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U.S. ATOMIC ENERGY COMMISSION

# REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

## REGULATORY GUIDE 5.27

## SPECIAL NUCLEAR MATERIAL DOORWAY MONITORS

### A. INTRODUCTION

Paragraph (b), "Exit Requirement," of § 73.60, "Additional Requirements for the Physical Protection of Special Nuclear Material at Fixed Sites," of 10 CFR Part 73, "Physical Protection of Plants and Materials," requires that individuals exiting from material access areas be searched for concealed special nuclear material (SNM). This guide describes means acceptable to the Regulatory staff for employing SNM doorway monitors to comply with that requirement.

### B. DISCUSSION

Special nuclear material doorway monitors provide an efficient, sensitive, and reasonably unobtrusive means of searching individuals exiting from a material access area for concealed SNM. With proper installation and operation, gram quantities or less of SNM can be detected with a high level of reliability while maintaining a low false alarm rate.

1. **Theory of Operation**

The doorway monitor is composed of a detector unit(s), associated electronics, and alarm logic. The detector unit(s) is sensitive to the radiations which emanate from the SNM and responds to these radiations (usually gamma rays) by generating current pulses. These pulses are amplified, filtered, and fed to alarm logic which interprets the number (or rate) of pulses in some period of time, for example, one second. The alarm logic may be either a digital or analog system; in either case, if the number (or rate) of pulses exceeds a set level, an alarm condition ensues.

2. **General Characteristics**

Typically, the detectors of a doorway monitor are NaI(Tl) scintillators or solid or liquid organic scintillators. Geiger-Mueller detectors have also been used in this application, although the lower intrinsic efficiency of these detectors renders them less suitable than scintillation detectors.

Detectors are arranged such that a detection area is defined by a plane perpendicular to the line of passage of individuals through the doorway monitor. Various arrangements of the detectors are possible; however, specific placement of detectors is usually dictated by the need to eliminate dead spots.

Some commercially available doorway monitors are equipped with an automatic background updating system. The automatic background updating system periodically monitors and averages the background. A doorway monitor equipped with an automatic background updating system is also provided with a treadle pad or beam-break system to indicate that the sensitive area is occupied. When the sensitive area is occupied, the radiation level detected by the doorway monitor is compared with the mean background. If the level is "significantly" greater than the mean background, an alarm condition ensues. Significance is usually determined by comparing the radiation level when the sensitive area is occupied with the mean background plus some multiple of the square root of the mean background*

*The square root of the mean of a Poisson-distributed quantity is the unbiased estimate of the standard deviation of that quantity.

Thus the condition for an alarm can be written as

$$G > B + n\sqrt{B},$$

where B is the mean background, G is the radiation level with the sensitive area occupied, and n is a multiplier, usually an integer between 4 and 10.* The value of n directly affects the false alarm rate, and the combination of B and n affect the sensitivity.

Although the automatic background updating system allows unattended use of the doorway monitor, for technical reasons, the system may be less effective in certain situations. Techniques to prevent this are described in the Regulatory Position.

Doorway monitors not equipped with an automatic background updating system either must rely on the inherent sensitivity of the instrument and low background variation to ensure that concealed SNM will be detected or must be attended so that a measurement of background can be taken immediately prior to use and the alarm level set to maintain the desired sensitivity to concealed SNM. As with the doorway monitor equipped with an automatic background updating system, a doorway monitor not so equipped compares the activity with the detection area occupied with some set value, usually the measurement of background taken just prior to use. In any case, the expression above can be used as a condition of alarm by replacing $B + n\sqrt{B}$ with the set level.

Whether or not a doorway monitor is equipped with an automatic background updating system, high background activity will decrease sensitivity. Measuring activity for longer periods will somewhat compensate for high background; however, longer measurement periods will make use of the doorway monitor less convenient.

## C. REGULATORY POSITION

1. **Minimum Qualifications for SNM Doorway Monitors**

a. General

(1) SNM Doorway monitors should be used in conjunction with a metal detector and should be installed in a passageway (see Regulatory Guide 5.7, "Control of Personnel Access to Protected Areas, Vital Areas, and Material Access Areas,") in such a manner that objects cannot be passed over, around, or under the detection area.

(2) The detector elements should be designed and positioned so that detection sensitivity is as uniform as possible over the detection area; in no case should any areas where SNM is not detectible be permitted.

(3) Power, sensitivity, and other controls of the doorway monitor should be tamper-safed when unattended.

(4) Signal lines connecting alarm relays to the alarm monitor should be supervised.

(5) Some doorway monitors may require an individual to occupy the detection area for a specified time, longer than a normal walking pace would provide. If this is the case, the doorway monitor should be provided with a treadle pad and a "clock" device to assure that the detection area is occupied for the requisite time. An aural and visual indication should be given if an individual being searched does not occupy the area sufficiently long.

b. System Specification

(1) *Plutonium-239.* A doorway monitor used to detect plutonium should be capable of detecting a minimum of 0.5 gram of plutonium-239 encased in a minimum of 3 mm of brass at a 90% confidence limit. The false alarm rate should be less than 0.1% (Appendix C).

(2) *Uranium-233.* A doorway monitor used to detect uranium-233 should be capable of detecting within 4 hours of purification* a minimum of 1 gram of uranium-233 containing between 7 and 10 ppm of uranium-232 encased in a minimum of 3 mm of brass at a 90% confidence limit. The false alarm rate should be less than 0.1% (Appendix C).

