EG&G ORTEC

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Telephone: 3402-35112, Telex: 40830

Be thoroughly familiar with the information that is furnished in this manual, and follow the operating instructions carefully. Know the symptoms of trouble so that the detector can be removed from danger before its usefulness is degraded or destroyed, and your EG&G ORTEC Charged Particle Detector will continue to provide excellent service over a very long period of time.

DAMAGE IN TRANSIT

Unpack your detector with care. DO NOT allow anything to touch the sensitive (gold) surface. In the event of loss or damage in transit, notify the transportation company immediately. Retain all containers and packing materials for their inspection. Please advise EG&G ORTEC within 10 days of any such loss or damage, and request instructions before making a return shipment.

RETURNS

If a detector should malfunction, please contact EG&G ORTEC Detector Marketing Department for information on possible causes and remedies. Should the device prove defective, this procedure will help us to repair or replace your device more quickly. If it is necessary to return your detector because of malfunction, please enclose as much information as possible concerning the symptoms and past history of the detector. This information will help make it possible for us to furnish you with detectors of even higher quality and greater reliability in the future. When packing the detector for return shipment to EG&G ORTEC, please replace the white protective cap that was furnished with the detector. Address the shipment to EG&G ORTEC, Attn.: Silicon Charged Particle Quality Control, 100 Midland Road, Oak Ridge, Tennessee 37830.

EG&G ORTEC **will not accept** for repair detectors which show signs of **radiation contamination** at levels which, in our opinion, might endanger our employees or impair our ability to manufacture low background radiation detectors.

Silicon Charged Particle Radiation Detectors Instruction Manual

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WARRANTY

EG&G ORTEC Charged Particle Detectors are warranted to be free from defects in material or workmanship.

Performance specifications for the A-Series, B-Series, C-Series, I-Series, P-Series, and R-Series detectors are warranted for a period of one year from date of purchase. The F-Series are warranted for three months.

Premium specifications for E-Series detectors are warranted for three months after purchase. For the succeeding nine months, E-Series detectors are warranted to operate within the specifications of comparable best category A-Series detectors.

The warranty period for all X-Series and for those D-Series detectors that are <26 microns thick is three months from purchase date, while those D-Series detectors that are $\geqslant 26$ microns thick carry a one year warranty against performance degradation. These detectors are extremely fragile and are not warranted against breakage.

Detectors that have been subjected to **mishandling** or **radiation damage** are not covered under this warranty. Failure to adhere to the **Use** and **Handling Precautions** as prescribed in **Section 2** of this manual will constitute **mishandling,** as will obvious **physical damage** to the detector. **Radiation damage** can be determined by standard tests performed at EG&G ORTEC laboratories.

EG&G ORTEC makes no other warranties, express or implied, and specifically NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

EG&G ORTEC's exclusive liability is limited to repairing or replacing, at EG&G ORTEC's option, items found by EG&G ORTEC to be defective in workmanship or materials within one year from the date of delivery. EG&G ORTEC's liability on any claim of any kind, including negligence, loss or damages arising out of, connected with, or from the performance or breach thereof, or from the manufacture, sale, delivery, resale, repair, or use of any item or services covered by this agreement or purchase order shall in no case exceed the price allocable to the item or service furnished or any part thereof that gives rise to the claim. In no event shall EG&G ORTEC be liable for special or consequential damages.

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ILLUSTRATIONS

1. MECHANICAL FEATURES OF STANDARD EG&G ORTEC CHARGED PARTICLE DETECTORS

The three basic EG&G ORTEC silicon charged particle detector configurations are shown in Fig. 1.1.* In each section of this figure, D is the effective diameter corresponding to the active area of the device, W is the depth of the sensitive (depletion) region, L is the total thickness of the silicon wafer, and L minus W is the thickness of the undepleted region. The region W corresponds to the silicon that contains an electric field resulting from the externally applied reverse bias (V_b) on the diode. Free charge carriers created in this region by the ionizing radiation are separated by the electric field. Integration of the current induced on the detector's contacts yields a charge proportional to the energy of the ionizing radiation.**

Information of the thickness of the electrodes in the different configurations is contained in the EG&G ORTEC Charged Particle Detectors Data Summary Chart (Table 7.3).

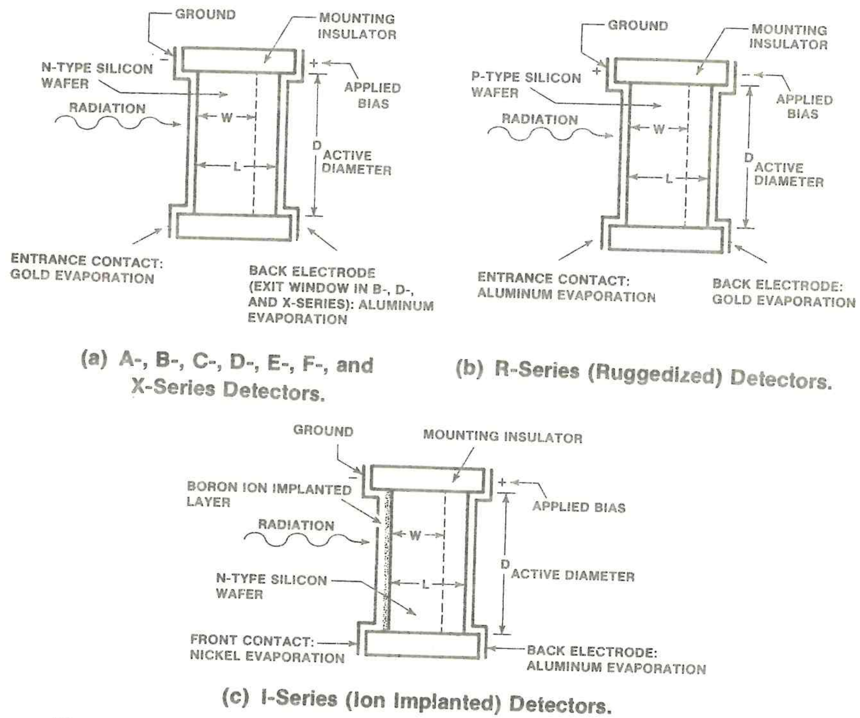


Fig. 1.1. Design of Typical EG&G ORTEC Charged Particle Detectors.

*The G-Series (HP Ge Ion Implanted) and P-Series (Position Sensitive) charged particle detectors are covered in separate manuals.

**For a more complete discussion of semiconductor detector physics see References 11, 15, and 16 (listed in Section 7 of this manual).

Figure 1.2 shows a cross section of a standard A-Series Charged Particle Detector. The sensitive surface (H) is evaporated with a thin layer of gold which must NEVER be touched or otherwise mechanically damaged. The circular silicon wafer (S) is mounted in an insulating ring (I) whose back and front surfaces are metallized. The front surface of this ring is grounded to the metal case (C), and thereby to the shield side of a standard Microdot or BNC connector (M). The back surface of the insulating ring is connected to the center electrode of the connector which serves as the signal output and bias voltage connection.

In the A-, B-, C-, D-, E-, F-, and X-Series detectors, the center electrode of the connector is supplied with positive bias potential and provides a negative output signal. In contrast, the EG&G ORTEC R-Series (Ruggedized) Charged Particle Detectors operate with these polarities reversed.

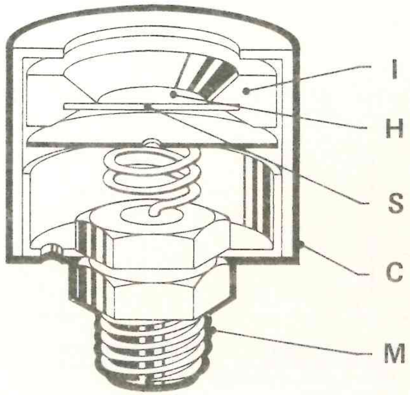


Fig. 1.2. Cross Section of an A-Series Charged Particle Detector in a B Mount.

2. HANDLING PRECAUTIONS FOR EG&G ORTEC CHARGED PARTICLE DETECTORS

NOTICE:

Read the Following Handling Precautions Carefully.

> FAILURE TO ADHERE TO THESE INSTRUCTIONS WILL USUALLY RESULT IN AN UNWORKABLE DETECTOR AND WILL NULLIFY YOUR WARRANTY.

2.1. A-, B-, C-, E-, AND F-SERIES*

1. Avoid mechanical shock. Silicon fractures easily. Damage to the epoxy-silicon interface will destroy the contact structure of the silicon diode.

2. Never touch the gold electrode on the sensitive surface. Damage to this surface will destroy the diode characteristics of your silicon detector. Keep the protective cap in place when the detector is not in use. A gentle air stream from a clean rubber syringe may be used to remove dust or lint.

3. Do not expose the detector to reducing atmospheres, such as hydrogen gas.

Avoid ambients where chemical contamination is present; e.g., mercury vapor, pump oil vapor, organic solvents, ionic salts, acetylene vapors, certain caustic or acid fumes (especially those of a reducing nature), soldering flux flames, large quantities of water vapor, etc. If the test chamber is cleaned with a solvent such as acetone or alcohol, evacuate the chamber thoroughly several times before installing the detector. If the detector is accidentally exposed to volatile contaminants, thoroughly evacuate the chamber several times with the detector installed before applying the bias voltage. Where ultimate performance and long term stability are required, it is preferable to use a cold-trapped vacuum system.

