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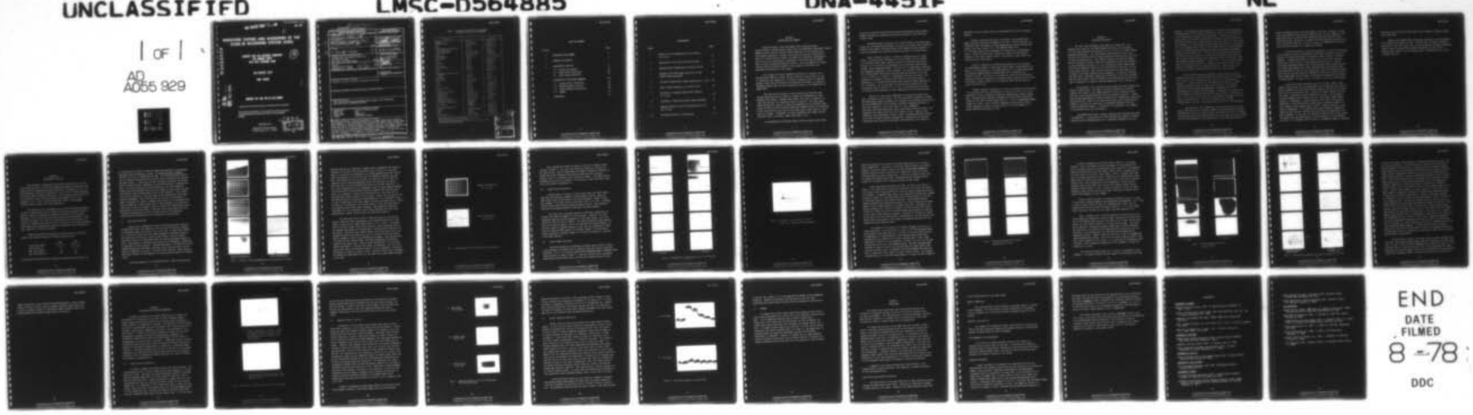

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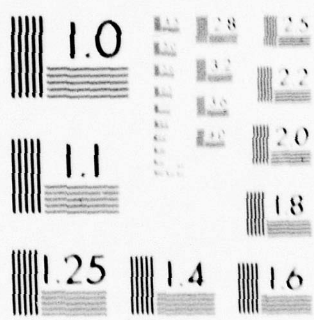

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RADIATION TESTING AND HARDENING OF THE CLOSE-IN RECORDING SYSTEM (CIRS)

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LOCKHEED PALO ALTO RESEARCH LABORATORY
3251 HANOVER STREET
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The relative merits, including sensitivity to normal tunnel-alcove radiation environments, of two alternative Close-In Recording System (CIRS) concepts have been evaluated. Radiation hardened versions of the 7912 and 519/SIT vidicon have been tested in the laboratory, at levels simulating environments encountered in the field. An optimized CIRS configuration, utilizing a hardened 7912, operates properly at the highest levels used, namely 2.5 - 3 rad absorbed dose. The 519 oscilloscope, by comparison, malfunctions at about 0.1 rad and the SIT vidicon at about 10 mrad, both due to direct target excitation.

Table 1. Conversion factors for U.S. customary to metric (SI) units of measurement.

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter^2 (m^2)	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
calorie (thermochemical)	joule (J)	4.184 000
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
curie	giga becquerel (GBq)*	3.700 000 X E +1
degree (angle)	radian (rad)	1.745 329 X E -2
degree Fahrenheit	degree kelvin (K)	$t_K = (t° f + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule/kilogram (J/kg) (radiation dose absorbed)	Gray (Gy)**	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m^2 (N-s/m^2)	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mil	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.834 952 X E -2
pound-force (lbf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 268 X E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	4.214 011 X E -2
pound-mass/foot^3	kilogram/meter^3 (kg/m^3)	1.601 846 X E +1
rad (radiation dose absorbed)	Gray (Gy)**	1.000 000 X E -2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -1

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society for Testing and Materials.

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ILLUSTRATIONS

SECTION 1
INTRODUCTION AND SUMMARY

This Final Report covers development work accomplished under addition P00004 to Defense Nuclear Agency Test Instrumentation Development Contract DNA001-76-C-0132 with the Nuclear Sciences Laboratory at the Lockheed Palo Alto Research Laboratory. Previous work under the contract was reported by means of a Project Officer's Report for MIGHTY EPIC (POR 6956, LMSC-D536649), which covers field developmental experiments on both HUSKY PUP and MIGHTY EPIC, as well as supporting laboratory effort. Since the P00004 work follows directly from the previous results, a brief summary of POR 6956 is an appropriate introduction to this report.

The original objective of DNA001-76-C-0132 was to evaluate the X-Ray Multiplier (XRM) as a faster and more sensitive x-ray detector for use in underground test diagnostics. In order to properly record the expected signals, faster and more sensitive data handling was needed, so a Close-In Recording System (CIRS) was also developed and tested on both HUSKY PUP and MIGHTY EPIC.

The CIRS concept consists of scan conversion and temporary data storage underground near the detector location and transmission in lower bandwidth form (namely, standard video format) over about 1 kilometer to a video tape recorder in a recording trailer on the mesa. The video transmission produces no risetime or amplitude degradation of the original input pulse, so that the total recording system gain-bandwidth product is determined by the scan converter input (plus a very short cable) rather than by a long cable to the mesa. Furthermore, the lower bandwidth video signal requires only RG213 cable to the mesa, rather than RG331 or 333.

An intermediate step has been taken by DNA on several recent tests, by the use of Recorder and Oscilloscope Sealed Environmental System (ROSES) chambers underground, separated from typical detectors by some 300 meters of RG331 cable.

The ROSES system has proved to be a viable method of recording underground, but the additional performance (as well as convenience and flexibility) available from smaller individual-channel CIRS chambers located adjacent to close-in experiments has justified continued interest in the CIRS concept.