(3) *Uranium-235.* A doorway monitor used to detect uranium-235 should be capable of detecting a minimum of 3 grams of uranium-235 contained in uranium enriched to 20% or more in the uranium-235 isotope encased in a minimum of 3 mm of brass at a 50% confidence limit. The false alarm rate should be less than 0.1% (Appendix C).

2. **Use of Doorway Monitors**

In general, doorway monitors should be used in locations of minimum background and minimum background fluctation. If circumstances dictate use of a doorway monitor in an area of high background, sufficient shielding should be provided to maintain necessary sensitivity.

a. Attended Doorway Monitor

(1) If the doorway monitor is attended during use, it need not be equipped with an automatic

*Note that, in general, for a count rate system, the condition for alarm should be modified to account for the response time of the instrument as follows:

$$G > B + n\sqrt{B}(1 - e^{-t/\tau})$$

where t is the counting time and $\tau$ is the time constant of the instrument. If, as should be the case, $t/\tau > 5$ the added factor is essentially unity.

*Purification means removal of all decay products.

background updating system, although such capability is preferred.

(2) Prior to each use* of a doorway monitor not equipped with an automatic background updating system, a measurement of background should be taken, and the alarm threshold should be set to the proper value listed in Table I for the measured background and the proper n value as determined in Appendix B. Each individual to be checked should, in turn, enter the detection area and be required to remain sufficiently long for the device to operate properly. During use, the background should be checked and the alarm threshold reset at least each 15 minutes.

(3) With the individual being checked in the detection area, an alarm should sound if the activity in the detection area exceeds the alarm threshold T, as such a situation would indicate the presence of SNM.

(4) The doorway monitor should be equipped with a high-background alarm which will sound if the measurement of background exceeds the appropriate maximum permissible background level listed in Table II as determined in Appendix C. The doorway monitor should not be used during such periods of high background.

b. Unattended Doorway Monitor

(1) If the doorway monitor is unattended, an automatic background update system should be incorporated into the doorway monitor electronics and alarm logic. The control circuitry, if possible, should be located at the central alarm station (or other monitoring point).

(2) Door interlocks and closed-circuit TV in combination with beam breaks, motion detectors, and/or treadle pads, should be employed to:

(a) Indicate to the person manning the central alarm station that an individual has entered the secure access passageway and/or is approaching the doorway monitor,

(b) Allow observation of the individual approaching the doorway monitor,

(c) Preclude a slow approach to the sensitive area of the doorway monitor, and

(d) Activate the electronics and alarm logic when an individual is within the detection area and initiate operation of the doorway monitor.

(3) An alarm should sound in the central alarm station if, when occupied, the activity in the detection area exceeds the internally set threshold level (the mean background plus some multiple times the square root of the mean background), as such a situation would indicate the presence of SNM upon the individual being checked.

(4) The doorway monitor should be equipped with a high-background alarm which will sound if the average background at the location of the doorway monitor exceeds the appropriate maximum permissible background level listed in Table II as determined in Appendix C. The doorway monitor should not be used during such periods of high background. Other monitored exits should be used.

3. **Testing and Calibration**

a. Testing

Doorway monitors should be tested by passing an appropriate source of the amount and isotope specified in Regulatory Position C.1.b. through the doorway monitor no less frequently than once per day.* In addition, a functional performance test should be carried out at least once per week. An acceptable functional performance test procedure is discussed in Appendix A of this guide

b. Calibration

Doorway monitors should be calibrated with a source of the amount, configuration, and variety of SNM to be detected (e.g., 0.5 gram Pu in 3 mm of brass). Calibration should be carried out according to a procedure such as that in Appendix B.

c. Operating Instructions

Operating instructions should be posted near the doorway monitor, if attended, or at the monitoring point if the doorway monitor is unattended. The instructions should clearly indicate the procedure for use of the doorway monitor and the procedure for setting thresholds, if appropriate. In addition, the operating instructions should indicate what corrective action is to be taken and who is to be notified in the event of a malfunction.

*By use is meant an individual or several individuals, each, in turn, being checked for SNM by the doorway monitor. The maximum period between threshold sets while the doorway monitor is in use is determined by the stability of local background and may necessarily be more frequent than every 15 minutes.

*Doorway monitors used to search for concealed U-233 should be tested according to §6 of Appendix A.