4. Apply bias only through a large (≥1 megohm minimum) series resistance. **Do not apply bias in excess of the rated operating voltage.** Do not apply excessive bias to the detector, nor allow it to operate under breakdown conditions. Unless you are adept at recognizing the onset of microplasma and are willing to risk destroying the diode, do not apply bias in excess of the rated operating voltage. If you require a detector which will operate at higher bias voltage, you will probably find it more satisfactory to allow us to select one for you.

Follow these steps when applying bias to a detector:

1. Apply 10 to 20 volts to the detector. The noise, as observed on an oscilloscope or noise meter, should decrease (assuming a low noise charge sensitive amplifier configuration is used).

2. Continue to increase the voltage in small steps, allowing the noise meter to recover from transients to a reasonably steady reading before making further increases in voltage. Frequently, the noise will continue to decrease slowly for a period of several minutes to several hours; this is normal, particularly for detectors which have not been used recently.

3. Sudden momentary increases in the noise pulses are an indication of incipient microplasma. If this phenomenon occurs, proceed very slowly, and if the frequency and/or intensity of noise pulses increase, reduce the bias by approximately 30 percent and allow the detector to "age" (for a time sufficient to permit increases in the bias level without the strong pulsing noise effect) before proceeding.

4. A sudden, very large increase in noise, usually accompanied by an increase and/or fluctuations in the reverse current, is an indication of com-

*These series will be referred to as the "Gold Surface Barrier Series."

plete microplasma breakdown. Remove the bias voltage immediately in order to minimize irreversible damage to the detector.

5. After the desired bias voltage is attained, observe the noise level for a short time, in order to determine that it is not increasing and that there is no incipient microplasma breakdown.

Do not change the pressure around the diode suddenly while high bias voltage is applied. The preferred procedure is to pump down or let up, slowly, with no bias voltage applied to the detector. If the detector is stored for extended time in vacuum, it is best to leave a small nominal bias applied even when not in use. (10^{-2} Torr)

The pressure region from 10 μm to several millimeters of Hg is a particularly serious one for surface breakdown. Neither the connector nor the diode is warranted for high voltage operation in this pressure region.

6. If the detector is cooled below room temperature, it is essential that it be operated in a very clean vacuum system; otherwise, condensation of water or organic vapors may initiate breakdown and excessive current leakage on the insulator and the diode. Adequately "clean" vacuum is best obtained with liquid nitrogen traps in close proximity to the space containing the detector, and between the detector and sources of contamination such as diffusion pumps. The performance of standard EG&G ORTEC detectors is not guaranteed below −30°C or above 25°C. If a cryogenic detector is required, it can be supplied on special order.

Artificial high humidity problems may be created when detector and preamp assemblies are operated at reduced temperatures. Here connections or input components may be cooled well below ambient air temperature with resultant condensation of moisture.

The use of careful design to prevent overloading of exposed components, baffles to properly divert cold gases, and attention to cleanliness of feedthrough connections are suggested.

7. When using radioactive sources, avoid unnecessary radiation damage or contamination by closing a shutter in front of the detector when it is not in use. Do not allow high-intensity beams, such as the main beam in an accelerator, to fall directly on the detector.

Always shield both the detector and all signal leads when using the detector in the vicinity of a charged particle accelerator beam; such a beam produces copious quantities of secondary low-energy electrons and ions from the target and residual background gas. Ion or electron currents to unshielded detector leads can cause excessive amplifier noise. Also, bombardment of the high purity silicon crystal can produce severe radiation damage in only a few hours of operation.

In addition to all precautions enumerated for the above-mentioned series, the Deep Series (nominally ⩾2000 microns) require very high bias voltages. It is very important that precautions against humidity and unclean conditions be taken to prevent breakdown of feedthroughs and connectors used with these high voltage devices. An air conditioned laboratory is highly recommended. In any case, be sure that all electronic components associated with your high voltage detector system are clean and dry.

2.2. THIN D- AND X-SERIES

All above comments for the proper handling of the gold surface barrier series also apply to the thin D- and X-Series detectors. The following additional comments are especially important when handling these very fragile devices.

1. Do not overbias the detector. Very thin ΔE detectors require only a very modest bias voltage to produce adequate electric field strengths and small amounts of overbias can produce excessive electric field strengths.

REMEMBER: For a 10-μm thick detector, each 10 volts of overbias corresponds approximately to an additional field strength of 10,000 volts/cm.

2. In order to preserve the high spectroscopic quality of your D- or X-Series detector, **always operate it in a clean, well-trapped vacuum**.

3. When mounting your thin D- or X-Series detector, be careful not to exert strain on the mounting assembly. Distortion of the assembly ring can fracture this paper-thin silicon crystal!

4. **Do not cool your thin D- or X-Series detector**, nor expose it to temperature conditions above 25°C.

The capacitance of these detectors is their most significant contribution to total system noise. Cooling, therefore, is not expected to significantly contribute to the detector's performance, and since the expansion coefficient of the epoxy encapsulant is not an absolute match to that of the silicon, there is a danger of fracturing the silicon during extreme temperature change.

For very thin detectors which require only small operating voltages, ambient temperature fluctuations can cause significant changes in the detector bias voltage.

2.3. RUGGEDIZED R-SERIES

In contrast to the ultra sensitive gold surface on the gold surface barrier detector, the Ruggedized Series detector has a thin layer (1850 Å) of evaporated aluminum on its front surface. Since aluminum is more adherent to an etched silicon surface than gold, the front surface of the Ruggedized detector is relatively more rugged than is that of the gold series. However, all reasonable precautions should still be enforced with this state-of-the-art scientific instrument.

Destruction of its aluminum surface is less likely than would be if it were a gold surface barrier, but sharp instruments can scratch it and possibly increase its noise and resolution characteristics.

If contaminated, the aluminum surface may be cleaned gently with methanol and a cotton swab. The detector should be dried thoroughly before use. If moisture is absorbed into the lavite rings, it may be necessary to allow the device to remain in vacuum for several hours before operating. Detailed cleaning instructions are included with each shipment of Ruggedized detectors.

All other precautionary steps for the gold surface barrier detector series apply to the Ruggedized Series.

2.4. ION IMPLANTED I-SERIES

For those applications where the ultimate in reliability and ruggedness is required, the I-Series ion implanted detectors should be chosen.

The contact is "buried in" under the silicon surface and the metallization shown in Fig. 1.1 is applied only for the purpose of reducing the electrical resistivity of the contact. As a consequence, the front contact of an I-Series detector is extremely robust and easily cleanable. Moreover as the junction is not established by a Schottky barrier, but rather by an ion implanted junction, the I-Series detectors are expected to be less sensitive to environmental conditions than any other EG&G ORTEC charged particle detector.

3. OPERATING INSTRUCTIONS FOR EG&G ORTEC CHARGED PARTICLE DETECTORS

3.1. APPLICATION OF BIAS

3.1.a. Gold Surface Barrier and I-Series Detectors

In these detectors, the center electrode of the connector is supplied with positive bias potential and provides a negative output signal.

The recommended operating bias voltage for your detector is recorded on your Detector Data Sheet. This is the bias voltage required to produce the specified alpha particle resolution and noise characteristics, and is a function of the resistivity of the silicon used in the manufacture of the detector and its associated depletion depth. The resistivity of the silicon used in the fabrication of EG&G ORTEC silicon detectors is carefully selected to achieve optimum field strength for best charge collection characteristics at a specific depletion depth and reverse bias voltage.

Do not operate your detector at a bias greater than specified. It is specified to operate at its optimum overbias. Increasing the bias may result in microplasma breakdown which will result in irrepairable damage and will nullify your warranty. Bias is best applied slowly and in increments of 1/10th full operating bias. Be alert to signs of trouble, as indicated in Sections 2 and 4 of this manual.

A special word of caution is needed for detectors with a depletion layer greater than 2000 microns. These detectors often require operating voltages in excess of 3000 volts, so it is very important to assure that all connectors are very clean and dry.

Noise spikes and other signs of breakdown are very apt to be due to the connector or the preamp. EG&G ORTEC supplies a specially designed high voltage preamp for this detector series. Ask about the proper preamplifier when purchasing high voltage charged particle detectors.

3.1.b. Thin D- and X-Series Detectors

The recommended operating bias voltage for your detector is recorded in the WARRANTY BIAS section of your copy of the detector test data sheet. For detectors $\geqslant 26\ \mu m$ thick, this is the bias voltage required to produce the specified alpha particle resolution with the alphas incident through the back (low field strength) contact. For detectors $< 26\ \mu m$ thick, this is the bias required to provide an electric field strength sufficient to efficiently collect charge produced by an alpha particle adjacent to the rear (low field strength) contact.