Typical figures of merit, in terms of resolvable detector charge within a recording system risetime, are 5 pico Coulombs (0.8 ns risetime x 6 ma typical design center detector current) for CIRS recording versus 60 pcoul (1.5 ns x 40 ma) for transmission to an equivalent oscilloscope through 1 km of compensated RG333. This factor of 12 improvement represents the fundamental advantage of CIRS recording. The equivalent figure of merit for a typical ROSES installation using the same oscilloscope is 22 pcoul (1.1 ns x 20 ma), or a factor of 3 improvement over mesa recording. This comparison has assumed a Tektronix 7A19 vertical oscilloscope plug-in, operating at 0.1 volts/div with design center predicted signal amplitude set for 3 divisions. So, in each case, the design center deflection at the oscilloscope requires $300 \text{ mV} \div 50\ \Omega = 6$ ma. The larger detector currents of 20 and 40 ma are required for cable compensation to the risetimes given.

Section 2 of this report summarizes the previously-reported CIRS work, including two field trials. The first preliminary experiment on HUSKY PUP demonstrated overall feasibility and verified our performance expectations. The second MIGHTY EPIC trial revealed a radiation background problem at a dose level estimated to be of the order of 1 rad. Subsequent laboratory tests using simulation sources gave almost identical results, and pinpointed the trouble within the 7912 cathode ray tube. Based on this experience, some reevaluation seemed in order, including additional testing of the 7912 in pulsed radiation environments, consideration of potential engineering fixes within the instrument, and evaluation of the results in comparison to other possible ways of accomplishing the close-in recording function.

Section 3 describes the bulk of the effort to be reported here, namely radiation testing and hardening of the 7912. Proper operation of a "radiation fixed" instrument has been demonstrated up to and including the highest level used, namely 2.5 - 3 rad absorbed dose, which is of the same order as the background level expected in an underground alcove. We have not been able to define the higher-level malfunction threshold of the final "fixed" version, only because of time, effort and simulator machine limitations.

Section 4 describes the testing and evaluation of one alternate recording method, namely an intensified vidicon camera "photographing" the face of a 519 oscilloscope. The scheme works well in a benign environment and achieves somewhat greater writing speed than is available with Polaroid 410 film. But both the 519 cathode ray tube and the intensified vidicon are much more sensitive to background gamma radiation than the 7912; the former by about a factor of 10 in radiation level and the latter by about a factor of 100.

Finally, Section 5 summarizes the tunnel survivability specifications of the hardened CIRS-7912 configuration as tested and proven by our total experience to date, including the radiation hardening and testing reported here. Pending further laboratory demonstration (and possible additional fixing) of the 7912 at levels higher than 2.5 - 3 rad, a conservative safety margin of a factor of ten or more in background can be achieved rather easily underground, either by proper location of the CIRS chamber or by modest additional shielding, or both.

SECTION 2
PREVIOUS CIRS RESULTS

The first field experiment using CIRS was on HUSKY PUP. Two chambers were located in the LPARL diagnostics alcove, each consisting of a 7912 scan conversion oscilloscope in a 0.46 x 0.97 x 1.07 meter sealed aluminum shielding box. The oscilloscopes (and detectors as well) were insulated and shielded from all tunnel grounds and received their power from the mesa recording trailer. Both channels produced the expected signals. One was recording the output from a fast avalanche detector, and displayed an overall measured risetime of 0.75 ns, indicating a better-than-average 7A19 vertical amplifier plug-in for the 7912 (which is rated at 0.8 ns for a step function input). The recorded intensities were quite high, but not so high as to preclude reading the data adequately. We were not surprised with this since a systematic temperature coefficient for the 7912 intensity had been noted preshot; and the intensities had deliberately been set quite high to compensate for possible late-time temperature rise in the alcove.

On the basis of this successful first attempt four CIRS channels were fielded on MIGHTY EPIC. Once again, individual insulated and isolated chambers were located in the LPARL diagnostics alcove, recording outputs from fast scintillator-photodiodes and x-ray multiplier detectors. Several small design improvements were made, including better temperature control and superposition of dc power on the single video output cable connecting each chamber to the mesa, but there were no fundamental departures from the successful HUSKY PUP design. In particular, the placement of the chambers in the shielded alcove was very similar.

The MIGHTY EPIC results, however, appeared much different than those from HUSKY PUP. In particular, the video playbacks were found to be almost completely white indicating some sort of systematic blooming on all four channels. The blooming was more complete to the right on all photographs, correlating with the 7912 electronic graticule, which is written from right to left immediately following each sweep trace. In each case, the first partial video field showed the characteristic angle of graticule onset but was entirely white to the right below the onset line and to the left showed some evidence of a normal intensity sweep trace above the line. Unfortunately, on all channels the position of the reading beam at zero time happened to be such that subsequent blooming obliterated the original (presumably normally written) sweep trace. The full-picture brightness persisted for the usual 5-6 fields required to replace the CRT matrix charge, decaying away in rather normal fashion; thus suggesting a strictly transient rather than permanent damage phenomenon. In fact, one of the tape records showed that #3 oscilloscope happened to retrigger on some noise at about + 400 millisec, presumably due to ground shock effects. That late-time noise trace was of perfectly normal intensity, both trace and graticule.

Our post-event laboratory evaluation started with the tentative hypothesis that the transient blooming may have been caused by the gamma ray level in the alcove acting directly on some part of the oscilloscope circuitry. A crude calculation of the expected dose behind our rather massive shielding wall gave an upper limit of about 1 rad (carbon), and the high energy background measurement associated with our F^2 experiment gave an almost identical number. Fortunately our Febetron 706 x-ray simulator can produce such levels in single pulses of 200-300 keV x rays, 2-3 ns wide; so one of the 7912 oscilloscopes was exposed at various levels from the Febetron. At a level of about 1 rad, the same blooming effect was seen, reproducing almost exactly the field phenomenon.