TABLE I

ALARM THRESHOLD

T

| B | n = 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|
| 100 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
| 120 | 164 | 175 | 186 | 197 | 208 | 219 | 230 |
| 140 | 187 | 199 | 211 | 223 | 235 | 246 | 258 |
| 160 | 211 | 223 | 236 | 249 | 261 | 274 | 286 |
| 180 | 234 | 247 | 260 | 274 | 287 | 301 | 314 |
| 200 | 257 | 271 | 285 | 299 | 313 | 327 | 341 |
| 220 | 279 | 294 | 309 | 324 | 339 | 353 | 368 |
| 240 | 302 | 317 | 333 | 348 | 364 | 379 | 395 |
| 260 | 324 | 341 | 357 | 373 | 389 | 405 | 421 |
| 280 | 347 | 364 | 380 | 397 | 414 | 431 | 447 |
| 300 | 369 | 387 | 404 | 421 | 439 | 456 | 473 |
| 320 | 392 | 409 | 427 | 445 | 463 | 481 | 499 |
| 340 | 414 | 432 | 451 | 469 | 488 | 506 | 524 |
| 360 | 436 | 455 | 474 | 493 | 512 | 531 | 550 |
| 380 | 458 | 477 | 497 | 516 | 536 | 555 | 575 |
| 400 | 480 | 500 | 520 | 540 | 560 | 580 | 600 |
| 420 | 502 | 522 | 543 | 563 | 584 | 604 | 625 |
| 440 | 524 | 545 | 566 | 587 | 608 | 629 | 650 |
| 460 | 546 | 567 | 589 | 610 | 632 | 653 | 674 |
| 480 | 568 | 590 | 611 | 633 | 655 | 677 | 699 |
| 500 | 589 | 612 | 634 | 657 | 679 | 701 | 724 |
| 520 | 611 | 634 | 657 | 680 | 702 | 725 | 748 |
| 540 | 633 | 656 | 679 | 703 | 726 | 749 | 772 |
| 560 | 655 | 678 | 702 | 726 | 749 | 773 | 797 |
| 580 | 676 | 700 | 724 | 749 | 773 | 797 | 821 |
| 600 | 698 | 722 | 747 | 771 | 796 | 820 | 845 |
| 620 | 720 | 744 | 769 | 794 | 819 | 844 | 869 |
| 640 | 741 | 766 | 792 | 817 | 842 | 868 | 893 |
| 660 | 763 | 788 | 814 | 840 | 866 | 891 | 917 |
| 680 | 784 | 810 | 836 | 863 | 889 | 915 | 941 |
| 700 | 806 | 832 | 859 | 885 | 912 | 938 | 965 |
| 720 | 827 | 854 | 881 | 908 | 935 | 961 | 988 |
| 740 | 849 | 876 | 903 | 930 | 958 | 985 | 1012 |
| 760 | 870 | 898 | 925 | 953 | 981 | 1008 | 1036 |
| 780 | 892 | 920 | 948 | 975 | 1003 | 1031 | 1059 |
| 800 | 913 | 941 | 970 | 998 | 1026 | 1055 | 1083 |
| 820 | 935 | 963 | 992 | 1020 | 1049 | 1078 | 1106 |
| 840 | 956 | 985 | 1014 | 1043 | 1072 | 1101 | 1130 |
| 860 | 977 | 1007 | 1036 | 1065 | 1095 | 1124 | 1153 |
| 880 | 999 | 1028 | 1058 | 1088 | 1117 | 1147 | 1177 |
| 900 | 1020 | 1050 | 1080 | 1110 | 1140 | 1170 | 1200 |
| 920 | 1041 | 1072 | 1102 | 1132 | 1163 | 1193 | 1223 |
| 940 | 1063 | 1093 | 1124 | 1155 | 1185 | 1216 | 1247 |
| 960 | 1084 | 1115 | 1146 | 1177 | 1208 | 1239 | 1270 |
| 980 | 1105 | 1137 | 1168 | 1199 | 1230 | 1262 | 1293 |

TABLE I (Cont'd)