The preamplifiers for these devices have an $\sim 100\ M\Omega$ (or greater) bias resistor; thus the voltage drop in the bias resistor can easily exceed the detector bias. In this case, it is necessary to make a careful measurement of the detector reverse leakage current so that the resulting voltage drop across the bias resistor can be calculated. The effective resistance of the bias resistor can be measured readily by shorting the preamplifier with a 50Ω or 100Ω terminator and then measuring the resulting I-V characteristics.

3.1.c. Ruggedized Series Detectors

In contrast to other charged particle detectors, the Ruggedized Series requires that a negative bias potential be supplied to the center electrode of the connector. The output signal will then be positive. (Ruggedized detectors that will accept positive bias are available on special order.)

In addition to reversed polarity, all standard precautions for application of bias are also applicable to the Ruggedized Series.

3.2. CONTROL OF RADIATION DAMAGE

EG&G ORTEC detectors owe many of their most useful properties to the fact that they are made from extremely pure (impurities of the order of parts per billion), perfect, single crystals of silicon. This high degree of crystal perfection makes semiconductor detectors sensitive to radiation damage, since irradiation-produced defects may affect the electrical behavior of the device as effectively as impurities.

Permanent radiation damage effects in silicon result primarily from dislocations within the crystal lattice. Incident radiation of sufficient energy can displace a silicon atom from its equilibrium site to an interstitial position, the energy level necessary for the displacement depends on the type of incident radiation. The resulting vacancy-interstitial pair, or Frenkel defect, acts as a charge carrier trapping site. These sites contribute to resolution broadening by reducing the charge collection efficiency. In addition, they contribute to the device noise and current by acting as charge carrier generation-recombination centers. Poor charge collection from trapping effects can be improved by increasing the bias voltage (average electric field).

Totally depleted detectors, which usually have larger average electric fields as well as constant depletion depth, are considerably more radiation-damage resistant than partially depleted devices.

The causes and effects of radiation damage in surface barrier radiation detectors are enumerated in Table 7.2.

3.3. ALPHA PARTICLE RESOLUTION MEASUREMENTS

Measurements of alpha particle resolution must be performed in vacuum, and the alpha particle source must be very thin and uniform so that it does not affect the resolution. This resolution varies with source-to-detector spacing at very close spacings. Unless otherwise noted, the original alpha particle resolution measurement on your EG&G ORTEC detector was performed with source-to-detector spacing equal to 1-1/2 times the active diameter of the detector.

All alpha resolutions and noise measurements are made with EG&G ORTEC preamplifiers and amplifiers. No specific model numbers are reported here for these instruments because EG&G ORTEC updates preamplifiers and amplifiers with advancement of the state-of-the-art, and the best available instruments are used for the measurements. Your nearest EG&G ORTEC representative will be glad to bring you up to date on the best electronics to use with your detector.

Although the alpha resolution and noise measurements are standardized on 0.5 μs differential and integral time constants in the shaping amplifier, it is possible for certain detector models to provide a better performance when using different values for the differential and integral time constants. In particular, larger time constants may result in better alpha resolution and/or noise characteristics for detectors with very large capacitance values (several hundred pF).

3.4. THICKNESS OF ACTIVE AREA AND FIELD STRENGTH REQUIREMENTS

The active thickness of a charged particle detector is a function of the bulk resistivity of the silicon wafer and the operating voltage. Figure 7.4 is a nomogram that shows these relationships.

EG&G ORTEC charged particle detectors are fabricated from ultra pure silicon with resistivities specifically selected, so as to give optimum field strength for good resolution for charged particles at the specified thickness and operating voltage.

EG&G ORTEC totally depleted charged particle detectors are required to operate at sufficient overbias to allow good charge collection for alpha particles at the rear contact.

Figure 7.13 graphs maximum field strength as a function of silicon resistivity and operating voltage.

The maximum field strength of first category EG&G ORTEC charged particle detectors averages about 5000 V/cm.

4. TYPICAL OPERATIONAL PROBLEMS

4.1. DIRTY 110-VOLT POWER LINE

If extraneous "hash" or noise which is synchronized with 60 cps appears in the scope at the output of the amplifier, be suspicious of noise on the power line or a ground loop problem. This problem can sometimes be helped by using a low harmonic distortion, constant voltage transformer with a floating secondary, noise filters, or by an isolation transformer, but is most effectively reduced by elimination of ground loops and use of high quality amplifying equipment.

4.2. PICKUP NOISE

The signal level at the input to the preamplifier is ordinarily in the millivolt region, and the normal noise level in a high resolution detector-amplifier arrangement is of the order of microvolts. Therefore, all signal leads and the detector must be well shielded from pickup. It is primarily for this reason that EG&G ORTEC has adopted the convention of operating the detector with the sensitive face at ground potential. These detectors are supplied with a shielded can, with the front face at ground potential.

4.3. GROUND LOOPS

Like all noise level instruments, semiconductor detector-amplifier combinations are subject to ground loop problems if the equipment is not properly installed. These problems are particularly bothersome in complicated instrument arrangements, arrangements with long interconnecting cables, or when interconnecting equipment from different manufacturers. In making noise level measurements with the detector replaced with an equivalent capacitance, the capacitor should be grounded to exactly the same point as the detector, in order to show equivalent ground loop noise.

5. TROUBLE SYMPTOMS AND DETERMINATION OF THEIR PROBABLE CAUSES

5.1. NOISE LEVEL DOES NOT DECREASE WHEN BIAS IS APPLIED TO THE DETECTOR

1. Make sure the pulser is turned off and all radiation sources are removed.
2. If the noise level corresponds to zero external input capacitance, check for an open circuit between the amplifier and detector.
3. Reduce detector bias voltage to zero and remove the cable to the detector at the preamplifier. The noise should decrease, the amount of decrease depending on the amount of capacitance removed from the input. If the noise level does not decrease, the trouble is in the amplifier system.
4. Check the noise level from the amplifier.
5. Check for ground loop noise.

6. Considerable diagnostic information can be obtained by examining the character of the noise with an oscilloscope attached to the amplifier output.

5.2. UNUSUALLY HIGH NOISE AT ZERO BIAS OR AT VERY LOW BIAS

1. High resistance in signal lead, connectors, etc., between preamplifier and detector.

2. Partial or intermittent short circuit from signal lead to ground.

5.3. NOISE SPIKES OR EXTRANEOUS COUNTS

1. Dirty power line, pickup noise, or ground loop noise.

2. Intermittent microplasma breakdown in the detector. Replace detector with equivalent capacitance grounded in same place as detector.

3. Unknown source of background radiation.

5.4. DETECTOR REVERSE LEAKAGE CURRENT ABNORMALLY HIGH

1. Leakage currents in vacuum feedthrough or other components in the system.
2. High ambient temperature at detector.
3. Breakdown in the detector (will be accompanied by excessive noise).
4. Radiation damaged detector.
5. Moisture or organic vapor condensation problems.

5.5. DRIFTS IN PULSE HEIGHT OUTPUT FROM MONOENERGETIC SOURCE

The drifts are probably in the amplifier or in the multichannel analyzer. See if pulser peak is also drifting while detector is exposed to radiation source.

5.6. DISTORTED PEAK SHAPES IN ENERGY SPECTRUM

1. The counting rate exceeds the capabilities of the amplifier system. Check the shape of the pulser spectrum peak while the detector is exposed to the source.

2. Gain shifts or drifts in the amplifier system or multichannel analyzer. Check shape and width of pulser peak.

3. The range of the ionizing particles exceeds the sensitive depth of the detector. This will produce an extra density of counts per channel on the high energy side of the spectrum.

4. High rate – low energy background radiation extraneous to the main spectrum which exceeds count rate capabilities of system.

5. Insufficient bias voltage on detector.

6. Radiation damaged detector.

5.7. ENERGY RESOLUTION DETERIORATES WITH TIME

1. Gain drifts or biased amplifier drift. Check pulser peak width with time.
2. System noise increasing with time.
3. Radiation damage.
4. Detector noise increasing with time.

5.8. DETECTOR CURRENT INCREASES OR BREAKDOWN VOLTAGE DECREASES WITH EXTENDED EXPOSURE TO HIGH VACUUM

1. Moisture or organic vapor condensation problems.

2. Detector breakdown occurs occasionally, even with carefully manufactured and inspected detectors, and for this reason, your EG&G ORTEC detector was checked out in a high vacuum ($\approx 10^{-6}$ Torr) at rated bias voltage for at least 16 hours before shipment to you. The problem is thought to be caused by pumping away adsorbed oxygen which is passivating an area on the detector where undesirable surface impurities are present, or where the very thin oxide film responsible for the p-type nature of the surface has a flaw. If the microplasma breakdown in this region has not been too extensive or prolonged, the detector will frequently recover after several days or weeks of exposure to room air. The probability of this problem is significantly reduced by keeping a small nominal bias on the detector while it is in vacuum.

5.9. DETECTOR FAILS TO MEET SPECIFIED RESOLUTION PERFORMANCE

1. Check amplifier system noise level and stability with detector replaced by equivalent capacitance.

2. Make sure peak broadening is not caused by poor source, kinematic source broadening, or unreasonable source-detector geometry.