This laboratory result immediately raised the question of why the earlier CIRS data were not similarly masked by radiation-induced blooming. The HUSKY PUP records were quite bright, particularly for the first frames, but the intensities had deliberately been set quite high to allow for fading if the alcove temperature rose significantly; and it had been possible to extract satisfactory data from later frames of the video. However, a closer look at the HUSKY PUP tape records showed that they too were brighter to the right than the left on the records, indicating the same correlation with graticule writing. Therefore, it appears that CIRS radiation sensitivity was also a problem on HUSKY PUP, but not so severe as on MIGHTY EPIC; and was at least partially mistaken for a temperature problem.

It was also possible to localize the problem in the 7912 oscilloscope in the postshot testing by collimating the Febetron x-ray beam to about 1 cm diameter and exploring through the instrument volume looking for sensitive elements. Triangulation showed the source to be in the cathode ray tube writing gun, in the vicinity of the intensity grid structure. Further electrical exploration showed that the grid structure can be driven positive in a pulsed high energy photon field, decreasing the grid-cathode holdoff bias sufficiently to turn on the writing beam. This "on" condition persists until the grid coupling capacitor recharges to beam cutoff voltage from the high voltage supply so the duration of blooming is determined by the degree of charge removed. At about 1 rad, this takes a few tens of milliseconds.

A more interesting observation was that the onset, namely charge removal from the grid, was not instantaneous on a millisecond time scale, as would be expected for direct photoelectron emission from the grid structure into the 10 kV accelerating field. Instead, the charge removal took place over almost a millisecond, which seemed much too long to be explained by electron transient time in vacuum, even in a badly space charge limited condition. Furthermore, a rough calculation of the direct photoelectric sensitivity of the grid structure (using typical calibration numbers for x-ray diodes at high energies) gave too small a charge released, by a few orders of magnitude. So it appeared that charge leakage or migration on insulators was involved, from both the duration and the magnitude of the effect observed. In any case, the radiation sensitivity was clearly inside the cathode ray tube rather than on its outer surface or in the external circuitry. So it appeared that any direct or fundamental change to eliminate the source of the difficulty would involve some redesign or material change in the CRT itself.

Based on this MIGHTY EPIC and post-test experience, some reevaluation of the CIRS concept seemed in order. In particular, the overall radiation sensitivity of the 7912 needed to be further documented, potential engineering fixes to raise its malfunction threshold considered, and the results evaluated with respect to other possible ways of accomplishing the close-in recording function.

SECTION 3
EVALUATION OF THE 7912

Our philosophy in evaluating the radiation sensitivity of the 7912 oscilloscope has been to record its' response when exposed to pulses of high energy x-rays at progressively higher intensities, attempting to "fix" or at least understand each mode of malfunction as it occurs, and then proceeding to the next higher threshold malfunction. Three separate sensitivities have been identified, with thresholds ranging from somewhat below 0.1 rad (carbon) to 2.5 - 3 rad. All three have been "fixed" to the highest radiation levels we have used in the laboratory.

Two individual 7912 instruments were used (S/N B150529 and B010166), in order to develop some feel for generic versus detail-dependent effects. Results indicated no substantial differences (within this very limited sampling), so we conclude that the modes observed are characteristic of the overall 7912 design. The tests were conducted with the oscilloscope in an electrical configuration which was close to that used in the field, including video output mode, similar sweep speeds and intensities, and recording the fast output from a field-like detector.

Radiation testing has been done with Febetron models 705 and 706 pulsed x-ray machines having the following characteristics:

	706	705
X-ray energy (MeV)	0.2 - 0.5	0.8 - 2.0
Pulse width (ns)	2-3	30 - 40
Max. Dose (rad)(c)	2	4
Max. Rate (rad/sec)	10^6	10^5

