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MODEL 105S-3 SINGLE-CHANNEL HIGH-SENSITIVITY RADIATION DETECTOR

Rev. E

Serial # _______________

The model 105S-3 from Carroll & Ramsey Instruments is a high-sensitivity radiation detector system used for HPLC, flow monitoring in radio-chemical synthesis, and similar applications.

GENERAL DESCRIPTION

The system comprises a compact detector probe (28 mm diameter x 45 mm long – exclusive of cable connection) in conjunction with a bench-top amplifier / console unit (7.75"W x 7.5"D x 2.5"H). The sensitive element of the detector probe is a CsI(Tl) scintillating crystal, 25 mm diameter x 25 mm long, optically coupled to a 1 cm^2 silicon PIN diode which, in turn, is connected to a charge-integrating preamplifier [1]. The noise floor for the detector probe is approximately 75 KeV at normal room temperature

[1] Covered by one or more of the following US Patents: 5,990,745; 6,054,705

Stable, reliable operation at low photon fluxes is enhanced by operating the detector in AC-coupled pulse-mode. This essentially eliminates drift and instability due to changes in system parameters, such as diode leakage current, with time and temperature. In this mode of operation, individual gamma ray photon interactions in the scintillating crystal are converted to flashes of light which are then converted in the diode / preamplifier to discrete pulses of current. The pulses of current are amplified, thresholded, and integrated to produce a "DC" signal which is proportional to the time-rate of energy (i.e., dose- rate) for photons which exceed threshold.

The CsI(Tl) crystal, PIN diode, and preamplifier are sealed inside the aluminum cylinder which houses the probe, and shields the active circuitry against ambient light and electromagnetic interference. The probe is connected to the post amplifier / display console through a short length of small-diameter coaxial cable. The post-amplifier produces three separate signals:

1) Analog pulses whose amplitude is proportional to the energy absorbed in the CsI crystal; these signal pulses may be used for spectroscopy (in conjunction with a multi-channel analyzer). The analog pulse shaping time-constant (~6 µsec) is chosen as a compromise between reasonably good pulse-height resolution and reasonable dead-time (total pulse width at the baseline ~25 µsec.)

2) An integrated (time-filtered) “ratemeter” signal which may be used to drive a chart recorder, computer-aided data acquisition system, or similar read-out system. The filter time constant is on the order of 1-2 seconds. Full-scale output is 10 volts; output impedance is ~10K ohms. The output signal level may be adjusted to suit the users data acquisition by means of a multi-turn gain-set potentiometer on the printed wiring board inside the chassis (right side, next to power supply, when viewed from the front) and --

3) Digital pulse rate which is proportional to the analog rate-meter signal amplitude, for use with a counting-type data-acquisition system. Output pulses are approximately 0.4 microsecond in width and are low-power TTL compatible, counts asserted low.

COUPLING TO SAMPLE

The detector count-rate is proportional to the amount of gamma-activity (decays per second) which passes close to the CsI(Tl) crystal. A loop of small diameter, flexible tubing wound tightly around the head of the probe provides the greatest sensitivity. More turns of tubing means more activity, but with a longer transit time.

Fewer turns spaced farther from the probe may be used when the activity concentration in the sample loop is more than a few tens of microcuries per ml.