5.10. DETECTOR WILL NOT WITHSTAND RATED BIAS VOLTAGE

1. Check to make sure breakdown is not in cables, connectors, feedthroughs, etc.

2. Check to make sure vacuum system is at proper pressure and is free from contaminating atmosphere.

6. SOME TYPICAL APPLICATIONS OF SILICON DETECTORS

6.1. CHARGED PARTICLE COUNTING

Silicon detectors make excellent beta-ray counters. For low energy betas, they are superior to sealed end-window gas counters since their dead layer (window thickness) is smaller, the detector is more compact, the background is usually smaller, and the problem of gas stability with time is absent. Their compactness, time stability, freedom from need for a continuous gas supply, and lower background with less shielding, also make them preferable to gas flow counters for many applications.

The efficiency of silicon detectors for charged particles is essentially 100% for any case where the energy lost in the sensitive region is much larger than the noise level. Consequently, these devices make excellent counters for natural alpha particles, fission fragments, protons, etc. For such simple counting applications, the detector's sensitive depth need only be large enough that the particle energy loss is sufficient to trigger the discriminator. The range-energy curves and energy loss curves in Figs. 7.7 and 7.8 can be used to estimate the required sensitive depth for any particular application.

If the capacitance of a device is too high to permit efficient counting with acceptable electronic background, a deeper depletion device will increase the energy deposited for particles that exceed the depletion depth and also reduce the capacitance, thereby reducing the noise and allowable discriminator level.

EG&G ORTEC offers an instrument that has been designed specifically for alpha counting. It is the 576 Alpha Spectrometer. This instrument is furnished in a standard double-width NIM module, and it contains two independent vacuum chambers, two R-Series detectors, and all of the front-end electronics (up to the scalers) necessary for low-level alpha counting. Contact your nearest EG&G ORTEC representative for further information.

6.2. FISSION FRAGMENT SPECTROSCOPY

The EG&G ORTEC F-Series heavy ion detectors may be utilized for determination of heavy ion and fission fragment mass and energy distributions. Devices of this design have performed satisfactorily for energy measurements and spectrum analysis when operated in the high field "saturation" region; i.e., that region where the pulse height ceases to increase in bias voltage. This region of operation provides sufficient electric field strength for complete charge collection or total sweep out of the high density of charge carriers generated by the incoming, highly ionizing, heavy ion. Operation below this region results in poor charge collection and poor resolution.

An upper limit to the useful operating region is established by the problems of internal avalanche multiplication at excessively high field strengths, and by microplasma breakdown and surface multiplication at excessively high bias voltages. The raw material properties and design criteria for EG&G ORTEC heavy ion detectors are carefully chosen to give the widest possible saturation region without detectable spectrum distortion. Surface multiplication via tunneling injection is prevented by proven surface treatments.

For optimum performance of these detectors for fission fragment analysis, careful attention must be given to the elimination of low-energy tailing and other spectral distortion problems. Low-energy tailing may be the result of source nonuniformity, excessive source thickness, or improper collimation

of the source and detector. Spectrum distortion and dispersion can result from an inadequate collimation of the reaction-inducing beam or from pulse shape distortion in the amplifier system. Consequently, the performance of these spectrometers will be enhanced by proper consideration for the problems associated with the source, collimation, and selection of an appropriate electronics system.

6.3. RUGGEDIZED DETECTORS

The Ruggedized Detector is an excellent choice for tutorial situations that involve handling by students or other inexperienced persons. The devices are comparable to standard gold surface barriers in resolution and noise specifications, but are much less prone to damage due to a careless thumb print on the front entrance window.

The 1850 Å thick aluminum entrance window is essentially light tight, and can consequently be operated as an environmental monitoring device in ordinary room light.

6.4. CHARGED PARTICLE SPECTROMETRY (see Bibliography reference 11) AND TIME RESOLUTION

The ultra thin entrance window, high field strength, and excellent noise and resolution characteristics of EG&G ORTEC Charged Particle Detectors make them especially useful for charged particle spectrometry. Their linearity over a wide energy range and their fast response time give these silicon detectors a decided advantage over other types of counters.

Another property of charged particle detectors, which is essential to charged particle spectroscopy, includes their availability in depletion depths suited for different experimental situations. Moreover, the combination of one total absorption detector with one or more dE/dx detectors can be used in particle discrimination.

In addition, the charged particle detector is not affected by magnetic fields, so it can be used in a magnetic spectrograph, where its characteristic low background counting is essential. The low background level also suggests a charged particle detector as the ultimate choice for polarization experiments using charged particles.

The fast response time of a charged particle detector makes it especially useful in coincidence experiments involving measurement of nuclear decay schemes with background reduction by suppression of parasitic reactions. For extremely low noise levels in these experiments, the charged particle detector can be operated at low temperatures.

Because of the compact size of EG&G ORTEC Charged Particle Detectors, large numbers of them can be placed into scattering chambers for angular distribution studies of nuclear reactions. Such simultaneous recording of events at different angles reduces costly accelerator time.

Angular correlation measurements with a simplified analysis can be done by placing one detector 180° with respect to the beam. For this experiment, a C-Series annular EG&G ORTEC Charged Particle Detector can be used in a position that allows the beam to pass through its annulus.

7. INFORMATIVE GRAPHS AND CHARTS

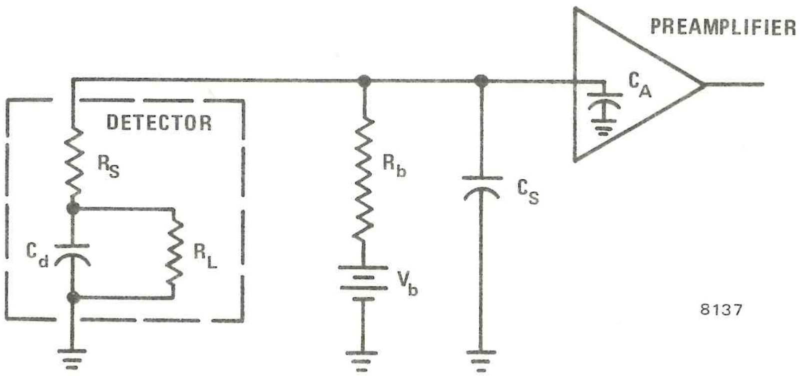


Fig. 7.1. Equivalent Circuit for Charged Particle Detector and First Preamplifier Stage.

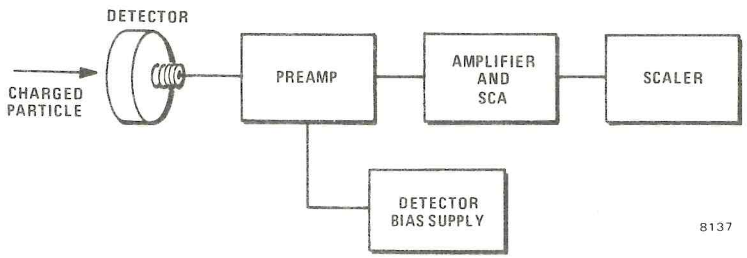


Fig. 7.2. Simple Charged Particle Counting System.