Dose levels were measured with a standard scintillator-diode detector, so

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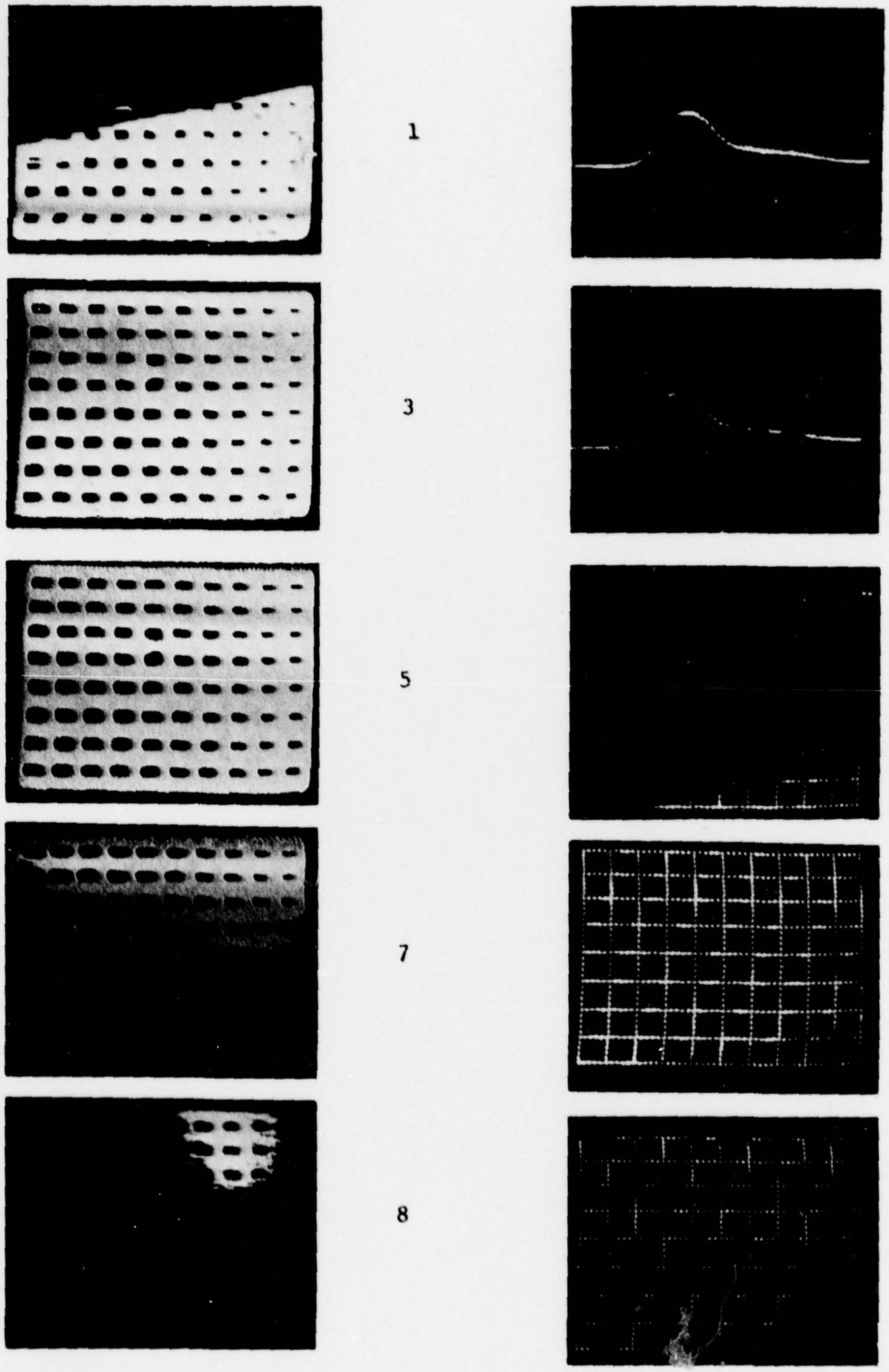
all intensities are given in terms of energy dose deposited in scintillator material, which is essentially carbon. At these high photon energies, the dose in silicon is essentially the same. The two machines were used in order to observe any possible effects due to their different photon energies and pulse widths. In particular, we were interested in whether the various modes of malfunction were responding to total dose absorbed or maximum dose rate. All tests showed that we were dealing with total dose dependent (rather than rate dependent) effects in this range of pulse widths, and that the different photon energies made little if any difference. This insensitivity was as expected, so that data from the two machines were used somewhat interchangeably. Most results came from the 706, just because it is smaller and easier to operate. Geometry with respect to the divergent x-ray flux was important in these tests, since it was necessary to use positions quite close to the x-ray target in order to achieve the required dose levels, particularly with the 706 source. Therefore, the levels quoted were often obtained by interpolation to get the correct value at the particular location which was responsible for the malfunction being studied.

3.1 Writing Gun Blooming

Initial tests confirmed the graticule blooming previously observed on MIGHTY EPIC and in the laboratory. The pictures on the left in Figure 1 are individual video fields after a shot at 0.3 rad. In this case, fields 1, 3, 5, 7 and 8 are shown, since the others displayed intermediate behavior. The video scan is from top to bottom on each picture, and (as observed previously) there is no disturbance until the graticule generator begins to write. That portion of the sweep trace which is not subsequently obliterated by blooming is written normally. Detailed measurement of the CRT grid circuit waveform during this time shows a relatively slow rise over about 1 ms and return to quiescent in a few ms. The graticule is affected, rather than the main sweep, because the CRT happens to be writing graticule when the blooming occurs.

From the standpoint of an engineering "fix" to make this particular

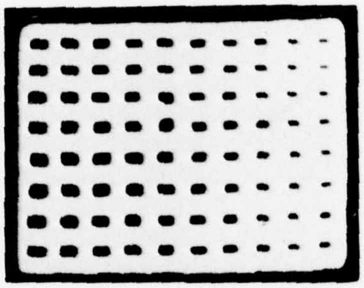


Without Circumvention With Circumvention

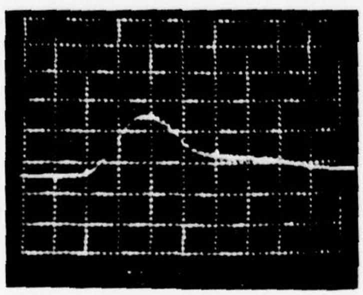
Fig. 1 Effect of 35 ms Circumvention on 7912 Output, at 0.3 rad.

radiation sensitivity unimportant (compared with a fundamental CRT change to eliminate it) the slow rise and relatively rapid recovery are fortuitous. There is no need for the instrument to be doing anything during this period, since the graticule can be written after the radiation transient has gone away. More generally, the fix is merely to disable the CRT for some circumvention period starting immediately after the data trace is written. This turns out to be quite feasible and solves the problem completely. In fact, the circumvention can be accomplished by any of three separate methods, all derived from a 35 ms one-shot flip-flop triggered from the sweep gate. First, it is adequate to merely delay the graticule so that there are no intensification pulses during the 35 ms period. Second, one can gate off the CRT intensity grid by driving the Z-axis amplifier to its saturation limit, so that it would take a very large signal to produce any beam current. Third, the beam can be deflected off the target matrix, so that any beam current which appears cannot cause target blooming. Each method was separately successful, but to be absolutely sure we have superposed all three, thus guaranteeing a complete lockout during the radiation transient.

The right hand side of Figure 1 shows the effect of this circumvention, under the same circumstances as the bloomed pictures on the left, except in this case the figure shows fields 1, 2, 3, 4 and 5. The signal trace is written cleanly, both because the grid circuit transient has not yet appeared and because the writing beam is already turned on hard for the fast sweep. During the next complete frame of the video scan (33 ms), two redundant fields of the sweep trace only are recorded, while the writing beam is disabled so that no new information can appear. Then the graticule is written for two or more fields, with some superposition of whatever remains of the sweep trace. Figure 2 shows the addition of all of these fields from Figure 1, both with and without circumvention. For all of the data we have taken, the dead-time length of 35 ms is adequate to allow the writing gun to return to normal; in fact, a shorter period would be adequate. But having two undisturbed fields of the signal trace alone seems desirable in any case.



Without Circumvention
at 0.3 rad.