ALARM THRESHOLD

T

| B | n = 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|
| 1000 | 1126 | 1158 | 1190 | 1221 | 1253 | 1285 | 1316 |
| 1200 | 1339 | 1373 | 1408 | 1442 | 1477 | 1512 | 1546 |
| 1400 | 1550 | 1587 | 1624 | 1662 | 1699 | 1737 | 1774 |
| 1600 | 1760 | 1800 | 1840 | 1880 | 1920 | 1960 | 2000 |
| 1800 | 1970 | 2012 | 2055 | 2097 | 2139 | 2182 | 2224 |
| 2000 | 2179 | 2224 | 2268 | 2313 | 2358 | 2402 | 2447 |
| 2200 | 2388 | 2435 | 2481 | 2528 | 2575 | 2622 | 2669 |
| 2400 | 2596 | 2645 | 2694 | 2743 | 2792 | 2841 | 2890 |
| 2600 | 2804 | 2855 | 2906 | 2957 | 3008 | 3059 | 3110 |
| 2800 | 3012 | 3065 | 3117 | 3170 | 3223 | 3276 | 3329 |
| 3000 | 3219 | 3274 | 3329 | 3383 | 3438 | 3493 | 3548 |
| 3200 | 3426 | 3483 | 3539 | 3596 | 3653 | 3709 | 3766 |
| 3400 | 3633 | 3692 | 3750 | 3808 | 3866 | 3925 | 3983 |
| 3600 | 3840 | 3900 | 3960 | 4020 | 4080 | 4140 | 4200 |
| 3800 | 4047 | 4108 | 4170 | 4232 | 4293 | 4355 | 4416 |
| 4000 | 4253 | 4316 | 4379 | 4443 | 4506 | 4569 | 4632 |
| 4200 | 4459 | 4524 | 4589 | 4654 | 4718 | 4783 | 4848 |
| 4400 | 4665 | 4732 | 4798 | 4864 | 4931 | 4997 | 5063 |
| 4600 | 4871 | 4939 | 5007 | 5075 | 5143 | 5210 | 5278 |
| 4800 | 5077 | 5146 | 5216 | 5285 | 5354 | 5424 | 5493 |
| 5000 | 5283 | 5354 | 5424 | 5495 | 5566 | 5636 | 5707 |
| 5200 | 5488 | 5561 | 5633 | 5705 | 5777 | 5849 | 5921 |
| 5400 | 5694 | 5767 | 5841 | 5914 | 5988 | 6061 | 6135 |
| 5600 | 5899 | 5974 | 6049 | 6124 | 6199 | 6273 | 6348 |
| 5800 | 6105 | 6181 | 6257 | 6333 | 6409 | 6485 | 6562 |
| 6000 | 6310 | 6387 | 6465 | 6542 | 6620 | 6697 | 6775 |
| 6200 | 6515 | 6594 | 6672 | 6751 | 6830 | 6909 | 6987 |
| 6400 | 6720 | 6800 | 6880 | 6960 | 7040 | 7120 | 7200 |
| 6600 | 6925 | 7006 | 7087 | 7169 | 7250 | 7331 | 7412 |
| 6800 | 7130 | 7212 | 7295 | 7377 | 7460 | 7542 | 7625 |
| 7000 | 7335 | 7418 | 7502 | 7586 | 7669 | 7753 | 7837 |
| 7200 | 7539 | 7624 | 7709 | 7794 | 7879 | 7964 | 8049 |
| 7400 | 7744 | 7830 | 7916 | 8002 | 8088 | 8174 | 8260 |
| 7600 | 7949 | 8036 | 8123 | 8210 | 8297 | 8385 | 8472 |
| 7800 | 8153 | 8242 | 8330 | 8418 | 8507 | 8595 | 8683 |
| 8000 | 8358 | 8447 | 8537 | 8626 | 8716 | 8805 | 8894 |
| 8200 | 8562 | 8653 | 8743 | 8834 | 8924 | 9015 | 9106 |
| 8400 | 8767 | 8858 | 8950 | 9042 | 9133 | 9225 | 9317 |
| 8600 | 8971 | 9064 | 9156 | 9249 | 9342 | 9435 | 9527 |
| 8800 | 9175 | 9269 | 9363 | 9457 | 9550 | 9644 | 9738 |
| 9000 | 9379 | 9474 | 9569 | 9664 | 9759 | 9854 | 9949 |
| 9200 | 9584 | 9680 | 9775 | 9871 | 9967 | 10063 | 10159 |
| 9400 | 9788 | 9885 | 9982 | 10079 | 10176 | 10273 | 10370 |
| 9600 | 9992 | 10090 | 10188 | 10286 | 10384 | 10482 | 10580 |
| 9800 | 10196 | 10295 | 10394 | 10493 | 10592 | 10691 | 10790 |

TABLE II

MAXIMUM PERMISSIBLE BACKGROUND $\alpha = 0$, $P_\alpha = 50\%$

B

| G | n = 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|
| 100 | 67 | 61 | 55 | 50 | 46 | 42 | 38 |
| 120 | 83 | 76 | 70 | 64 | 59 | 54 | 50 |
| 140 | 100 | 92 | 85 | 78 | 72 | 67 | 62 |
| 160 | 117 | 108 | 100 | 93 | 86 | 80 | 74 |
| 180 | 134 | 124 | 116 | 107 | 100 | 93 | 87 |
| 200 | 151 | 141 | 131 | 123 | 114 | 107 | 100 |
| 220 | 168 | 157 | 147 | 138 | 129 | 121 | 113 |
| 240 | 186 | 174 | 163 | 153 | 144 | 135 | 127 |
| 260 | 203 | 191 | 180 | 169 | 159 | 150 | 141 |
| 280 | 221 | 208 | 196 | 185 | 174 | 165 | 155 |
| 300 | 238 | 225 | 213 | 201 | 190 | 179 | 170 |
| 320 | 256 | 242 | 229 | 217 | 205 | 194 | 184 |
| 340 | 274 | 259 | 246 | 233 | 221 | 210 | 199 |
| 360 | 292 | 277 | 263 | 249 | 237 | 225 | 214 |
| 380 | 310 | 294 | 280 | 266 | 253 | 240 | 229 |
| 400 | 328 | 312 | 297 | 282 | 269 | 256 | 244 |
| 420 | 346 | 329 | 314 | 299 | 285 | 272 | 259 |
| 440 | 364 | 347 | 331 | 316 | 301 | 287 | 274 |
| 460 | 382 | 365 | 348 | 332 | 317 | 303 | 290 |
| 480 | 400 | 382 | 365 | 349 | 334 | 319 | 305 |
| 500 | 418 | 400 | 383 | 366 | 350 | 335 | 321 |
| 520 | 436 | 418 | 400 | 383 | 367 | 351 | 337 |
| 540 | 455 | 436 | 417 | 400 | 383 | 367 | 352 |
| 560 | 473 | 454 | 435 | 417 | 400 | 384 | 368 |
| 580 | 491 | 471 | 452 | 434 | 417 | 400 | 384 |
| 600 | 510 | 489 | 470 | 451 | 433 | 416 | 400 |
| 620 | 528 | 507 | 488 | 468 | 450 | 433 | 416 |
| 640 | 546 | 525 | 505 | 486 | 467 | 449 | 432 |
| 660 | 565 | 543 | 523 | 503 | 484 | 466 | 448 |
| 680 | 583 | 562 | 541 | 520 | 501 | 482 | 464 |
| 700 | 602 | 580 | 558 | 538 | 518 | 499 | 481 |
| 720 | 620 | 598 | 576 | 555 | 535 | 516 | 497 |
| 740 | 639 | 616 | 594 | 573 | 552 | 532 | 513 |
| 760 | 657 | 634 | 612 | 590 | 569 | 549 | 530 |
| 780 | 676 | 652 | 629 | 607 | 586 | 566 | 546 |
| 800 | 695 | 671 | 647 | 625 | 603 | 583 | 563 |
| 820 | 713 | 689 | 665 | 643 | 621 | 600 | 579 |
| 840 | 732 | 707 | 683 | 660 | 638 | 617 | 596 |
| 860 | 750 | 725 | 701 | 678 | 655 | 633 | 613 |
| 880 | 769 | 744 | 719 | 695 | 673 | 650 | 629 |
| 900 | 788 | 762 | 737 | 713 | 690 | 667 | 646 |
| 920 | 806 | 780 | 755 | 731 | 707 | 685 | 663 |
| 940 | 825 | 799 | 773 | 748 | 725 | 702 | 679 |
| 960 | 844 | 817 | 791 | 766 | 742 | 719 | 696 |
| 980 | 863 | 835 | 809 | 784 | 760 | 736 | 713 |