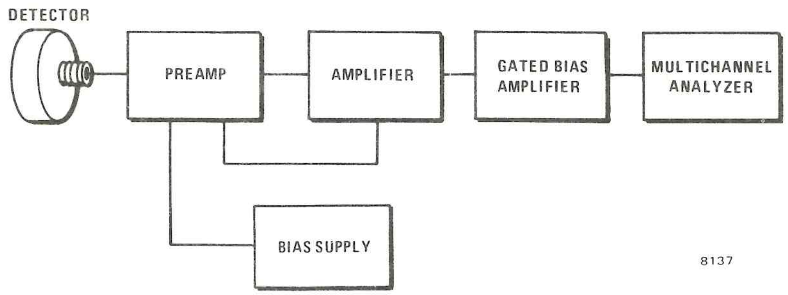
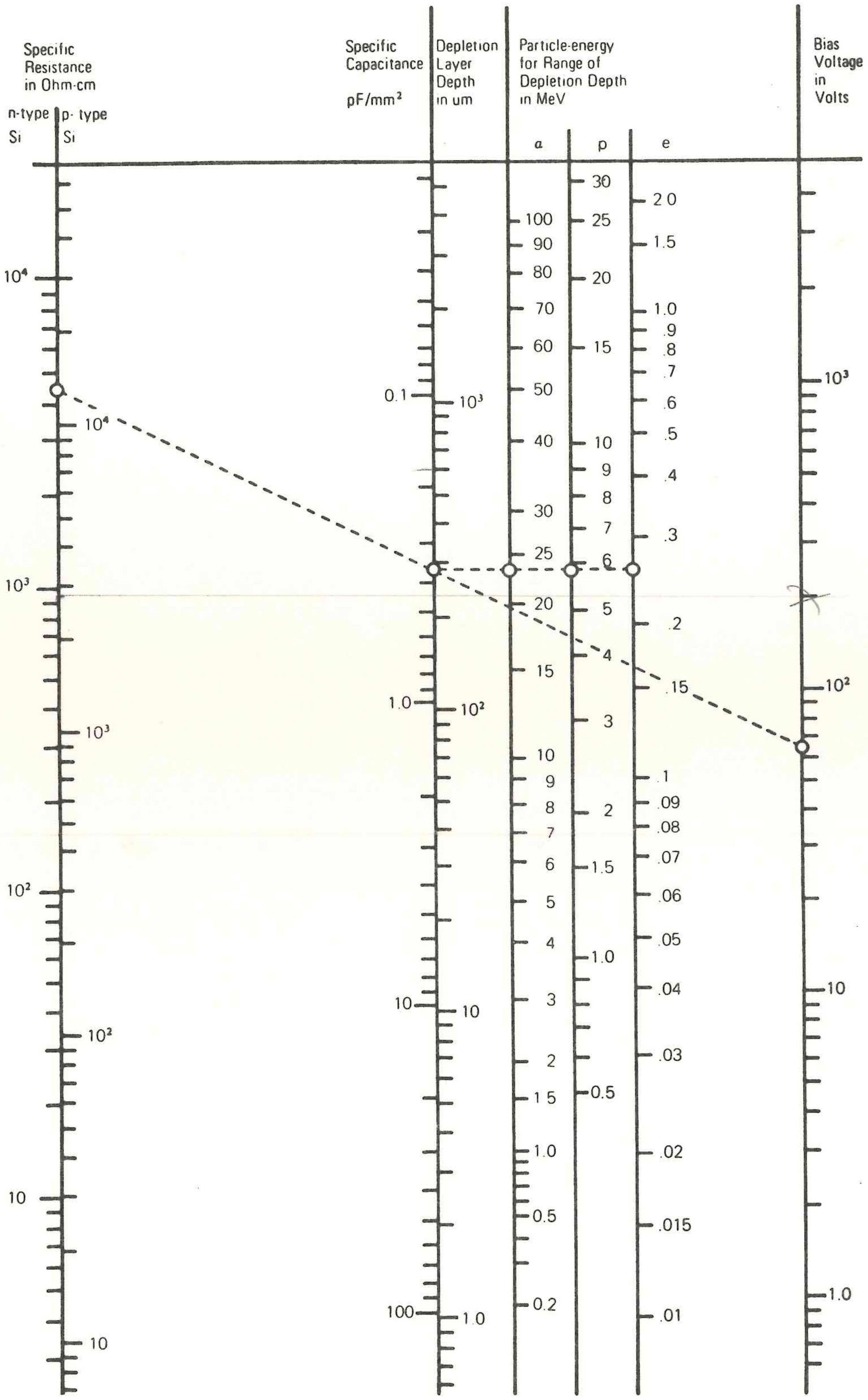


Fig. 7.3. Typical System for Charged Particle Spectroscopy.

Table 7.1. Selected Physical Properties of Silicon.

Atomic Density	5.0×10^{22} atoms – cm^{-3}
Density	2.33 gm – cm^{-3}
Dielectric Coefficient	12
Energy Gap	1.1 eV
Energy per Electron-Hole Pair	3.6 eV – pair
Mobility	
Electron	1350 cm^2 – $volt^{-1}$ – sec^{-1} (2.1×10^9 $T^{-2.5}$ cm^2 – $volt^{-1}$ –sec^{-1})
Hole	480 cm^2 – $volt^{-1}$ – sec^{-1} (2.3×10^9 $T^{-2.7}$ cm^2 – $volt^{-1}$ – sec^{-1})
Thermal Expansion, linear	4.2×10^{-8} $(°C)^{-1}$

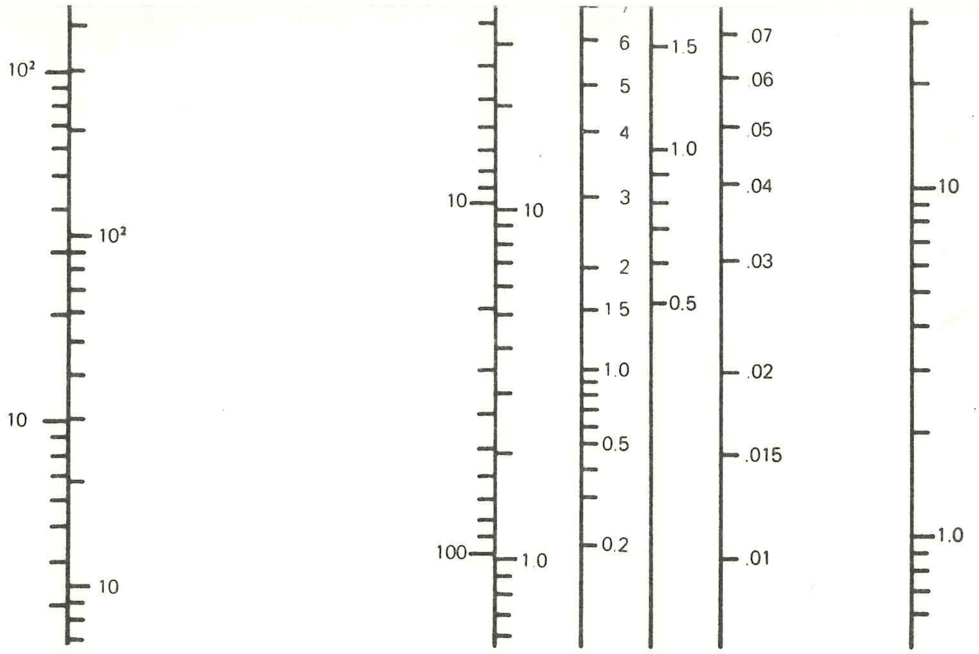
Unless otherwise indicated, above quantities correspond to 25°C.



1 um Si=0.2325 mg/cm²
1 mg/cm² Si=4.3um

A straight edge intersecting the center vertical line at the required depletion depth will give combinations of resistivity and detector bias that may be used to achieve that depth. (Shown, for example, is the voltage that must be applied to a 13,000 ohm-cm p-type or 4500 ohm-cm n-type silicon detector to stop a 23-MeV alpha, a 6-MeV proton, or a 250-keV electron within the depletion depth.)

Fig. 7.4. Silicon Detector Parameters Nomogram.
[Similar to Nomogram reported by J. L. Blankenship, *IREE Trans.* **NS-7**(2–3):190 – 195 (1960).]



1 um Si=0.2325 mg/cm²
1 mg/cm² Si=4.3um

A straight edge intersecting the center vertical line at the required depletion depth will give combinations of resistivity and detector bias that may be used to achieve that depth. (Shown, for example, is the voltage that must be applied to a 13,000 ohm-cm p-type or 4500 ohm-cm n-type silicon detector to stop a 23-MeV alpha, a 6-MeV proton, or a 250-keV electron within the depletion depth.)

Fig. 7.4. Silicon Detector Parameters Nomogram.
[Similar to Nomogram reported by J. L. Blankenship, *IREE Trans.* **NS-7**(2-3):190 - 195 (1960).]

Silicon Detector Nomogram

This nomogram was obtained directly from the Schottky theory for an abrupt junction. In conjunction with the use of this nomogram, the following facts should be pointed out:

1. The fundamental derivation upon which the calculations are based ceases to be valid once the sensitive region extends completely through the wafer (dE/dx devices).

2. For detector configurations where the sensitive surface does not extend completely to the edge of the wafer (e.g., Schottky Barrier models), fringing field effects at the edge will cause a small departure from the capacitance relationships by changing the effective area as a function of applied bias.

3. The effective sensitive depth will be somewhat larger (from a few to 20 microns, depending on such factors as amplifier time constants) than the indicated barrier depth because of charge diffusion into the sensitive region. For betas (electrons), pronounced diffusion collection from depths as great as 500 μm has been frequently observed in surface barrier detectors.

4. In cryogenic applications where the resistivity of the silicon becomes very large, the Schottky Barrier model no longer gives a valid approximation of the internal field distribution.

5. The depletion depth and resultant capacitance are fundamentally related to the uncompensated impurity density N. Since for a fixed temperature (fixed mobility) the resistivity of the material is related to N through the mobility, it is possible to also add a scale relating to the sensitive depth to the **room temperature resistivity**. At other temperatures, the resistivity scale is not valid since the carrier mobilities are temperature dependent.

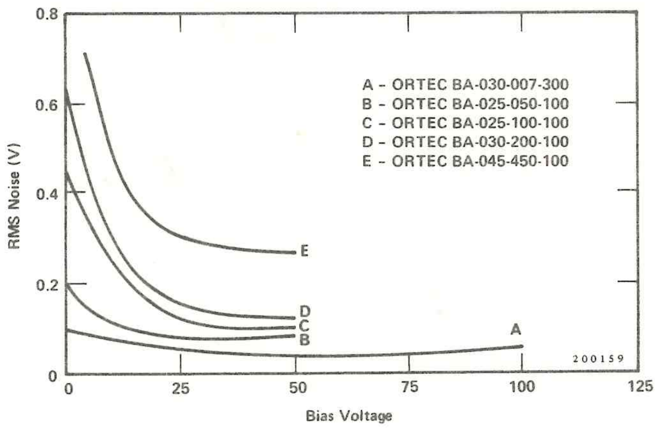


Fig. 7.5. Noise as a Function of Bias Voltage.

