ROSPEC	631
	SWENDI	833
Vault, Room E	PRESCILA	646
	ROSPEC	621
	SWENDI	777
	REMbrandt	219
Vault, Room G	PRESCILA	384
	ROSPEC	333
	SWENDI	391
	REMbrandt	318
Vault, Room J	PRESCILA	660
	SWENDI	734
	REMbrandt	377
Vault, Room K	PRESCILA	540
	SWENDI	604
	REMbrandt	261
Hallway/Room A	PRESCILA	121
	SWENDI	132
	REMbrandt	48
Hallway/Room G	PRESCILA	186
	SWENDI	185
	REMbrandt	93
Hallway/Room K	PRESCILA	132
	SWENDI	127
	REMbrandt	79
Hallway/Room M	PRESCILA	152
	SWENDI	161
	REMbrandt	123

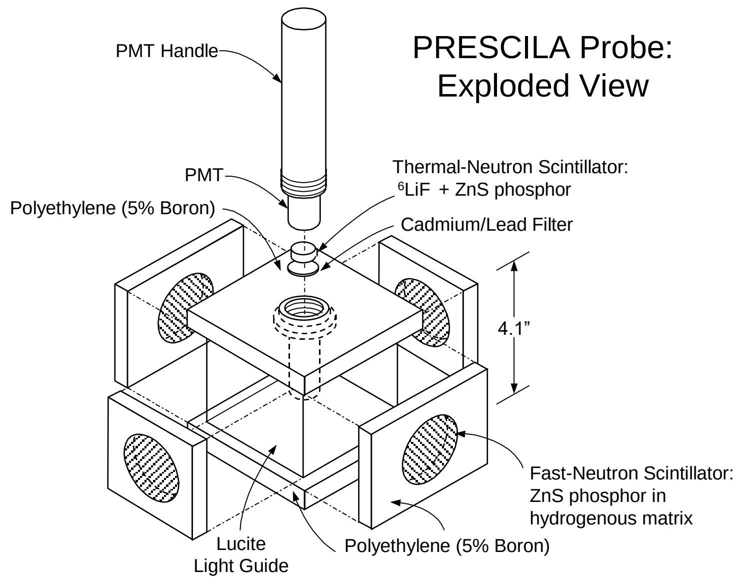


Figure 1. An exploded view of the PRESCILA neutron rem meter (US Patent No. 6,529,573)

Figure 2. Eljen EJ410-P Fast Scintillator

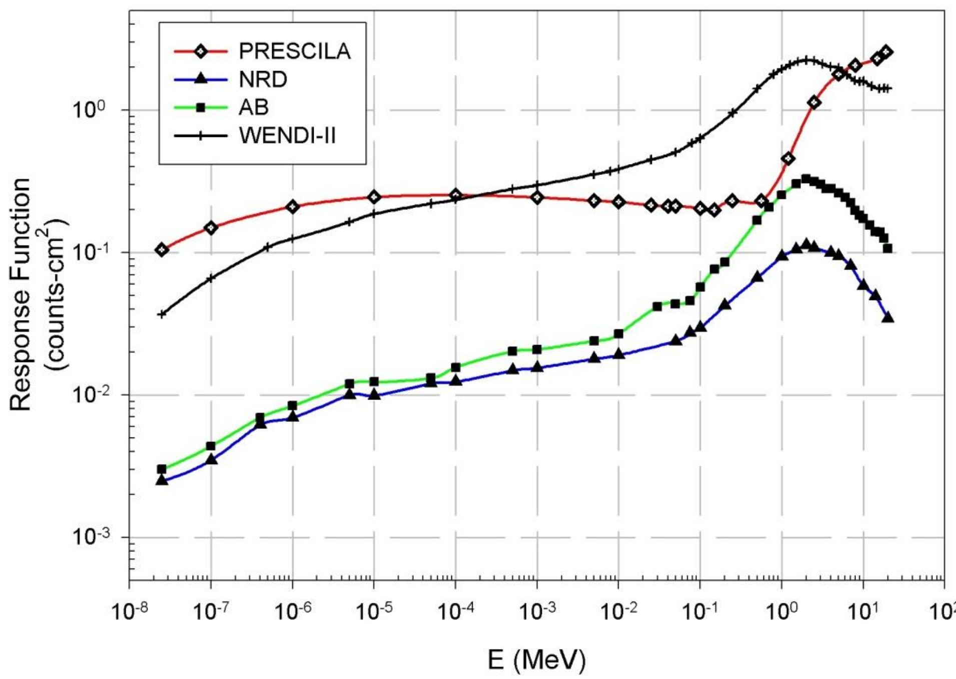


Figure 3. Response per unit Fluence.