TABLE II (Cont'd)

MAXIMUM PERMISSIBLE BACKGROUND $\alpha = 0$, $P_\alpha = 50\%$

B

| G | n = 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|
| 1000 | 881 | 854 | 827 | 802 | 777 | 753 | 730 |
| 1200 | 1069 | 1039 | 1009 | 981 | 953 | 926 | 900 |
| 1400 | 1258 | 1225 | 1193 | 1161 | 1131 | 1101 | 1073 |
| 1600 | 1448 | 1412 | 1377 | 1343 | 1310 | 1278 | 1247 |
| 1800 | 1638 | 1600 | 1563 | 1527 | 1491 | 1457 | 1423 |
| 2000 | 1829 | 1789 | 1749 | 1710 | 1673 | 1636 | 1600 |
| 2200 | 2020 | 1978 | 1936 | 1895 | 1855 | 1816 | 1778 |
| 2400 | 2212 | 2167 | 2124 | 2081 | 2039 | 1998 | 1958 |
| 2600 | 2404 | 2357 | 2312 | 2267 | 2223 | 2180 | 2138 |
| 2800 | 2596 | 2548 | 2500 | 2453 | 2407 | 2363 | 2318 |
| 3000 | 2789 | 2738 | 2689 | 2640 | 2593 | 2546 | 2500 |
| 3200 | 2982 | 2929 | 2878 | 2828 | 2778 | 2730 | 2682 |
| 3400 | 3175 | 3121 | 3068 | 3016 | 2964 | 2914 | 2865 |
| 3600 | 3368 | 3312 | 3258 | 3204 | 3151 | 3099 | 3048 |
| 3800 | 3561 | 3504 | 3448 | 3392 | 3338 | 3284 | 3232 |
| 4000 | 3755 | 3696 | 3638 | 3581 | 3525 | 3470 | 3416 |
| 4200 | 3949 | 3888 | 3829 | 3770 | 3713 | 3656 | 3600 |
| 4400 | 4143 | 4081 | 4020 | 3960 | 3900 | 3842 | 3785 |
| 4600 | 4337 | 4273 | 4211 | 4149 | 4088 | 4029 | 3970 |
| 4800 | 4531 | 4466 | 4402 | 4339 | 4277 | 4216 | 4155 |
| 5000 | 4725 | 4659 | 4593 | 4529 | 4465 | 4403 | 4341 |
| 5200 | 4919 | 4852 | 4785 | 4719 | 4654 | 4590 | 4527 |
| 5400 | 5114 | 5045 | 4977 | 4910 | 4843 | 4778 | 4713 |
| 5600 | 5309 | 5238 | 5169 | 5100 | 5032 | 4966 | 4900 |
| 5800 | 5503 | 5432 | 5361 | 5291 | 5222 | 5154 | 5087 |
| 6000 | 5698 | 5625 | 5553 | 5482 | 5411 | 5342 | 5274 |
| 6200 | 5893 | 5819 | 5745 | 5673 | 5601 | 5531 | 5461 |
| 6400 | 6088 | 6012 | 5938 | 5864 | 5791 | 5719 | 5648 |
| 6600 | 6283 | 6206 | 6130 | 6055 | 5981 | 5908 | 5836 |
| 6800 | 6478 | 6400 | 6323 | 6247 | 6172 | 6097 | 6024 |
| 7000 | 6673 | 6594 | 6516 | 6438 | 6362 | 6286 | 6212 |
| 7200 | 6868 | 6788 | 6709 | 6630 | 6552 | 6476 | 6400 |
| 7400 | 7064 | 6982 | 6902 | 6822 | 6743 | 6665 | 6588 |
| 7600 | 7259 | 7176 | 7095 | 7014 | 6934 | 6855 | 6777 |
| 7800 | 7455 | 7371 | 7288 | 7206 | 7125 | 7045 | 6965 |
| 8000 | 7650 | 7565 | 7481 | 7398 | 7316 | 7234 | 7154 |
| 8200 | 7846 | 7760 | 7674 | 7590 | 7507 | 7425 | 7343 |
| 8400 | 8041 | 7954 | 7868 | 7782 | 7698 | 7615 | 7532 |
| 8600 | 8237 | 8149 | 8061 | 7975 | 7889 | 7805 | 7721 |
| 8800 | 8433 | 8343 | 8255 | 8167 | 8081 | 7995 | 7911 |
| 9000 | 8628 | 8538 | 8449 | 8360 | 8272 | 8186 | 8100 |
| 9200 | 8824 | 8733 | 8642 | 8553 | 8464 | 8376 | 8290 |
| 9400 | 9020 | 8928 | 8836 | 8745 | 8656 | 8567 | 8479 |
| 9600 | 9216 | 9122 | 9030 | 8938 | 8848 | 8758 | 8669 |
| 9800 | 9412 | 9317 | 9224 | 9131 | 9039 | 8949 | 8859 |