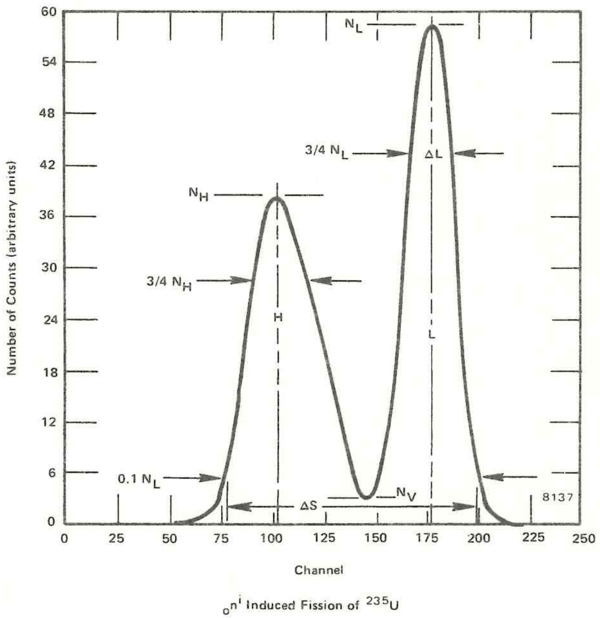


Fig. 7.6. Typical Energy Distribution Spectrum for ^{235}U.

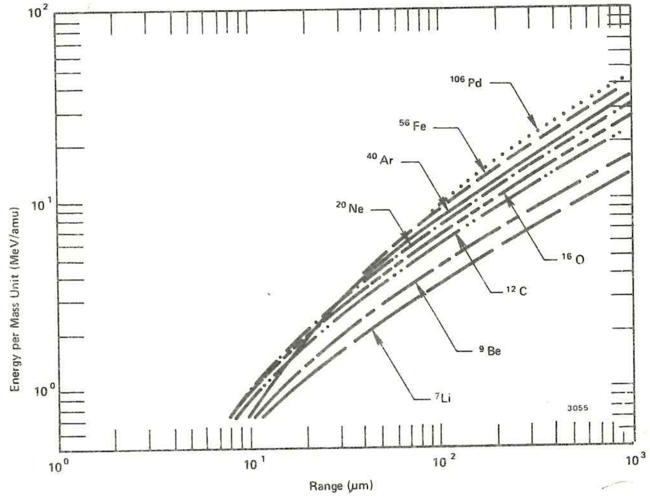


Fig. 7.7. Range-Energy Curves for Several Types of Heavy Ions in Silicon.
[Data taken from Northcliffe and Schilling (1970).]

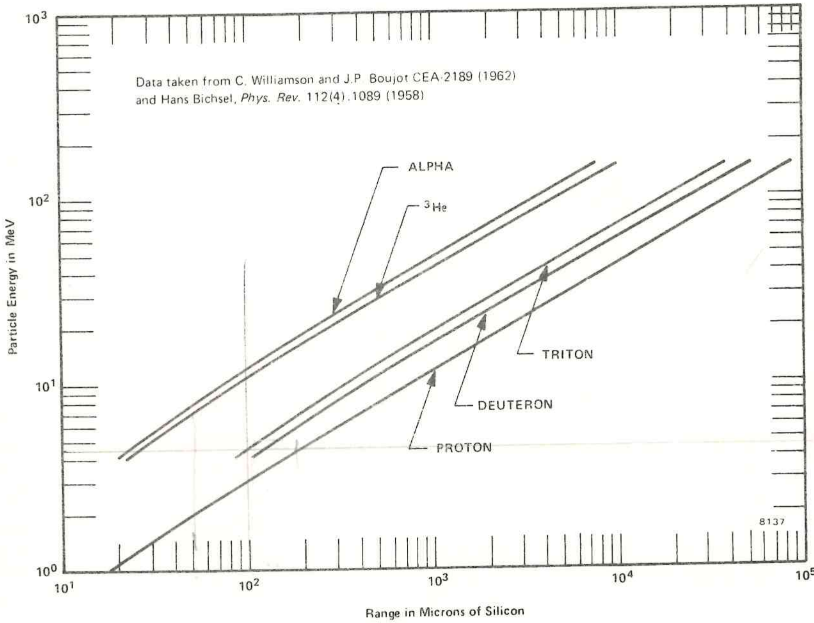


Fig. 7.8. Range-Energy Curves for Charged Particles in Silicon.
NOTE: Channeling of ions between crystal planes can result in significant variations from the data shown here.

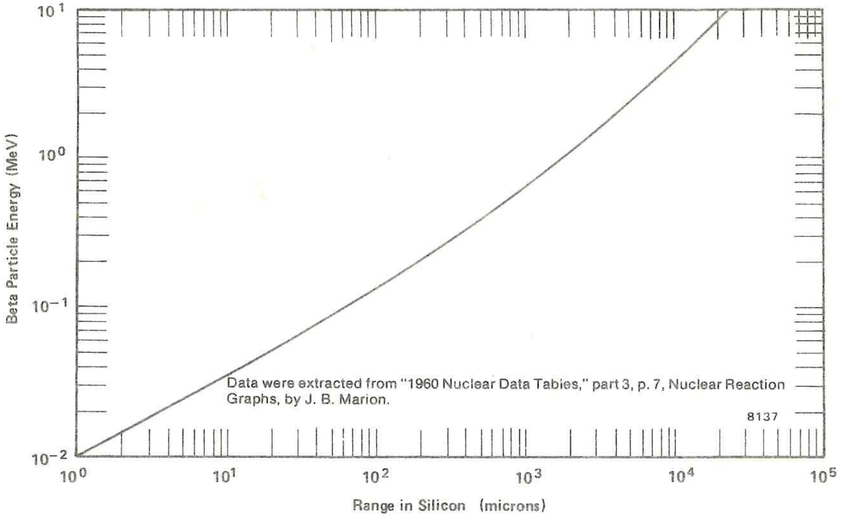


Fig. 7.9. Beta-Ray Range-Energy Curve in Silicon.

NOTE: Channeling of ions between crystal planes can result in significant variations from the data shown here.

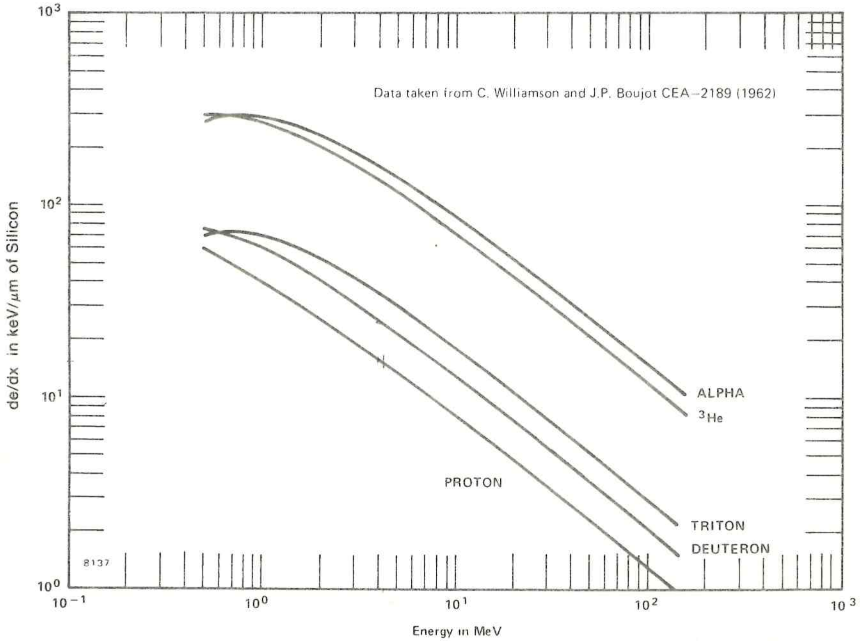
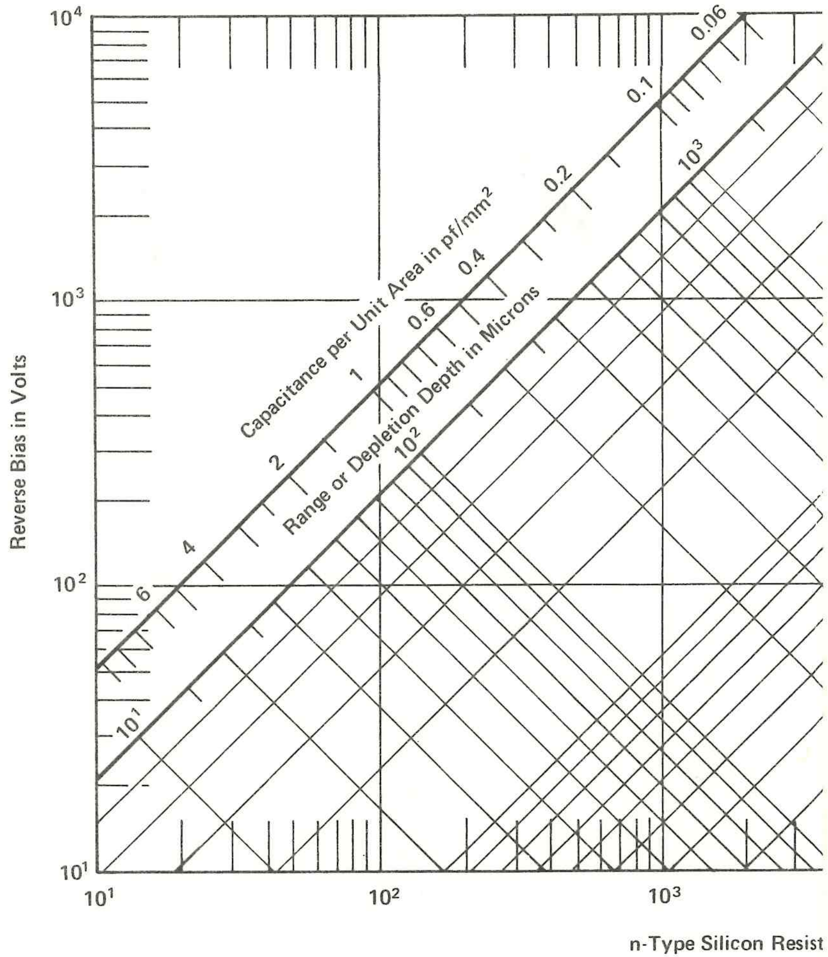