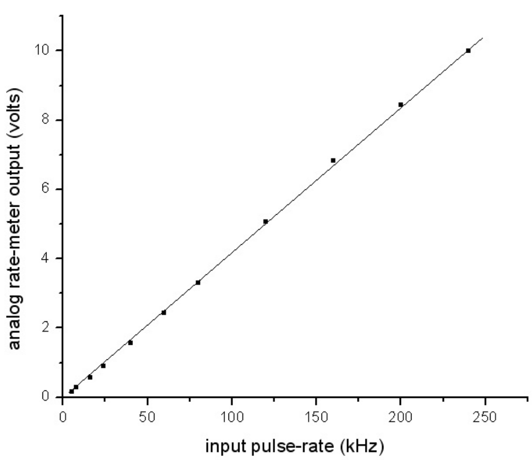
SENSITIVITY

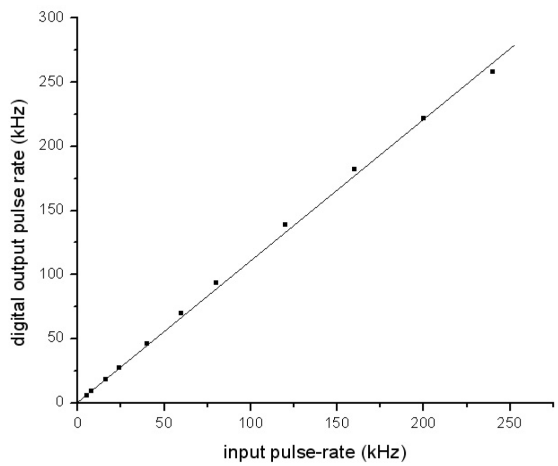
Sensitivity of the detector probe with the 10 cm^3 crystal for commonly-used gamma and β^+ emitters (assuming the threshold is set just above the noise floor) is of the order of 720 counts per minute per nanocurie for sources in close proximity; i.e., where the sampling loop is wound tightly around the probe.

A screwdriver-adjust, multi-turn potentiometer on the printed wiring board inside the chassis (center of circuit board, viewed from the front of the chassis) controls the setting of the lower energy threshold. This potentiometer is normally set at ~1/4 of the amplitude of the principle energy peak of the isotope being monitored.

COUNT-RATE LINEARITY

This latest version of the Model 105S has an improved analog pulse-processing circuit [2] with enhanced linearity, as illustrated below:





The input excitation for these plots was provided by a random-pulse generator; data were taken with the gain-set trim potentiometer at ~1/4 of maximum gain. Vertical scales are somewhat arbitrary, as the actual value also depends on the average analog pulse amplitude, which depends, in turn, on the radio-nuclide being observed, and which may also vary from unit to unit.

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[2] U.S. Patent 9,081,102

RADIATION SHIELDING

Since the detector probe is so compact, a sample loop tightly wound around the probe can provide some spatial resolution by exploiting the inverse-square law -- being relatively blind to activity which is more than a few cm from the probe. However, for best signal / noise ratio at low-activity, the detector probe and its sample loop should be shielded in a lead vessel or within a stack of lead blocks 2" thick or more, depending on the isotope being utilized and the ambient radiation background.

SPECTROSCOPY

An analog pulse signal output on the front panel allows gamma-ray spectroscopy in the range 100 KeV to 1500 KeV. System gain is fixed; one volt peak nominally corresponds to ~0.5 MeV. A multi-channel analyzer or equivalent computer-based instrument, with an input impedance of 10K ohms or greater, is required to record a pulse-height spectrum. The probe's pulse-height resolution is ~12 % FWHM at 511 KeV -- which is sufficient to identify principal peaks of commonly-used isotopes.

UNPACKING AND ASSEMBLY

Open the package with care, being sure to not discard any small components, cables, etc. Verify that the unit has not been damaged in shipment. Look for any obvious loose or broken pieces. If there is evidence of damage in transit, notify the freight carrier and contact Carroll & Ramsey Associates for instructions for return shipment, if required.

Be sure all the parts are present:

Scintillation Detector Probe with connecting cable
Amplifier Chassis
Country-specific or Region-specific AC power cord
Signal Output Cable (6 ft coax cable)

INSTALLATION AND OPERATING ENVIRONMENT

Mains power for units sold in North America is 110 VAC, 60 Hz. Mains power for units sold in Europe is 230 VAC, 50 Hz. Verify correct mains voltage rating for your location – see label on rear of chassis. A country-specific, safety-approved AC line cord is included with the system. Internal operating voltages (+24 VDC, + 12 VDC, and +5VDC) are provided by a built-in, regulated power supply. There is no on-off switch; the unit may be left plugged into the mains and “on” at all times (power drain is less than ~4 watts). The fuse-holder is mounted inside the chassis, on the top of the printed wiring board, next to the modular power supply. Fuse type: 5 x 20 mm; 0.040A ‘slow-blow’.