With Circumvention
at 0.3 rad.

Fig. 2 Superposition of the Video Fields from Figure 1.

This circumvention scheme continues to work well at higher levels, as shown in Figure 3. The first five fields are shown, but at levels of 0.65 and 0.8 rad. There is absolutely no evidence of graticule blooming, at levels which would otherwise have produced completely white pictures. However, there is a different effect starting to appear: the slight general blooming at the top left in Figure 3 is from direct target excitation, which will be discussed in paragraph 3.3.

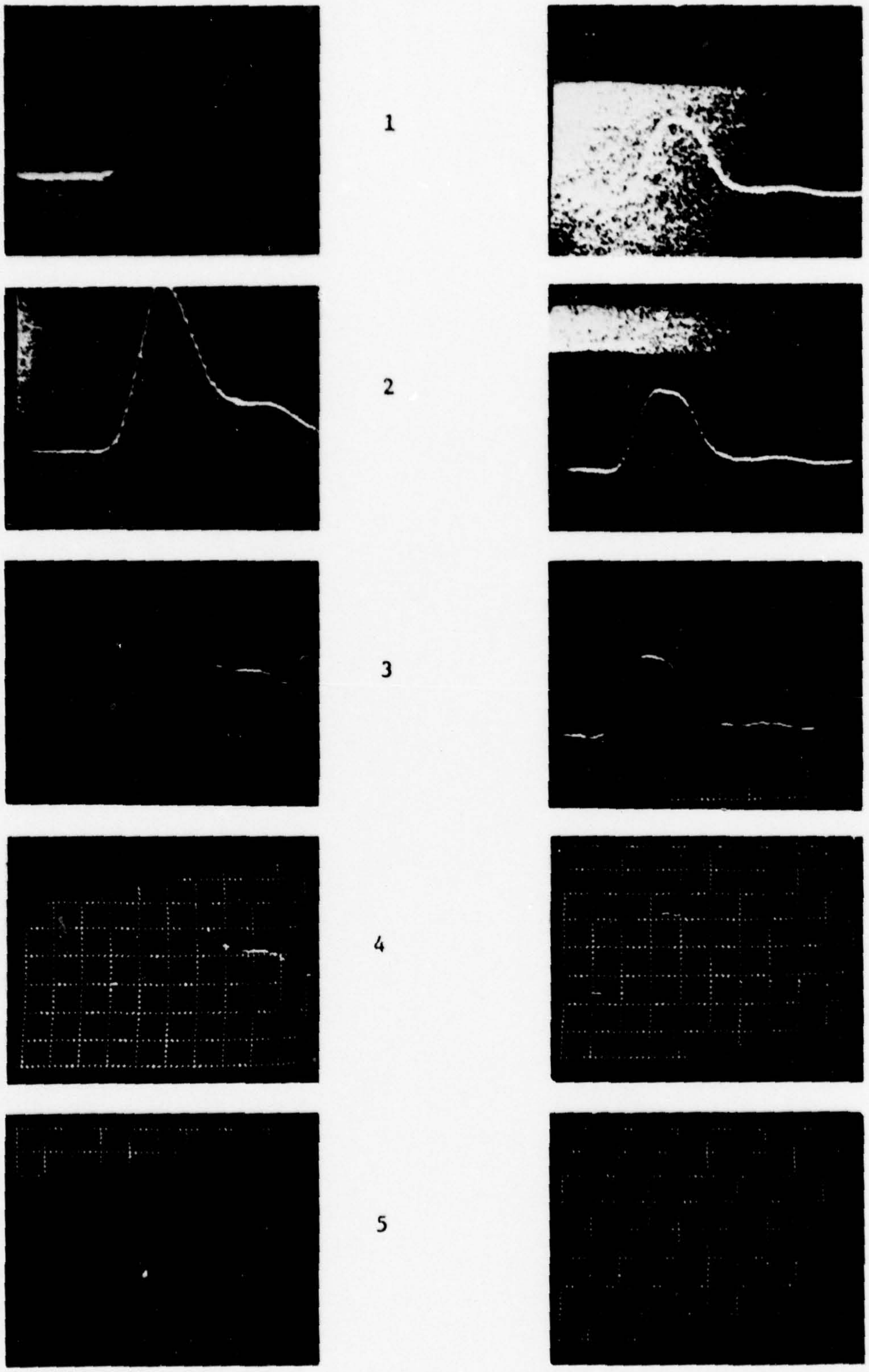
3.2 Sweep Circuit Sensitivity

Another feature of Figure 3 is that those shots were taken using a relatively new Tektronix redesign of the horizontal plug-in, namely the 7B80, rather than the 7B70 which we had used previously. Figure 4 shows what happens to the 7B70, even at a much lower level of 0.2 rad. The sweep circuit turns around and goes backward during the pulse. Four individual 7B70 units all behaved similarly, with about the same threshold.

The 7B70 is now considered obsolete by Tektronix, having been replaced by the 7B80 (presumably for other reasons). Similarly, the 7B92 horizontal plug-in has been superseded by a new 7B92A design. So we also tested one 7B80 unit and two 7B92A's. All showed perfectly normal behavior, not only as shown in Figure 3 but at all levels which we have achieved. We have not looked for detailed behavior in the 7B70, nor attempted any fixes, since the 7B80 and 7B92A appear to be already "fixed". But three units hardly constitute an adequate sample, so it would be desirable to test more of the newer plug-ins.

3.3 Direct Target Excitation

With the writing gun circumvention and newer sweep circuit in place, it was possible to proceed upward in radiation level and look for other malfunctions. At 0.6 - 0.8 rad, an overall white background began to appear on the target readout, as shown in Figure 3. This was a prompt effect, apparently simultaneous with the sweep trace, and was most pronounced when the x-ray



1 1

2 2

3 3

4 4

5 5

0.65 rad 0.8 rad

Fig. 3 Response With Circumvention at 0.65 and 0.8 rad.