Fig. 7.10. Specific Energy Loss for Charged Particles in Silicon.

NOTE: Channeling of ions between crystal planes can result in significant variations from the data shown here.



MAXIMUM FIELD STRENGTH—$E_g = 4.2 \times 10^4 \, (V_b/\rho_n)^{1/2}$ V/cm

DEPLETION DEPTH—D =

EXAMPLE: If resistivity is 3400 Ω-cm and the bias voltage is 190 V, the detector parameters are determined by first locating the point of interception of 3400 Ω-cm and 190 V. This point falls on: (1) 1 x 10^4 V/cm maximum field strength line; (2) 400 μm depletion depth line; (3) 0.26 pF capacitance per unit area line. The intercept of the depletion depth line and the α, He^3, t, d, and p curves referred to the particle-energy scale give the maximum energy of the particle that will be stopped within the sensitive volume of the detector. It can be seen that the 400 μm depletion depth line intercepts the range curves as follows: He^3 = 25 MeV, α = 28 MeV, t = 11 MeV, d = 9 MeV, and p = 7 MeV.

Fig. 7.13. Field Strength Rel

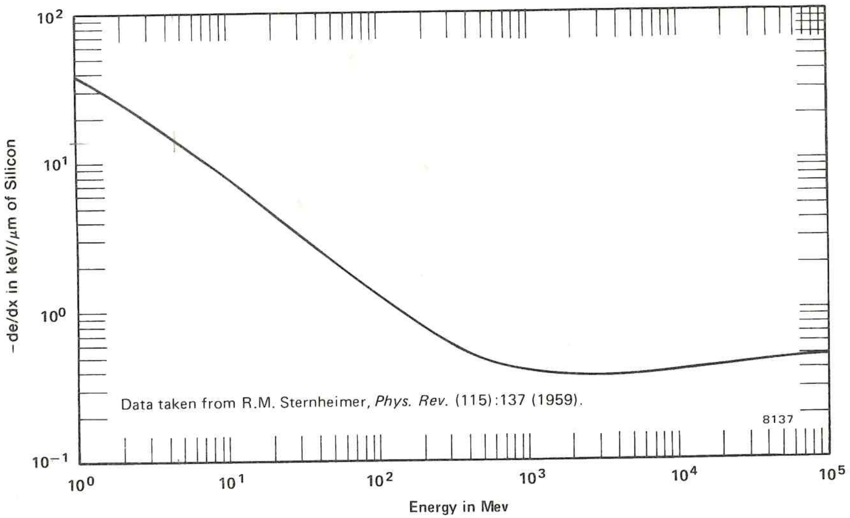


Fig. 7.11. Specific Energy Loss for Protons in Silicon.
NOTE: Channeling of ions between crystal planes can result in significant variations from the data shown here.

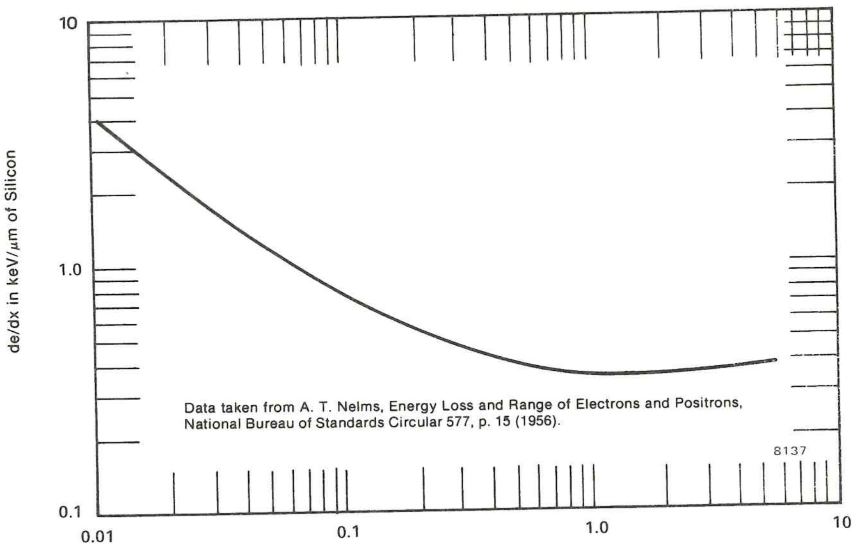
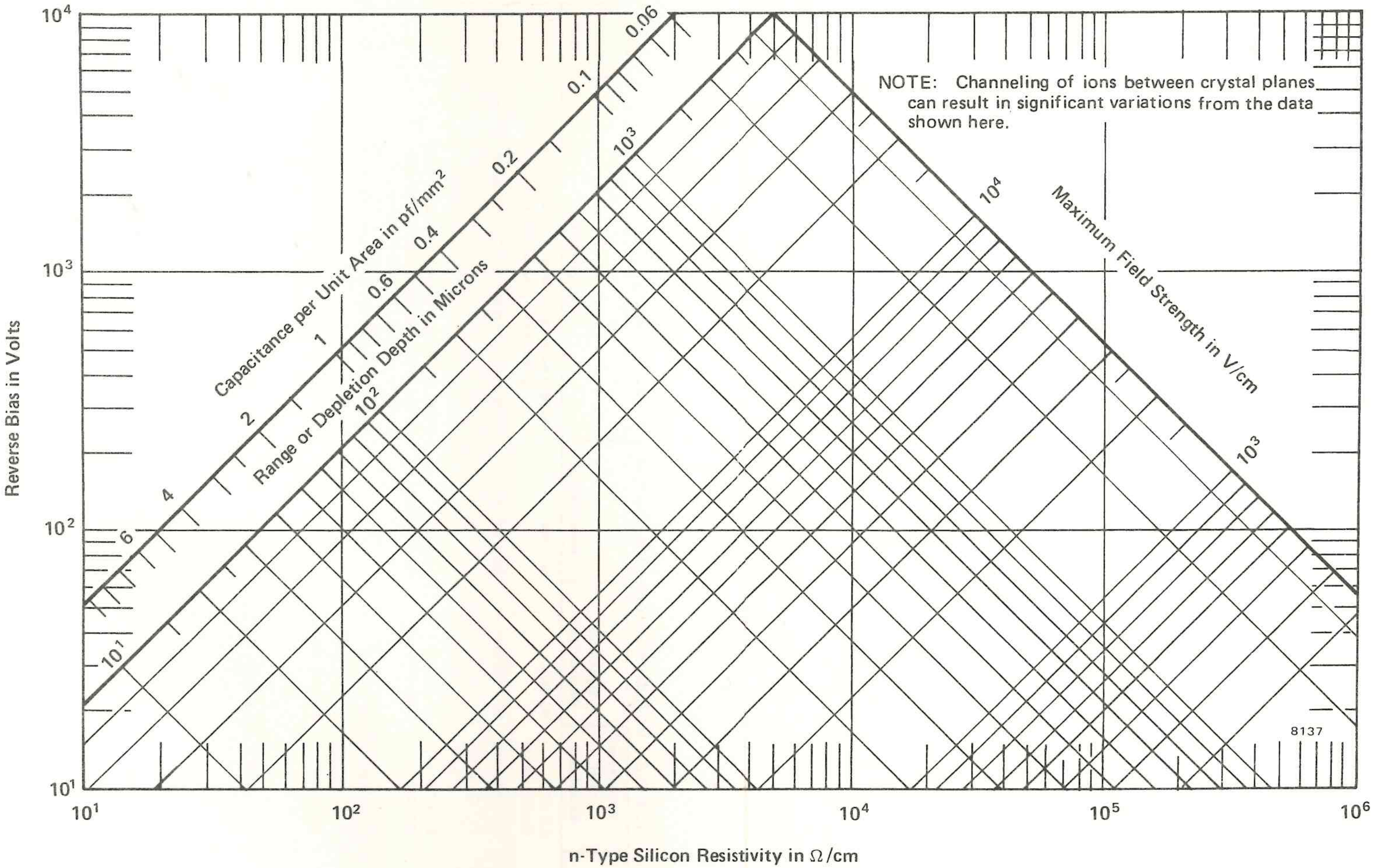