TABLE II (Cont'd)

MAXIMUM PERMISSIBLE BACKGROUND B  $\alpha = 1.3$, $P_\alpha = 90\%$

| G | n = 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|
| 100 | 57 | 51 | 46 | 42 | 38 | 34 | 31 |
| 120 | 72 | 65 | 59 | 54 | 49 | 45 | 41 |
| 140 | 87 | 80 | 73 | 67 | 62 | 57 | 52 |
| 160 | 103 | 95 | 87 | 81 | 75 | 69 | 64 |
| 180 | 119 | 110 | 102 | 95 | 88 | 81 | 76 |
| 200 | 135 | 126 | 117 | 109 | 101 | 94 | 88 |
| 220 | 151 | 141 | 132 | 123 | 115 | 107 | 100 |
| 240 | 168 | 157 | 147 | 138 | 129 | 121 | 113 |
| 260 | 185 | 173 | 163 | 153 | 143 | 135 | 127 |
| 280 | 201 | 189 | 178 | 168 | 158 | 149 | 140 |
| 300 | 218 | 206 | 194 | 183 | 172 | 163 | 154 |
| 320 | 235 | 222 | 210 | 198 | 187 | 177 | 167 |
| 340 | 252 | 239 | 226 | 214 | 202 | 191 | 181 |
| 360 | 270 | 255 | 242 | 229 | 217 | 206 | 196 |
| 380 | 287 | 272 | 258 | 245 | 233 | 221 | 210 |
| 400 | 304 | 289 | 275 | 261 | 248 | 236 | 224 |
| 420 | 322 | 306 | 291 | 277 | 263 | 251 | 239 |
| 440 | 339 | 323 | 308 | 293 | 279 | 266 | 254 |
| 460 | 357 | 340 | 324 | 309 | 295 | 281 | 268 |
| 480 | 374 | 357 | 341 | 325 | 311 | 297 | 283 |
| 500 | 392 | 374 | 357 | 342 | 326 | 312 | 298 |
| 520 | 409 | 391 | 374 | 358 | 342 | 327 | 313 |
| 540 | 427 | 409 | 391 | 374 | 358 | 343 | 329 |
| 560 | 445 | 426 | 408 | 391 | 374 | 359 | 344 |
| 580 | 463 | 443 | 425 | 407 | 391 | 375 | 359 |
| 600 | 480 | 461 | 442 | 424 | 407 | 390 | 375 |
| 620 | 498 | 478 | 459 | 441 | 423 | 406 | 390 |
| 640 | 516 | 496 | 476 | 457 | 439 | 422 | 406 |
| 660 | 534 | 513 | 493 | 474 | 456 | 438 | 421 |
| 680 | 552 | 531 | 511 | 491 | 472 | 454 | 437 |
| 700 | 570 | 549 | 528 | 508 | 489 | 470 | 453 |
| 720 | 588 | 566 | 545 | 525 | 505 | 487 | 469 |
| 740 | 606 | 584 | 562 | 542 | 522 | 503 | 485 |
| 760 | 624 | 602 | 580 | 559 | 539 | 519 | 500 |
| 780 | 642 | 619 | 597 | 576 | 555 | 535 | 516 |
| 800 | 660 | 637 | 614 | 593 | 572 | 552 | 532 |
| 820 | 679 | 655 | 632 | 610 | 589 | 568 | 549 |
| 840 | 697 | 673 | 649 | 627 | 605 | 585 | 565 |
| 860 | 715 | 690 | 667 | 644 | 622 | 601 | 581 |
| 880 | 733 | 708 | 684 | 661 | 639 | 618 | 597 |
| 900 | 751 | 726 | 702 | 679 | 656 | 634 | 613 |
| 920 | 770 | 744 | 720 | 696 | 673 | 651 | 630 |
| 940 | 788 | 762 | 737 | 713 | 690 | 668 | 646 |
| 960 | 806 | 780 | 755 | 731 | 707 | 684 | 662 |
| 980 | 824 | 798 | 773 | 748 | 724 | 701 | 679 |

TABLE II (Cont'd)