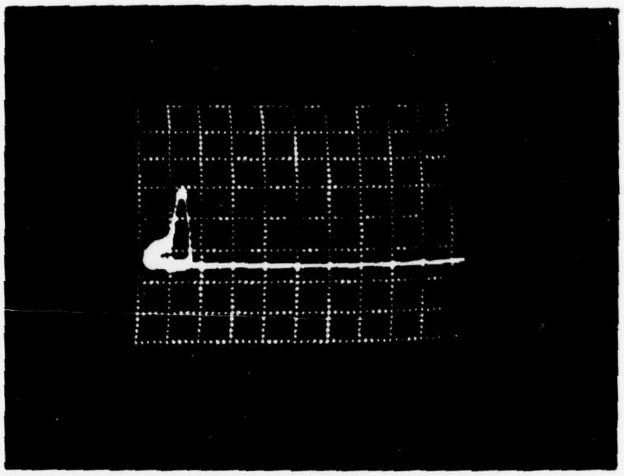


Fig. 4 Response of the 7B70 Sweep Circuit at 0.2 rad. (Video fields superposed.)

beam was directed in the vicinity of the CRT target matrix (or its nearby video preamplifier). The nature of the effect further defined the sensitive element as the matrix itself, since at 0.8 rad the whitening disappeared abruptly exactly one video field after the sweep trace, when the reading beam had scanned the entire target once. A variety of detailed tests, such as varying the reading beam current, confirmed that the reading beam was wiping off an overall level of radiation-induced target charge.

A more interesting observation was that, at least at the level of Figure 3, the target was not saturated or disabled by the direct excitation; the original sweep trace persisted after even the whitest background portions were removed. At somewhat high levels, this superposition became more evident, as shown in Figure 5. The writing beam trace is merely added to an overall dc background caused by the incident radiation. The radiation-induced Compton electrons look essentially identical to 10 keV writing gun electrons, except for their number density; the target stores both. Fortunately, the target thickness (10 μ meters) is optimum for 10 keV electrons and a small fraction of a mean free path for the much higher energy Compton secondaries, so that quite a high radiation intensity is required to saturate the target. At any lower level, the charge density corresponding to the writing gun trace should still be extractable, even though the background may make the first reading beam scan completely white.

An estimate of the charge to be expected confirms this picture of target excitation. At a dose level of 1 rad, 4×10^{10} electron-hole pairs are produced in the target mass of 2.5 mg (at 3.6 electron volts per pair), corresponding to 6 ncoul deposited on the reverse-biased diode matrix. Assuming the 10 μm substate to be totally depleted gives a total target capacitance of about 1 nf, and therefore a decrease of 6 volts in the diode reverse bias due to the 1 rad radiation pulse. The total quiescent bias available is about 12 volts, so we conclude that the target should reach zero bias at about 2 rad. In addition, the 300 nA reading beam should be able to replace the lost charge of 6 ncoul in about 20 msec. The observed recharge time at 1.3 rad is one video field, or 17 msec, as seen in Figure 5.