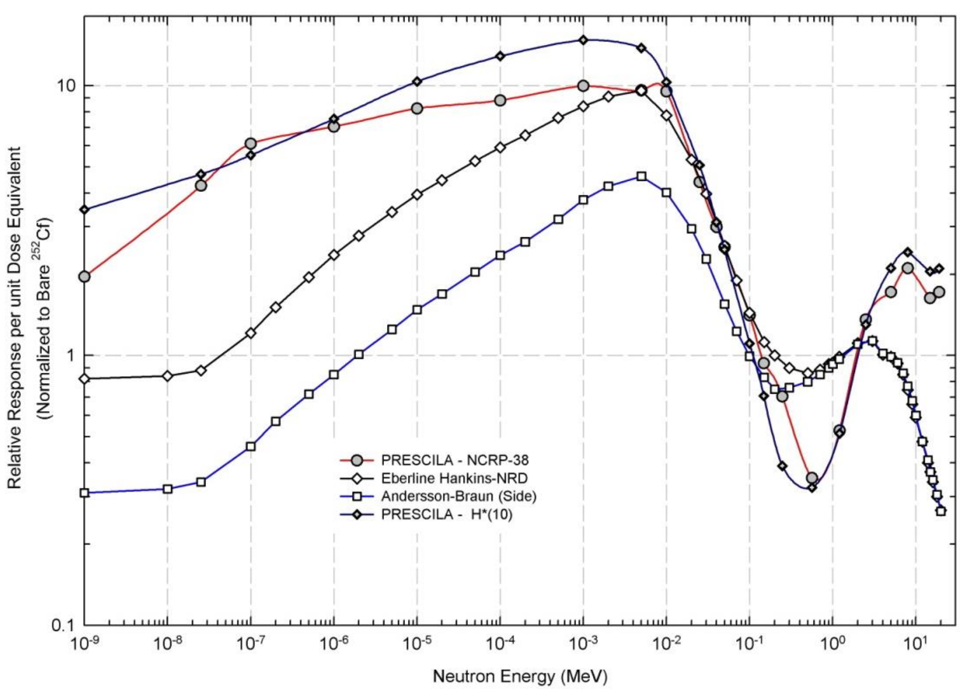


Figure 4. Energy Response Functions per unit dose

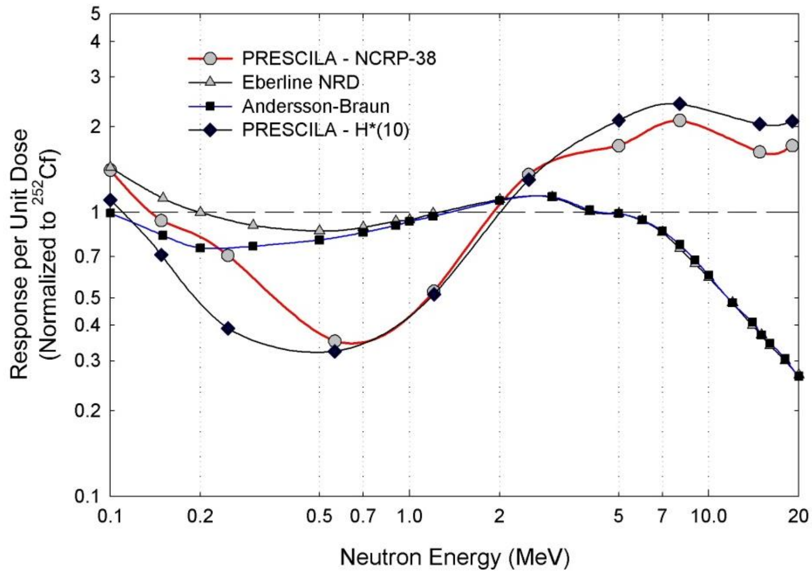


Figure 5. Energy Response Functions per unit dose

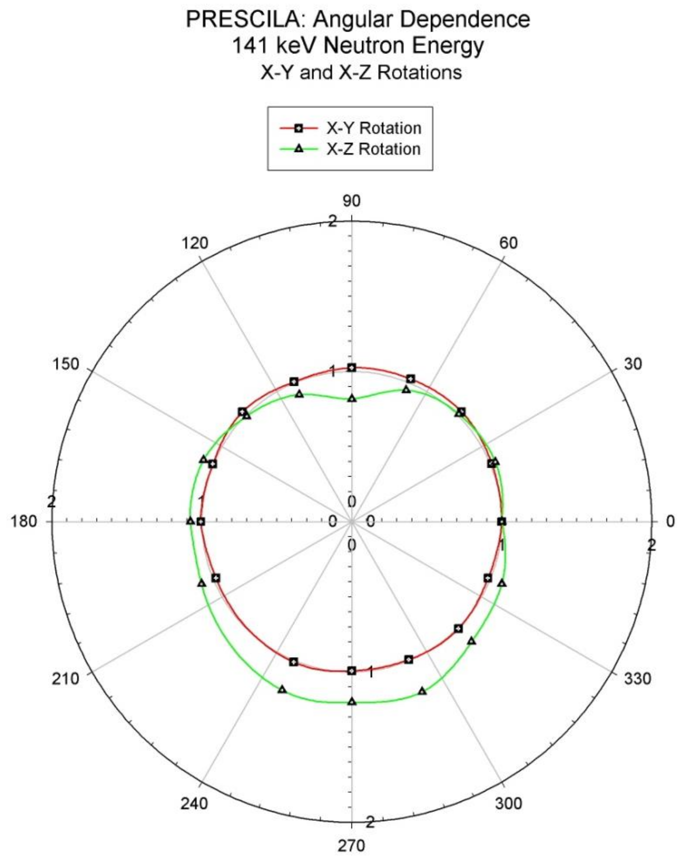

PRESCILA: Angular Dependence
141 keV Neutron Energy
X-Y and X-Z Rotations
X-Y Rotation
X-Z Rotation
90
60
30
0
330
300
270
240
210
180
150
120
0
1
2

Figure 6.