Warning!

Unplug unit from mains before opening for service, adjustment, or replacement of fuse. Such service should be carried out only by qualified personnel.

The probe is attached to its signal cable (type RG-316 double shielded coaxial cable) by means of a type '*smb*' subminiature coaxial connector. To assemble, align the small plug on the end of the cable against the receptacle on the body of the probe. Press together firmly – but carefully -- until the connector is seated correctly. To remove the cable from the probe, reverse the above procedure, taking care to pull only on the body of the connector – ***not on the cable!*** The probe assembly is reasonably rugged, but is not designed to endure rough treatment such as environmental extremes, high humidity, excessive mechanical shock, continuous vibration, etc. ***Handle with care!*** The detector will also produce spurious electronic signals (microphonics) if the probe or its connecting cable is subject to shock, stress, or vibration during operation. The probe should be held fixed in place and padded, if necessary, to minimize any vibration coupled from other mechanical apparatus such as motors, fans, pumps, etc.

A coaxial signal cable is provided for connecting the analog "ratemeter" signal to the user's data acquisition system. The analog (+) signal appears on the center conductor of the coaxial cable; the colored wire pigtail and shield should be connected to data-acquisition signal (-) and data-acquisition chassis ground, respectively.

The system is intended for indoor use. Components have not been characterized for operation outside the range 10°C - 45°C. The system components and system wiring must not be in close proximity to any flame, heating element, or exposed electrical terminals. The system components have not been characterized for operation in extreme radiation fields such as encountered in close proximity to accelerator targets during irradiation. The system should be protected from mechanical shock or vibration, or contact with volatile or corrosive reagents or solvents.

EMI and RF SUSCEPTIBILITY

Nuclear particle accelerators are used for the production of short-lived radio-isotopes. Such accelerators usually employ high-powered radio-frequency (RF) systems which have the potential to 'leak' RF energy into the environment.

The Model 105-S radiation detector system is widely -- and successfully -- installed and used in PET / Radio-chemistry laboratories, which are often situated close to a cyclotron or similar type of 'RF continuous wave' nuclear particle accelerator.

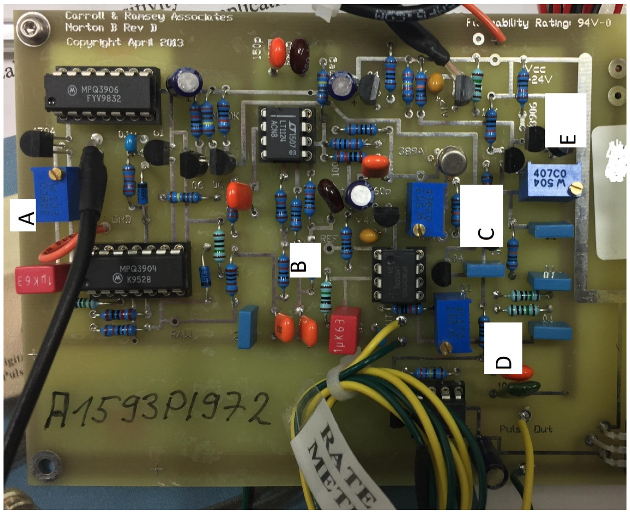
However, the Model 105-S detects and amplifies very low-level input signals. Thus, there is a possibility that RF interference from other equipment – either radiated through free space or conducted through power or signal wiring – may occasionally cause spurious or false detector signal outputs. This may occur as a result of fast electrical transients or modulated RF signals -- for example -- from nearby digital cellular telephones or from electrically 'noisy' devices such as on / off (make-and-break) relay contacts, or from small 'universal' (AC/DC) motors often used in small electrical appliances.