MAXIMUM PERMISSIBLE BACKGROUND $\alpha = 1.3$, $P_\alpha = 90\%$

| G | n = 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|
| 1000 | 843 | 816 | 790 | 765 | 741 | 718 | 695 |
| 1200 | 1027 | 997 | 968 | 940 | 913 | 887 | 861 |
| 1400 | 1212 | 1180 | 1148 | 1117 | 1088 | 1059 | 1030 |
| 1600 | 1398 | 1363 | 1329 | 1296 | 1264 | 1232 | 1201 |
| 1800 | 1586 | 1548 | 1512 | 1476 | 1441 | 1407 | 1374 |
| 2000 | 1773 | 1734 | 1695 | 1657 | 1620 | 1584 | 1548 |
| 2200 | 1962 | 1920 | 1879 | 1839 | 1800 | 1761 | 1724 |
| 2400 | 2151 | 2107 | 2064 | 2022 | 1980 | 1940 | 1900 |
| 2600 | 2340 | 2294 | 2249 | 2205 | 2162 | 2119 | 2078 |
| 2800 | 2530 | 2482 | 2435 | 2389 | 2344 | 2300 | 2256 |
| 3000 | 2720 | 2670 | 2622 | 2574 | 2527 | 2481 | 2435 |
| 3200 | 2911 | 2859 | 2808 | 2759 | 2710 | 2662 | 2615 |
| 3400 | 3101 | 3048 | 2996 | 2944 | 2894 | 2844 | 2795 |
| 3600 | 3292 | 3238 | 3183 | 3130 | 3078 | 3027 | 2976 |
| 3800 | 3484 | 3427 | 3371 | 3317 | 3263 | 3210 | 3158 |
| 4000 | 3675 | 3617 | 3560 | 3503 | 3448 | 3393 | 3340 |
| 4200 | 3867 | 3807 | 3748 | 3691 | 3634 | 3577 | 3522 |
| 4400 | 4059 | 3998 | 3937 | 3878 | 3819 | 3762 | 3705 |
| 4600 | 4251 | 4188 | 4126 | 4066 | 4006 | 3946 | 3888 |
| 4800 | 4443 | 4379 | 4316 | 4253 | 4192 | 4131 | 4072 |
| 5000 | 4636 | 4570 | 4505 | 4442 | 4379 | 4317 | 4256 |
| 5200 | 4828 | 4761 | 4695 | 4630 | 4566 | 4502 | 4440 |
| 5400 | 5021 | 4953 | 4885 | 4819 | 4753 | 4688 | 4624 |
| 5600 | 5214 | 5144 | 5075 | 5007 | 4940 | 4874 | 4809 |
| 5800 | 5407 | 5336 | 5266 | 5196 | 5128 | 5061 | 4994 |
| 6000 | 5600 | 5528 | 5456 | 5386 | 5316 | 5247 | 5180 |
| 6200 | 5793 | 5720 | 5647 | 5575 | 5504 | 5434 | 5365 |
| 6400 | 5987 | 5912 | 5838 | 5765 | 5692 | 5621 | 5551 |
| 6600 | 6180 | 6104 | 6029 | 5954 | 5881 | 5808 | 5737 |
| 6800 | 6373 | 6296 | 6220 | 6144 | 6070 | 5996 | 5923 |
| 7000 | 6567 | 6488 | 6411 | 6334 | 6258 | 6184 | 6110 |
| 7200 | 6761 | 6681 | 6602 | 6524 | 6447 | 6371 | 6296 |
| 7400 | 6955 | 6874 | 6794 | 6715 | 6636 | 6559 | 6483 |
| 7600 | 7148 | 7066 | 6985 | 6905 | 6826 | 6747 | 6670 |
| 7800 | 7342 | 7259 | 7177 | 7096 | 7015 | 6936 | 6857 |
| 8000 | 7536 | 7452 | 7369 | 7286 | 7205 | 7124 | 7044 |
| 8200 | 7731 | 7645 | 7561 | 7477 | 7394 | 7313 | 7232 |
| 8400 | 7925 | 7838 | 7753 | 7668 | 7584 | 7501 | 7419 |
| 8600 | 8119 | 8031 | 7945 | 7859 | 7774 | 7690 | 7607 |
| 8800 | 8313 | 8225 | 8137 | 8050 | 7964 | 7879 | 7795 |
| 9000 | 8508 | 8418 | 8329 | 8241 | 8154 | 8068 | 7983 |
| 9200 | 8702 | 8611 | 8521 | 8433 | 8345 | 8257 | 8171 |
| 9400 | 8897 | 8805 | 8714 | 8624 | 8535 | 8447 | 8360 |
| 9600 | 9091 | 8998 | 8906 | 8815 | 8725 | 8636 | 8548 |
| 9800 | 9286 | 9192 | 9099 | 9007 | 8916 | 8826 | 8737 |

## APPENDIX A

# PROCEDURE FOR TESTING SNM DOORWAY MONITORS FOR FUNCTIONAL PERFORMANCE

Doorway monitors should be tested by employing a test source of the same isotope of SNM the doorway monitor is used to detect as follows:

1. With the detection area unoccupied, measure and record background.

2. Determine alarm threshold T from Table I (see Appendix B).

3. Place a test source in the detection area of the doorway monitor. The test source should be such that the activity in the detection area slightly exceeds the T level.* The doorway monitor should go into an alarm condition if operating properly.

4. Remove test source to its original location and measure background once again. If the measurement of background taken immediately after the test varies by more than $2\sqrt{B}$ from the background taken before the test, the test should be repeated, for such a difference indicates nonrandom fluctuations of the background or equipment malfunction. The probability of such an occurrence due to the randomness of the background is less than 8%.

5. A calibration source (Appendix B) should be carried repeatedly to various places within the detection area of the doorway monitor in simulation of actual use to verify that the SNM can be detected everywhere within the detection area and to assure proper operation of treadle pads, beam-break, or similar devices if the doorway monitor is so equipped.

6. Doorway monitors used to search for concealed uranium-233 should be tested with each uranium purification run, but no more frequently than daily. The test source should be freshly purified uranium-233 (within four hours of removal of decay products).