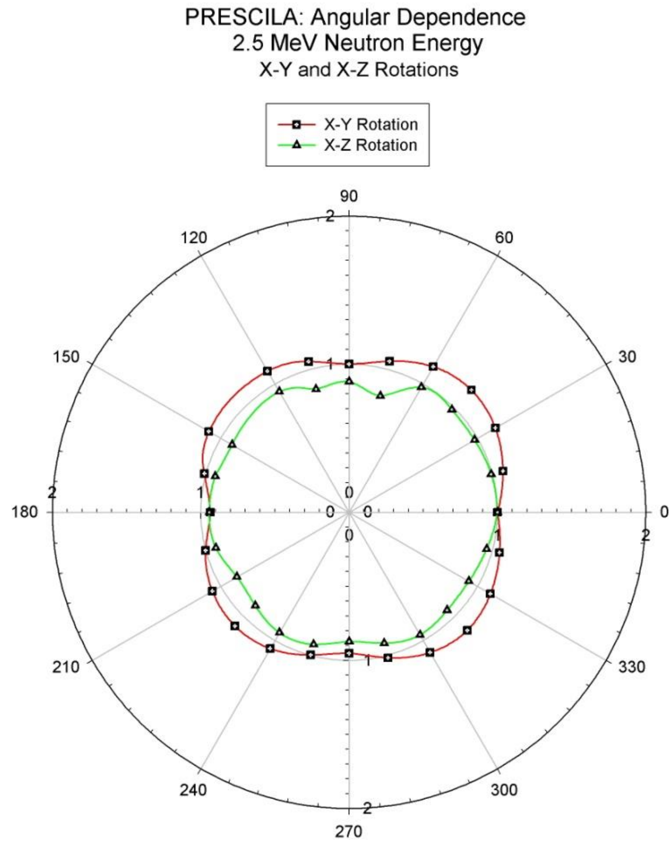

PRESCILA: Angular Dependence
2.5 MeV Neutron Energy
X-Y and X-Z Rotations
X-Y Rotation
X-Z Rotation
90
120
60
150
30
180
0
210
330
240
300
270
0
1
2

Figure 7.

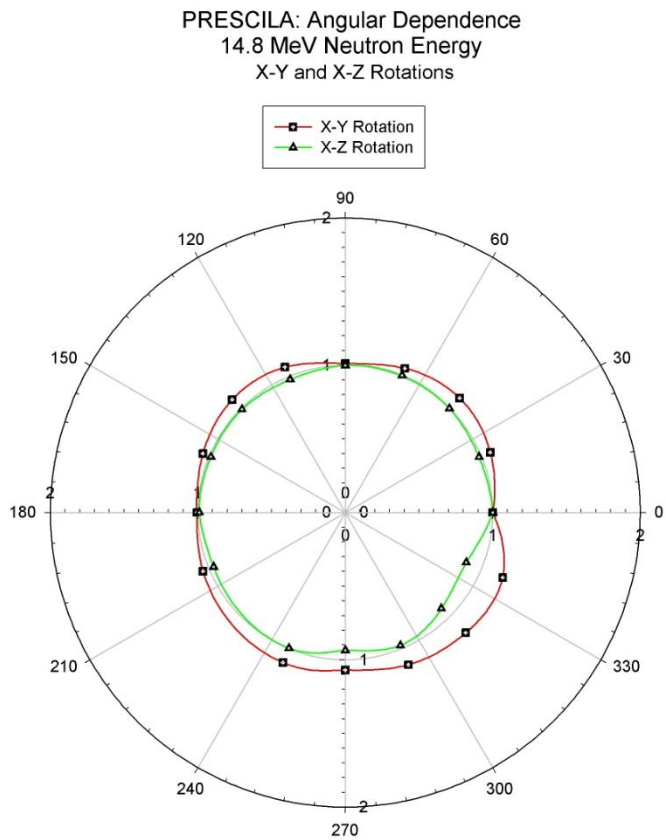

PRESCILA: Angular Dependence
14.8 MeV Neutron Energy
X-Y and X-Z Rotations
X-Y Rotation
X-Z Rotation
90
120
60
150
30
180
0
210
330
240
300
270
0
1
2

Figure 8.