For best results, signal cables should be high-quality shielded coaxial type (examples: RG-174 , RG-58, or equivalent). Signal cables which are longer than a few meters in length should be run in separate conduits or wire-ways -- away from facility power and control wiring. RF devices such as cellular telephones and electrically 'noisy' equipment should not be operated in the near vicinity of sensitive radiation detection equipment (or -- for that matter – near any sensitive electronic instrumentation). ***Be sure that AC power cords from the detector chassis itself and / or from other instruments or apparatus are not placed near the detector probe or its cable.***

DETECTOR SYSTEM CHARACTERIZATION

Since we have no control as to how these instruments are utilized in our customer's various applications, characterization and validation of detector systems supplied by Carroll & Ramsey Associates remains the responsibility of the user. *However, we can offer some advice and some suggestions, with the understanding that these techniques are to be employed only by qualified and knowledgeable persons who are trained in the handling and use of radioactive materials.*

Before attempting system characterization, set the detector system gain and level so that the signal amplitude is compatible with the requirements of your chromatography data collection system. Unless otherwise specified, the output signal from the detector is set in our lab at 0-10 volts out of the '*analog rate-meter*' front-panel coax connector. There are two trim potentiometers that govern the signal: **Gain** (designated **E** in the photo) and **Level** (designated **D** in the photo. Gain set trim potentiometer E is normally set at mid-level, but can be adjusted upward or downward, depending on the user's preference for maximum *dynamic range*, by reducing gain – or maximum *sensitivity* by increasing gain. The signal **level** can be tailored to match the user's chromatography data system's maximum allowable signal by adjusting level potentiometer D. For example, the Agilent chromatography data interface accepts signals only up to a maximum amplitude of 1 volt.



Calibration of the detector in absolute terms (e.g., millivolts per microcurie, or millivolts per microcurie per milliter) is rarely necessary. However, it is important to characterize and to understand the system so as not to substantially overload the detector over the range of activity concentrations expected in your application.

The simplest way to characterize detector linearity entails monitoring and recording the decay of a short-lived radionuclide such as ^{18}F or ^{13}N in aqueous solution. The method requires an additional, independent, non-counting – hence non-saturating – radiation detector such as an ion-chamber dose calibrator, or a 'DC-mode' Si PIN diode radiation detector system, such as our Model 101SDC-P. Also required are two independent voltage-measuring and recording instruments, such as two digital voltmeters [3], or a dual-channel chart-recorder, or a dual-channel

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[3] recording data manually with pad and pencil

computer-aided data-acquisition system which has been independently validated for linearity of voltage response.

The HPLC detector probe should be configured in the same manner as the intended application – closely wrapped with a few turns of flexible tubing and shielded with ~ 2" of Pb, assuming it will be used with positron-emitting radionuclides.

Fill a syringe equipped with a shut-off valve with ~ 1 -2 mCi of activity diluted in aqueous solution. If a dose-calibrator is available, record the amount of activity in the syringe, as well as the time of day [4], then inject a portion of the syringe contents into the tubing so that the isotope solution surrounds the active volume of the detector probe. The aim is to inject an amount of activity which will 'stress' the detector so that the effects of count-rate saturation in the HPLC detector can be observed.

Next, record the amount of activity remaining in the syringe, and again note the time of day. The difference in the two syringe readings (back-corrected for isotope decay) tells us how much activity (and when) was initially injected into the detector loop. Pinch off the ends of the HPLC tubing after injection to prevent gaseous or volatile products from leaking out into the room [5]. The syringe should also be valved off to prevent loss of volatile or gaseous products, then placed in an ion-chamber dose-calibrator, or in a separate, shielded compartment together with the Si PIN diode detector. Absolute calibration is not strictly necessary for this test, but the PIN diode detector or ion-chamber dose-calibrator must be linear and non-saturating.