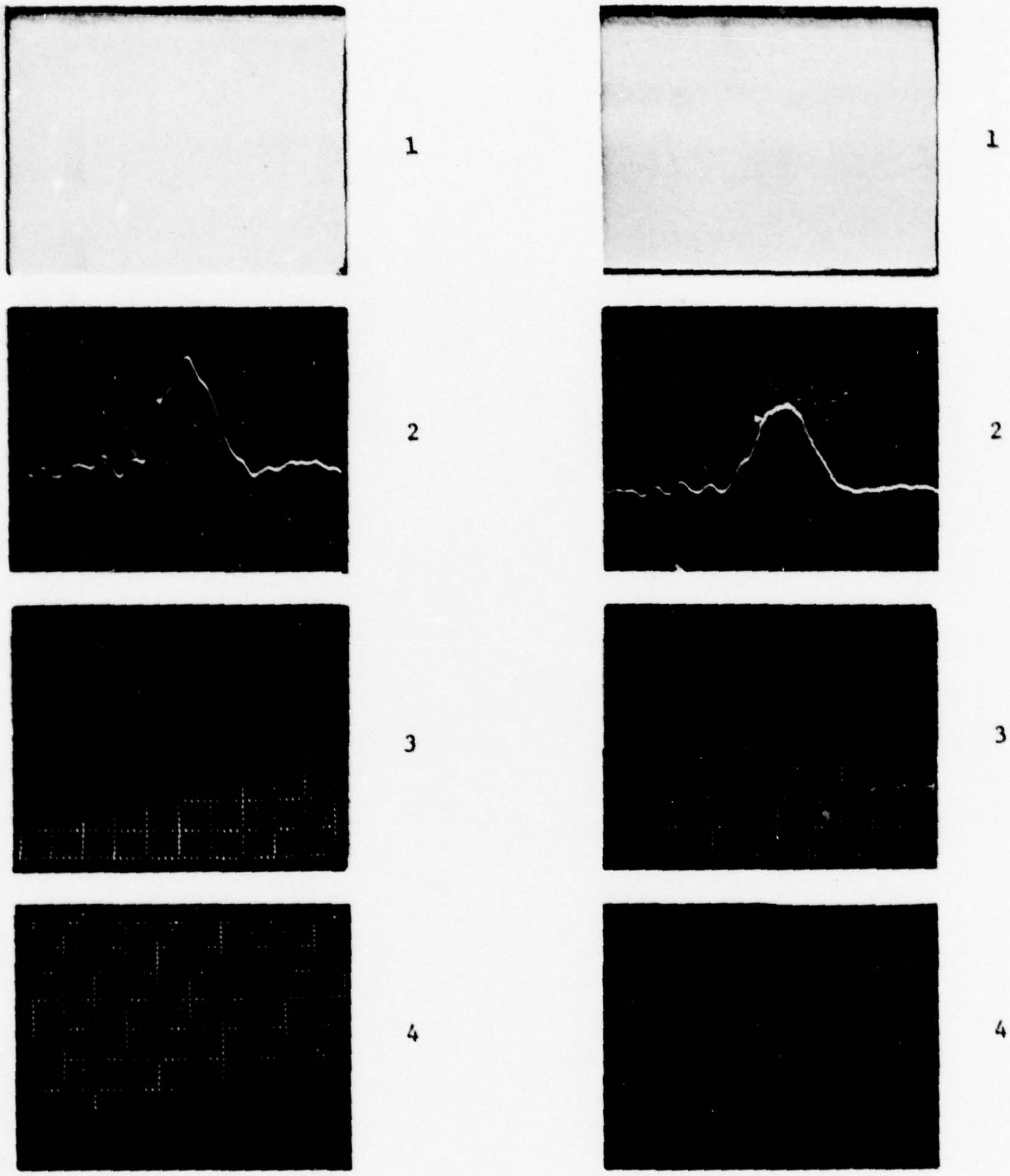


Fig. 5 Two Shots Showing Direct Target Excitation at 1.3 rad.

We were encouraged by the results shown in Figure 5, in several respects. First, the almost-fortuitous agreement with calculations from first principles indicated a qualitatively-correct picture of the phenomenon. Second, indications were that even higher levels could be tolerated before the trace could not be read in later frames. Third, it appeared that some sort of automatic-gain-control type of feedback to the reading beam voltage might allow the video output signal to ride on top of the overall radiation-induced level, thus suppressing the white background. Fourth, such an automatic gain control would also cope with and suppress normal voltage-dependent target leakage, so that it might be possible to raise the target charging voltage and thus achieve ever higher background saturation levels without being swamped by diode leakage.

Figure 6 shows the result of raising the radiation level to 2.5 and 3.3 rad, with no further change in the oscilloscope configuration. At 2.5 rad, it took two video fields to remove the background white level, and the original trace was just barely discernible thereafter. At 3.3 rad, almost three fields were required, and the signal trace was completely lost.

Next, a feedback loop of limited bandwidth was added between video output signal and reading gun cathode voltage, operating in the direction to cut off the reading beam current to the target for any slowly varying video output, but allow rapid variations to be read without change. The result was as expected: progressively higher feedback gain settings suppressed more and more of the overall white background while leaving the trace and graticule. At an optimum gain, the radiation-induced background was suppressed entirely. Figure 7 shows the effect at 2.5 rad, for optimum and almost-optimum gain settings. The first four video fields are shown in each case, plus a composite of all fields. It is clear that the background shown in Figure 6 can be completely suppressed by this technique, at least for levels up to 2.5 rad.

The radiaticn-induced charge is, of course, not eliminated by the feedback. It is merely removed from the target at a sufficiently slow rate

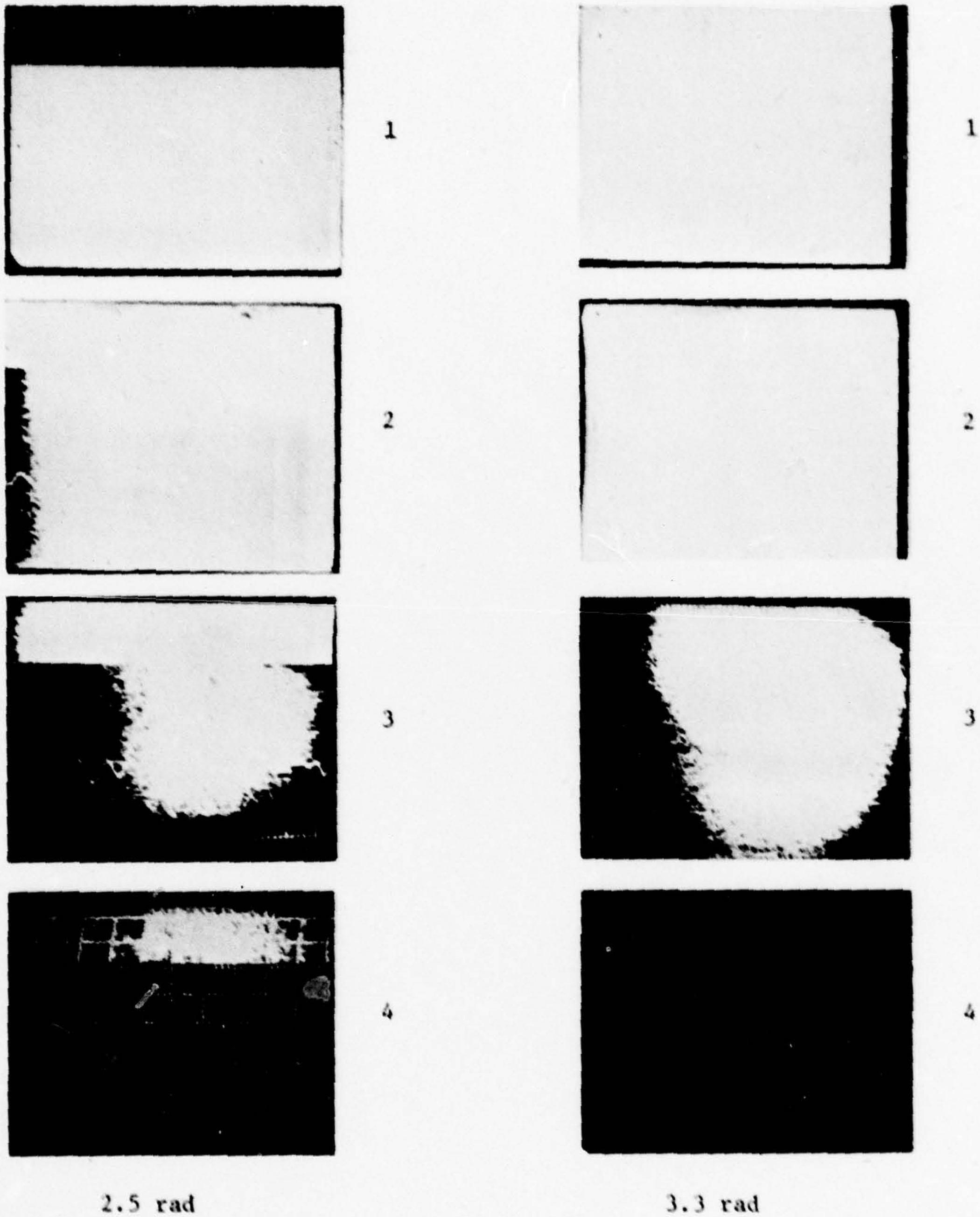


Fig. 6 Direct Target Excitation at 2.5 and 3.3 rad.