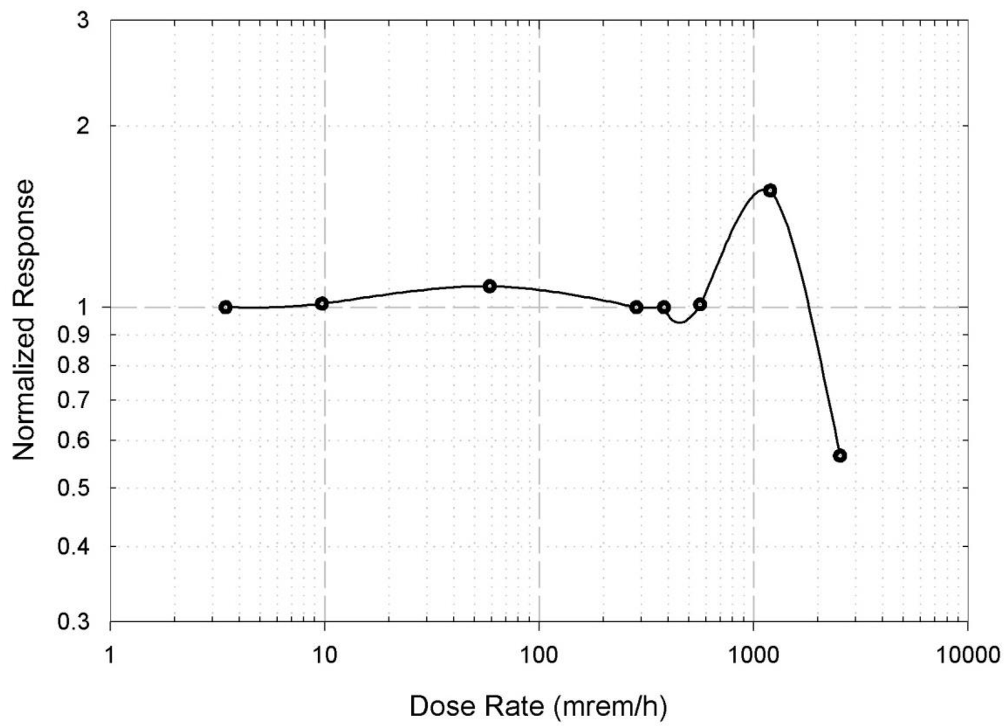


Figure 9. PRESCILA: Response Linearity

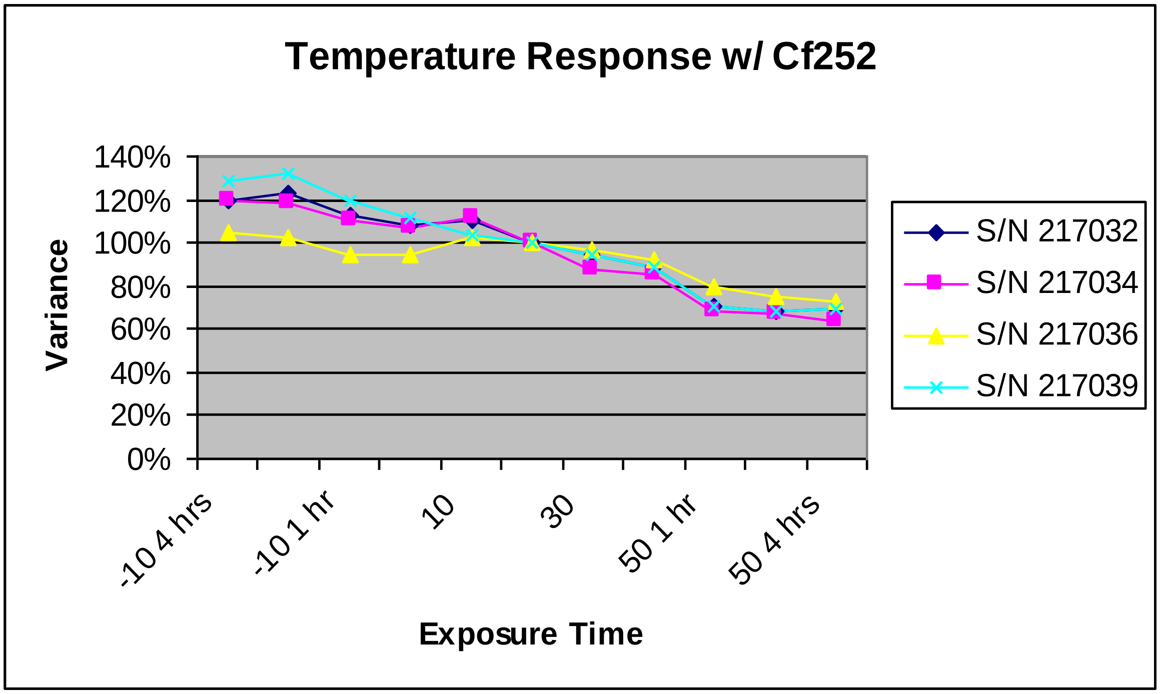


Figure 10. PRESCILA: Temperature Response

Table 5. PRESCILA Temperature Response Data

Temperature	SN 217032 Counts	% Variation from Base	SN 217034 Counts	% Variation from Base
-10°C 4 hrs	1997	120%	1942	119%
-10°C 2 hrs	2043	123%	1922	118%
-10°C 1 hr	1875	113%	1797	110%
0°C	1799	108%	1741	107%
10°C	1823	110%	1821	111%
20°C	1662	100%	1634	100%
30°C	1563	94%	1438	88%
40°C	1477	89%	1389	85%
50°C 1 hr	1178	71%	1105	68%
50°C 2 hrs	1133	68%	1093	67%
50°C 4 hrs	1151	69%	1046	64%