Record data at appropriate time intervals [6] – simultaneously – from both the syringe detector and the sensitive HPLC detector. Continue taking data for several half-lives – long enough to cover 100-fold (or more) decay in activity. This will require 7 or 8 half-lives (70 - 80 minutes for ^{13}N, or approximately 14 hours for ^{18}F). When data collection is complete, import the data into a computational 'spreadsheet' program such as *EXCEL™* and plot the HPLC detector signal output data as the 'Y' variable directly against the corresponding syringe detector data as the 'X' variable on a *linear* graph scale.

Allowing for inevitable deviations due to fluctuations in detector readings – especially at low (late) activity levels – the result should be a straight line plot – best fit 'by eye' – over the range of

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[4] For subsequent half-life correction – especially when using ^{13}N for this test.

[5] If you are sure that the sample contains only a single radionuclide, then a time-record of HPLC detector rate-meter output <u>voltage</u> plotted against <u>time</u> on a semi-log scale should yield a straight line whose slope exactly corresponds to the half-life the isotope. However, depending on the purity and degree of enrichment of the original cyclotron target material, a fresh batch of aqueous ^{18}F fluoride ($t_{1/2}$ = 109.8 minutes) may contain other nuclides, such as ^{13}N ($t_{1/2}$ = 9.97 minutes) or, conversely, a batch of ^{13}N may contain a small amount of ^{18}F due to the presence of ^{18}O in 'normal' ^{16}O target-water used to produce ^{13}N. The dual-sample / dual detector scheme corrects for this effect, but keep in mind that liquid drawn directly from a cyclotron target may contain radionuclides in various chemical forms, including dissolved N_2 and oxides of nitrogen in the case of ^{13}N, or volatile or gaseous products in the case of ^{18}F.

[6] For example, every 2-3 minutes for ^{13}N or every 20 - 30 minutes for ^{18}F

later (lower) activity levels To the extent that the HPLC detector saturates at the highest activity levels, the ‘Y’ variable will not necessarily follow a straight line all the way, but will tend to ‘flatten’ – to be more horizontal – at the early (high-activity) portion of the curve.

Take note of where – and to what extent – the detector output voltage deviates from a straight-line response. This is an important benchmark: Keep the test data on file as part of your equipment validation record, and take care to insure that – during actual operation – injected activities do not result in a ratemeter signal that substantially exceeds this ‘saturation’ level.

Finally, if the ‘saturation’ signal level is too high (or too low) for your requirements, then it will be necessary to re-adjust the detector gain-set and level-set trim potentiometers and repeat the above procedure until the maximum expected signal levels are compatible with your data acquisition system.

WARRANTY

Systems are warranted against defects in materials and workmanship for a period of 1 year from date of shipment. Carroll & Ramsey Associates' (CRA) sole obligation for products that prove to be defective will be repair or replacement. In no event shall CRA's obligation exceed the buyer's purchase price. CRA specifically disclaims any implied warranties for merchantibility or fitness for a specific purpose, nor will CRA be liable for any indirect, incidental, or consequential damages.

This warranty does not apply to products which have been subject to mis-use such as accident, severe mechanical shock and distress, over-voltage, immersion, exposure to volatile or corrosive agents, etc. The warranty does not apply to defects due to unauthorized modification, or which have been altered in such a way as to not be capable of undergoing functional test.

Products sold by Carroll & Ramsey Instruments are not intended for use as critical components in medical devices or life-support devices or systems. Performance specifications, physical configuration, and packaging are subject to revision, change, or improvement at any time -- without prior notice.

END OF LIFE (DECOMMISSIONING) There may be a small amount of lead-based solder used to assemble the printed-wiring boards. Please contact the manufacturer, Carroll & Ramsey Instruments, or an approved disposal company to decommission or dispose of your equipment