*The test source may be improvised by partially shielding the calibration source.

## APPENDIX B

# PROCEDURE FOR DETERMINING MAXIMUM PERMISSIBLE BACKGROUND

Background should be measured over several workshifts to determine the setpoints for alarm threshold (with or without automatic background updating) to assure that normal operation will be minimally affected by alarms due to high background.

The doorway monitor should be calibrated with the amount of the appropriate isotope specified in Regulatory Positions C.1.b(1), (2), or (3) of this guide (e.g., 0.5 gram plutonium-239 in 3 mm of brass).

The calibration procedure described below is essentially a means of determining maximum permissible background for effective operation of the doorway monitor.

1. Place a calibration source variously about the detection area and take readings to determine the least sensitive point. This location of minimum sensitivity should be maintained as the calibration point.

2. Measure background over several workshifts to determine the periods of high background and the range of background. A minimum of 20 measurements should be taken. The variance of the background is given by

$$\text{Var } B = \frac{1}{N-1} \sum_{i=1}^{N} (B_i - B)^2 \qquad (1)$$

where N is the number of measurements, B is the mean of the background measurements, and $B_i$ is the $i^{th}$ background measurement.

3. With the calibration source at the calibration point, the mean gross counts G should be determined during a period of high background to establish the upper operating range of the doorway monitor. Table II lists various maximum permissible background levels for a given value of G for values of the parameters n and $\alpha$. During periods when the background exceeds the value found from Table II, the sensitivity of the doorway monitor will generally be below that specified as minimum in Regulatory Position C.1.b of this guide.

The parameter n is a function of the background variation and the permissible false alarm rate and is calculated from

$$n \geq 3.1 \left( \frac{\text{Var } B}{B} \right)^{1/2} \qquad (2)$$

Generally, n is taken as an integer. If n satisfies the above expression, the expected false alarm rate (Appendix C) due to background fluctuations should be less than 0.1%. Larger values of n will decrease the expected false alarm rate; however, the maximum allowable background for a given G will also decrease.

4. For doorway monitors equipped with automatic background updating systems, the alarm threshold is

$$\text{Counts} > B + n\sqrt{B}, \qquad (3)$$

where n should be derived from expression (2), and the instrument set accordingly.

5. The high-background alarm should be set at the B value given in Table II for the measured G and calculated n values.

6. For doorway monitors not equipped with an automatic background update, the value of n determined above should be employed in the use of the doorway monitor according to Regulatory Position C.2.a.

*The false alarm rate is estimated by the probability that an observation of a quantity distributed normally about some value X will exceed X by n(Std. deviation of X). The factor 3.1 limits the false alarm rate to 0.1%, while the factor $(\text{Var } B/B)^{1/2}$ compensates for observed deviations in the background distribution from Poisson.

## APPENDIX C

# DETECTION CONFIDENCE LIMITS, THRESHOLDS, AND MAXIMUM PERMISSIBLE BACKGROUND

With a calibration source at the calibration point, the condition for an alarm is, in general,

$$g > T = B + m\sqrt{\text{Var } B} \tag{1}$$

where g is a single measurement of G (the mean radiation level with the source), B is the mean background, and m is some multiplier. The detection confidence limit is the probability that with the calibraiton source at the calibration point, any single determination of G will exceed a threshold T, i.e., the above inequality will be satisfied. For any given probability $P_\alpha$, there exists a value $\alpha$ such that

$$g > G - \alpha\sqrt{\text{Var } G} \tag{2}$$

with a probability of $P_\alpha$, where g is any single measurement of the quantity G. Hence the condition for a detection confidence limit of $P_\alpha$ is

$$G - \alpha\sqrt{\text{Var } G} > T = B + m\sqrt{\text{Var } B}. \tag{3}$$

For a given value of G, solving (3) gives the maximum permissible B at which the doorway monitor will detect the source with a confidence $P_\alpha$. For $P_\alpha = 90\%$, $\alpha = 1.3$, and for $P_\alpha = 50\%$, $\alpha = 0$.

The condition for a false alarm* is written as

$$b = B + \beta\sqrt{\text{Var } B} > T \tag{4}$$

where b is a single measurement without the source and $\beta$ is a number corresponding to a false alarm probability $P_\beta$. For $P_\beta = 0.1\%$, $\beta = 3.1$. Hence the necessary condition for maintaining a false alarm rate below $P_\beta$ is

$$b = B + \beta\sqrt{\text{Var } B} < B + m\sqrt{\text{Var } B}. \tag{5}$$

However, the doorway monitor actually compares b with $B + n\sqrt{B}$, hence the condition on n becomes

$$\beta\sqrt{\text{Var } B} < m\sqrt{\text{Var } B} = n\sqrt{B} \tag{6}$$

or

$$n > \beta \left(\frac{\text{Var } B}{B}\right)^{1/2} \tag{7}$$

In Table I threshold values of T were determined by substituting equation (6) into equation (3):

$$T = B + n\sqrt{B}$$

The values of B in Table II were then calculated for $\alpha = 1.3$ and $\alpha = 0$ from equation (3) assuming that, for the determination of G, the background should be reasonably stable and therefore $\sqrt{\text{Var } G} \sim \sqrt{G}$.

*False alarm means an alarm condition generated by statistical fluctuations in the background radiation or by instabilities of the electronics which appear as background fluctuations when the detection area is occupied.