Temperature	SN 217036 Counts	% Variation from Base	SN 217039 Counts	% Variation from Base
-10°C 4 hrs	1839	105%	2431	129%
-10°C 2 hrs	1807	103%	2474	132%
-10°C 1 hr	1665	95%	2238	119%
0°C	1679	95%	2078	111%
10°C	1788	102%	1959	104%
20°C	1760	100%	1881	100%
30°C	1698	97%	1719	94%
40°C	1615	92%	1566	89%
50°C 1 hr	1409	80%	1367	71%
50°C 2 hrs	1322	75%	1354	68%
50°C 4 hrs	1276	73%	1223	69%

Section 7

Parts List

Reference	Description	Part Number
UNIT	Completely Assembled Model 42-41 and Model 42-41L PRESCILA Neutron Probe	47-3309

HP/SHP-380 VOLTAGE DIVIDER, Drawing 435 × 1804

	Reference	Description	Part Number
	BOARD	Completely Assembled 1.125 inch Voltage Divider Board	5435-554
CAPACITOR	C1-C2	0.001uF, 3KV	04-5727
RESISTORS	R1-R2	7.5M, 1/8W, 5%	12-7971
	R3-R13	5.1M, 1/8W, 2%	12-7979
MISCELLANEOUS	*	CONTACT-003-0312-000	7526-028

Assembly View, Drawing 467 × 25A

Quantity	Description	Part Number
1 each	Model 42-41 INNER CUBE ASSY.	01-5719
1 each	GRIP	21-9097
1 each	Model 42-41 BODY ASSY.	4467-025
1 each	Model 42-41 PM TUBE ASSY.	4467-078
34 SI	FOIL-NETIC	01-5019
18 SI	FOIL-CO-NETIC	01-5026
1 each	PM TUBE- 1.125	01-5718
1 each	RECPT – UG706/U "C" LMI	4478-011
5 each	SPONGE 4-P BS	7002-065-04
1 each	Model 42-41 PMT SIDE FOAM	7467-162