Table 7.2. Radiation Damage for Charged Particle Detectors.

tector Type	Incident Radiation	Energy	Total Dose in Ref. Experiment	Significant Deterioration	Device Failure	Type of Failure	Ref.
ice er	Electrons	2 MeV	2.3 x 10^{13} electrons/cm^2	No data	No data	Multiple peaking; some noise increase. Multiple peaking removed by increasing bias voltage.	1
ice er Ω-cm	^{14}N ions	4 MeV	4.8 x 10^9/cm^2	0.2 x 10^9/cm^2	2.0 x 10^9/cm^2	Catastrophic increase in noise and reverse current.	2
ice er	^{252}Cf fission fragments	104 MeV & 79 MeV	2.5 x 10^8 fragments/cm^2	~1.5 x 10^8 fragments/cm^2	~2 x 10^8 fragments/cm^2	Noise and reverse current increased; pulse height defect increased. Current damage partially annealed at room temperature.	9
ice ier	Fast Neutrons	Fission Spectrum	10^{13} n/cm^2	10^{12} n/cm^2	10^{13} n/cm^2	Resolution broadening ≈15 keV for 5.5 MeV alphas.	3
ice ier	Fast Neutrons	Fission Spectrum	10^{12} n/cm^2	3.5 x 10^{11} n/cm^2	2 x 10^{12} n/cm^2	Resolution broadening; multiple peaking after 3.5 x 10^{11} n/cm^2; no single peak response after 2 x 10^{12} n/cm^2.	4
ace ier	Neutrons	14 MeV	2.6 x 10^{12} n	3 x 10^{11} n	10^{12} n	Multiple peaking; resolution broadening; increased reverse current; decreased pulse height.	1
ace ier	Alphas	5.5 MeV	10^{11} α/cm^2	10^8 - 10^9/cm^2	10^{11} α/cm^2	Increased reverse current and noise; resolution broadening; multiple peaking between 10^9 and 10^{10} α/cm^2.	5, 6
ace ier	Alphas	5.3 MeV	10^{10} α/cm^2			No significant change in current; only slight increase in pulse-height defect.	9
ace ier	^{252}Cf fission fragments	104 MeV & 79 MeV	3.3 x 10^6/cm^2	10^6/cm^2	No data	Timing degradation.	12
ace ier	Electrons	0.2 - 1.0 MeV	10^{16}/cm^2	10^{13} - 10^{16}/cm^2	No data	Noise degradation.	13
ace ier	Protons	0.8 -- 5.0 MeV	10^{17}/cm^2	10^{12}/cm^2	5 x 10^{14}/cm^2	Spectrum degradation.	14



MAXIMUM FIELD STRENGTH—$E_g = 4.2 \times 10^4\ (V_b/\rho_n)^{1/2}$ V/cm

CAPACITANCE PER UNIT AREA—$C_D/A_D = 212/(V_b\rho_n)^{1/2}$ pF/mm^2

DEPLETION DEPTH—$D = 0.5\ (V_b\rho_n)^{1/2}\ \mu$

EXAMPLE: If resistivity is 3400 Ω-cm and the bias voltage is 190 V, the detector parameters are determined by first locating the point of interception of 3400 Ω-cm and 190 V. This point falls on: (1) 1×10^4 V/cm maximum field strength line; (2) 400 μm depletion depth line; (3) 0.26 pF capacitance per unit area line. The intercept of the depletion depth line and the α, He^3, t, d, and p curves referred to the particle-energy scale give the maximum energy of the particle that will be stopped within the sensitive volume of the detector. It can be seen that the 400 μm depletion depth line intercepts the range curves as follows: $He^3 = 25$ MeV, $\alpha = 28$ MeV, t = 11 MeV, d = 9 MeV, and p = 7 MeV.

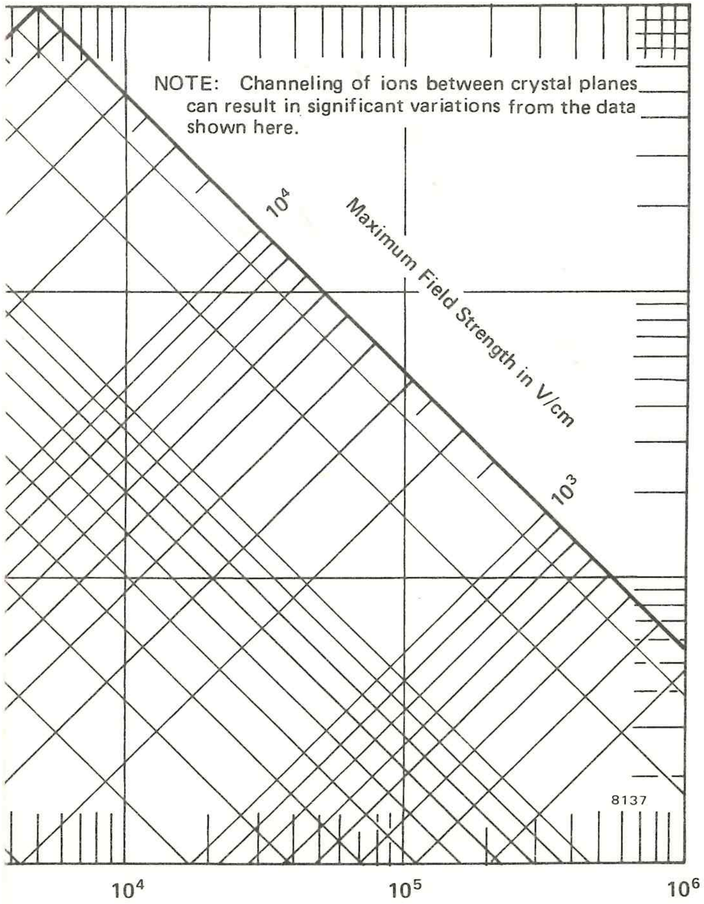
NOTE: All curves are for n-type silicon.

Highly ionizing particles such as fission fragments produce avalanche multiplication fields in excess of $\approx 6 \times 10^4$ V/cm.*

Range data were taken from Williamson and Boujot (CEA-2189, 1962).

*Chynoweth, A. G., "Multiplication Processes in p-n Junctions," National Academy of Sciences – National Research Publication 871:171 (1961).

Fig. 7.13. Field Strength Relationships in Silicon.



CAPACITANCE PER UNIT AREA—$C_D/A_D = 212/(V_b\rho_n)^{1/2}$ pF/mm^2

$0.5\ (V_b\rho_n)^{1/2}\ \mu$

NOTE: All curves are for n-type silicon.

Highly ionizing particles such as fission fragments produce avalanche multiplication fields in excess of ≈6 x 10^4 V/cm.*

Range data were taken from Williamson and Boujot (CEA-2189, 1962).

*Chynoweth, A. G., "Multiplication Processes in p-n Junctions," National Academy of Sciences – National Research Publication 871:171 (1961).

ationships in Silicon.

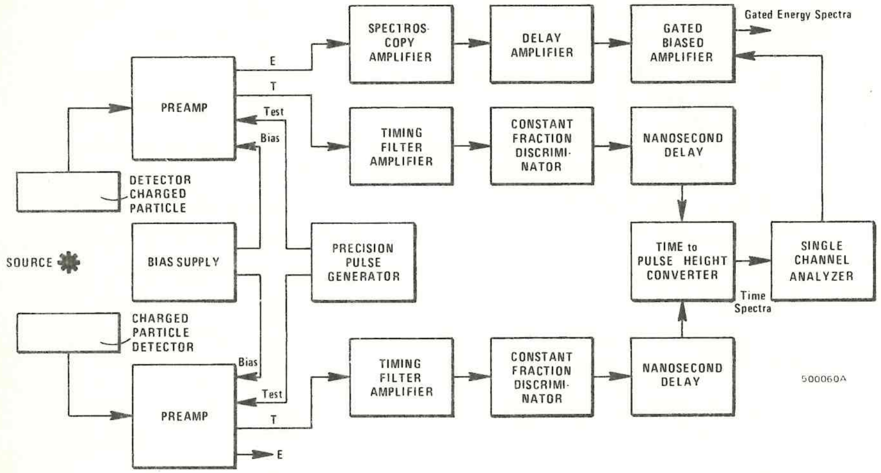


Fig. 7.14. Timing Spectra Permitting Energy Spectra to be Gated with Coincidence Events.

Bibliography references 7 through 10 provide additionl information for Figs. 7.7 through 7.13.

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