Section 8

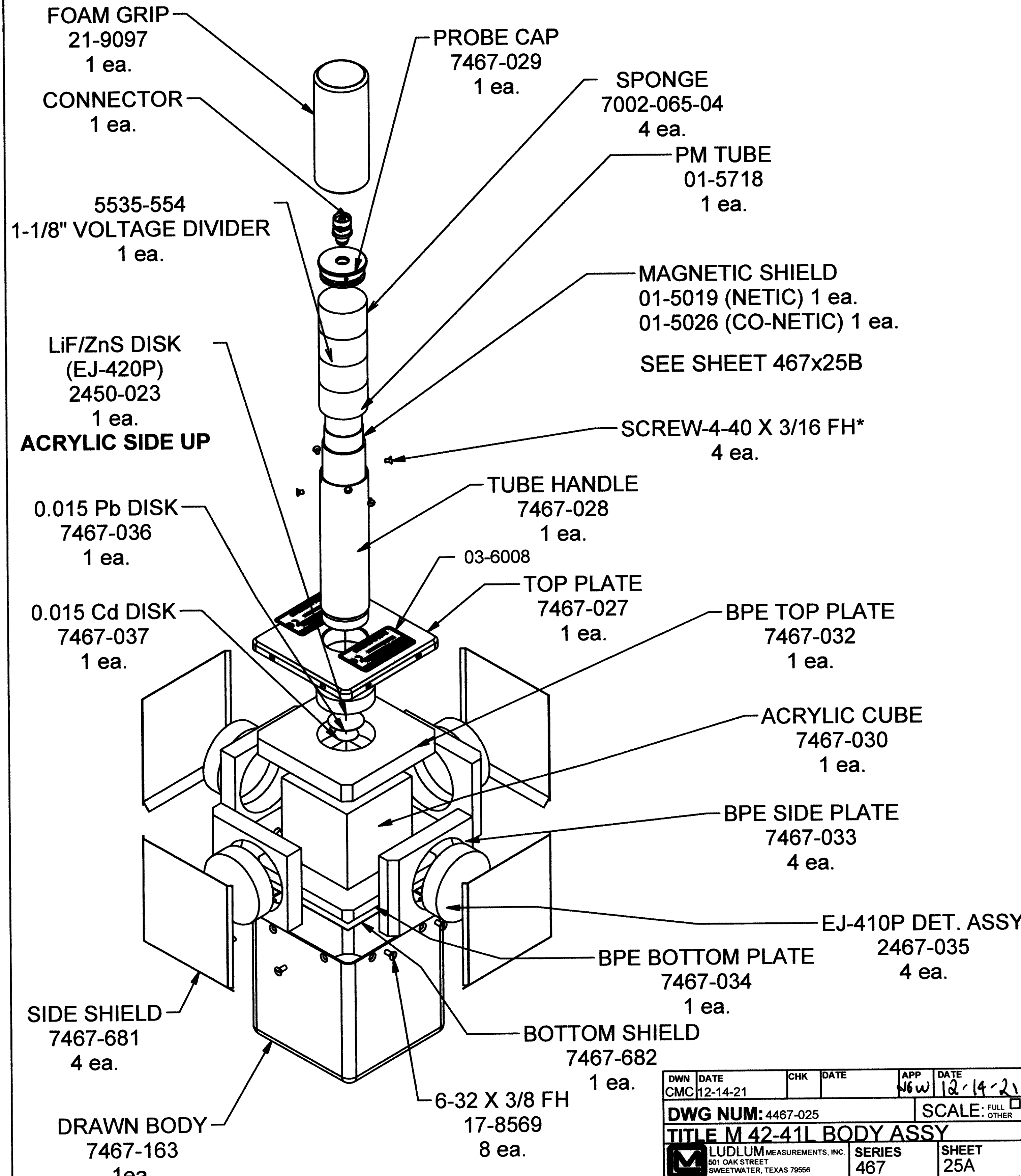
Drawings

ASSEMBLY VIEW, Drawing 467 × 25A

HP/SHP-380 VOLTAGE DIVIDER, Drawing 435 x 1804

HP/SHP-380 VOLTAGE DIVIDER Component Layout, Drawing 435 x 1808 (2 sheets)

REVISION HISTORY			
REV	DESCRIPTION	DATE	BY
6	ADDED VOLTAGE DIVIDER	12/21/2011	MSC
7	ADDED LiF/ZnS DISK	06/04/2012	ADG
8	ECF#2600(PMT ASSY DRAWING)	09/21/2012	ADG

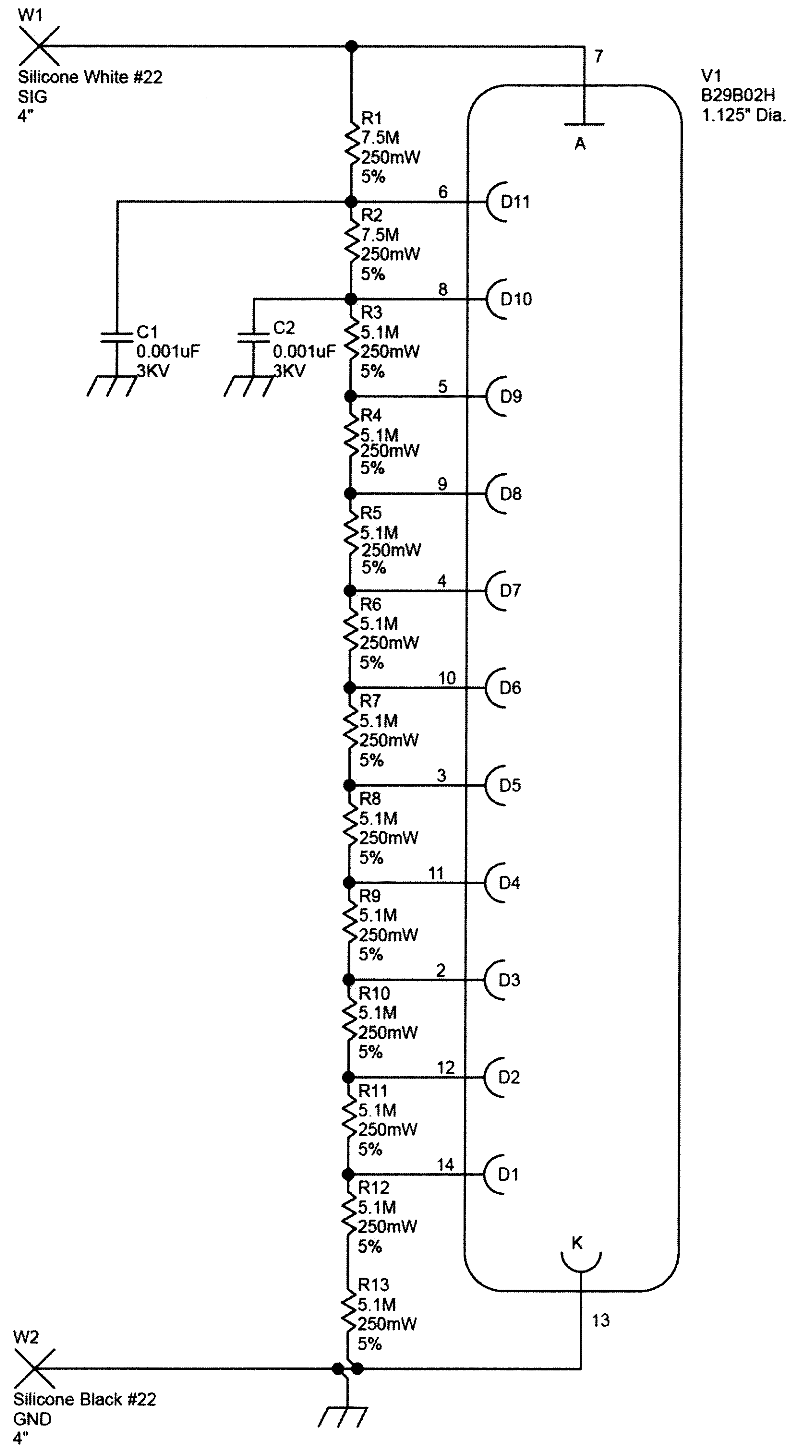


DWN	DATE	CHK	DATE	APP	DATE
CMC	12-14-21			[illegible]	12-14-21

DWG NUM: 4467-025 | SCALE: FULL ☐ OTHER

TITLE M 42-41L BODY ASSY

LUDLUM MEASUREMENTS, INC. 501 OAK STREET SWEETWATER, TEXAS 79556 | SERIES 467 | SHEET 25A



LUDLUM MEASUREMENTS, INC.

PO Box 810
501 Oak Street
Sweetwater, Texas 79556
U.S.A. 1-800-622-0828

Drawn: PAB	9/15/2021	**Title:** 1-1/8" VOLTAGE DIVIDER		
Design: RSS	9/15/2021	**Model:**		
		Board#: 5435-554		
Approve: JMt	9/15/2021	**Sheet:** 1 of 1	**Series**	**Sheet**
Print Date: 9/15/2021	1:10:17 PM	**Rev:** 1	435	1804

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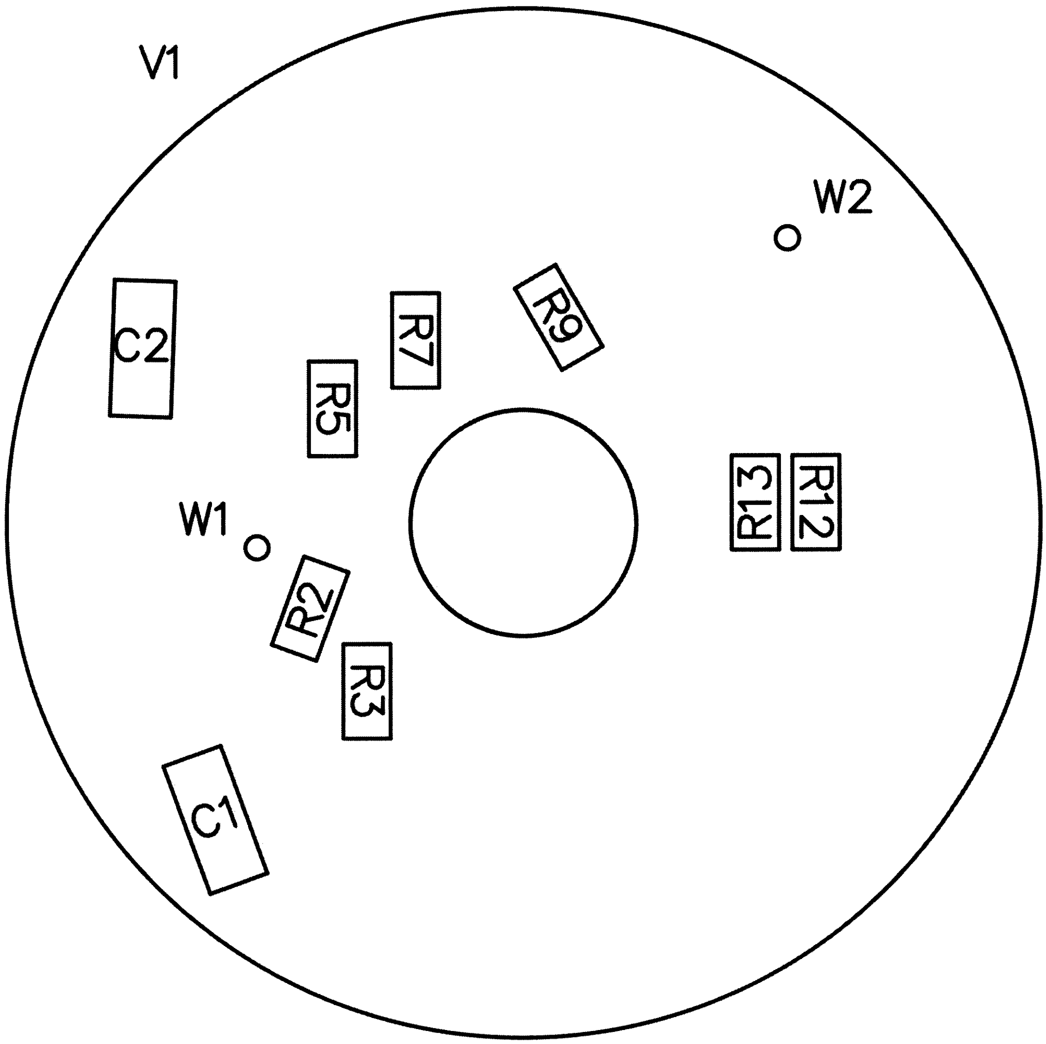

LUDLUM MEASUREMENTS				
Part: 5435-554	**Model:**			
Desc: 1-1/8" VOLTAGE DIVIDER			**MANUAL**	
Design: RSS	**Date:** 9/15/2021		**Rev:**	1
Drawn: PAB	**Date:** 9/15/2021	**SHEET**	**SERIES**	**SHEET**
Apr: JMC	**Date:** 12/2/2021	1 of 2	435	1808
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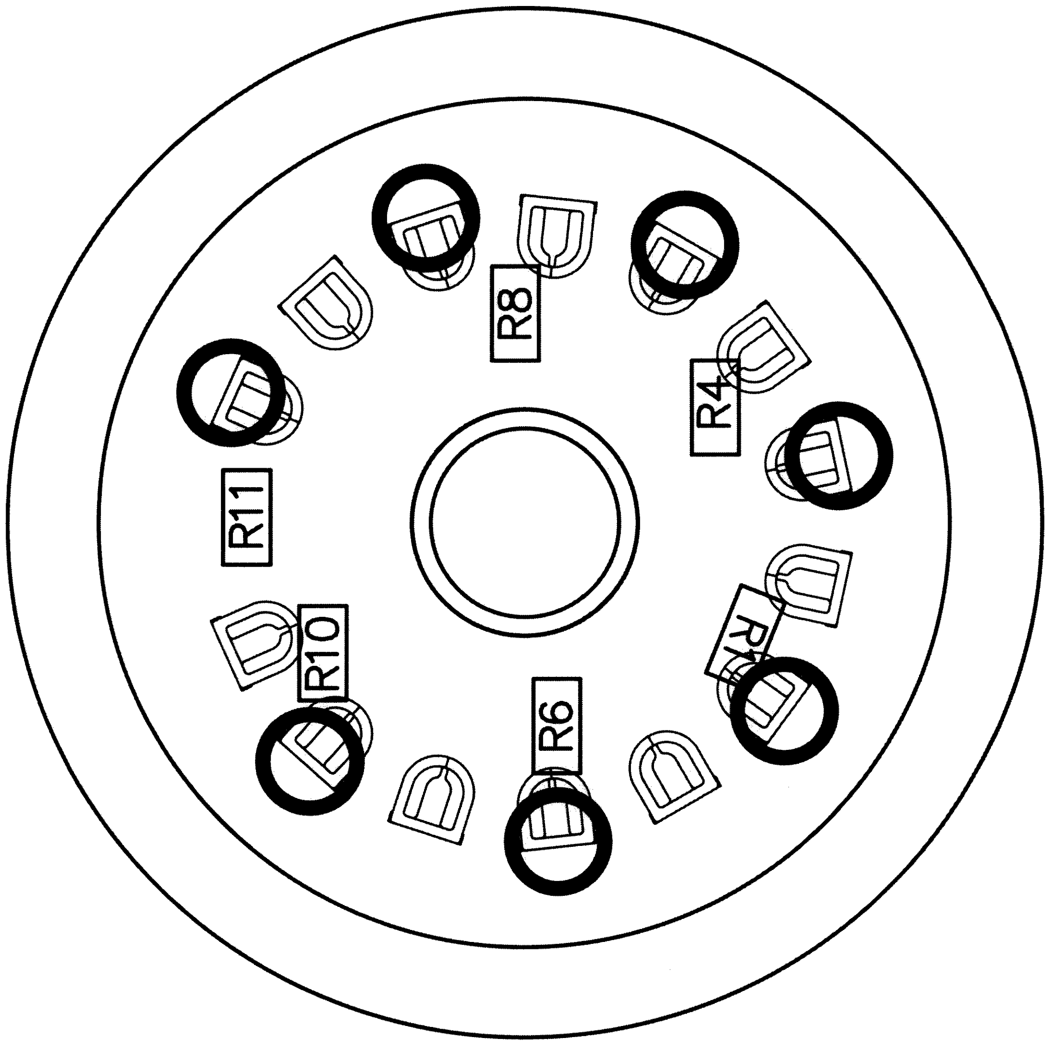

LUDLUM MEASUREMENTS

Part: 5435-554		Model:		
Desc: 1-1/8" VOLTAGE DIVIDER			MANUAL	
Design: RSS	Date: 9/15/2021		Rev:	1
Drawn: PAB	Date: 9/15/2021	SHEET	SERIES	SHEET
Apr: JML	Date: 12/2/2021	2 of 2	435	1808
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