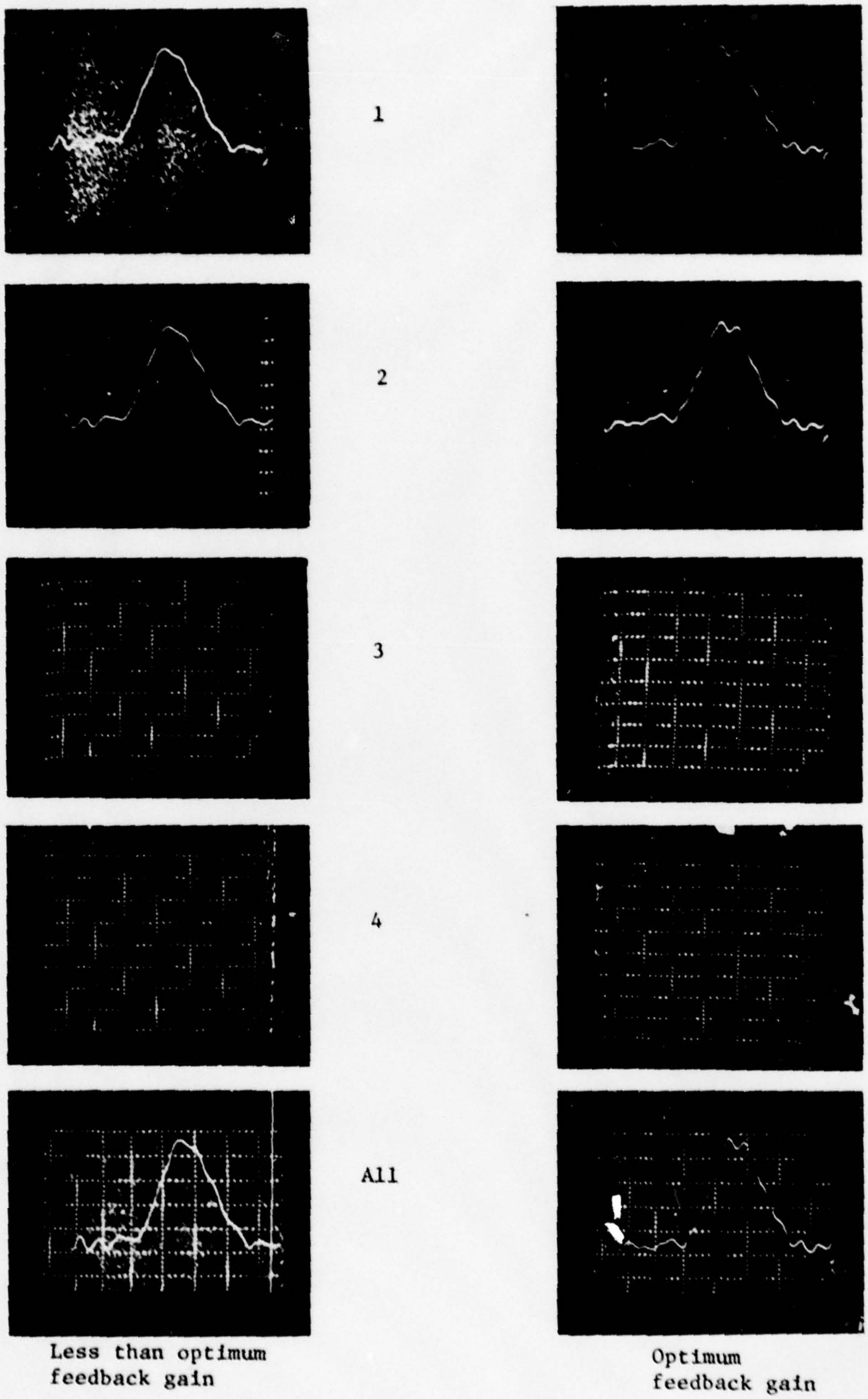


Fig. 7 The Effect of Automatic Gain-Control Feedback at 2.5 rad.

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so that the resultant video intensity is negligible compared with that from the trace and graticule. The slow recovery to pre-shot bias conditions is quite acceptable for single-shot or low-repetition-rate transient signals, particularly since the slow recharge should effectively eliminate the direct target radiation background problem up to some level which discharges the target diodes completely, leaving no additional modulation from the writing beam. This target saturation level is determined by the quiescent reading beam voltage, prior to the writing beam signal; so from the standpoint of radiation resistance it would be desirable to increase the reading gun electron energy as much as possible in order to store maximum charge on the target. However, diode leakage is a rapid function of reverse bias, and under normal circumstances can produce an overall white background similar to that which we observe from radiation. Therefore, Tektronix specifies the target bias for each cathode ray tube individually, using a criterion of 15 nA leakage at 30°C. But with the feedback which we have incorporated, leakage background is suppressed along with the radiation background. Therefore, in this case the only limit on target bias is actual punch-through voltage, rather than leakage current as such. One merely allows the reading beam voltage (and therefore the target bias) to rise until the dc leakage reaches some acceptable value corresponding to discernible but not objectionable whitening, and servo controls at that point. Radiation backgrounds (as well as temperature variations) will then be treated as perturbations, and the circuitry will adjust reading beam voltage to compensate and hold the video background signal constant. A bonus from this kind of feedback operation is that the CRT writing speed is held at the maximum available for the particular target and temperature, since greater target bias will always produce greater writing speed.

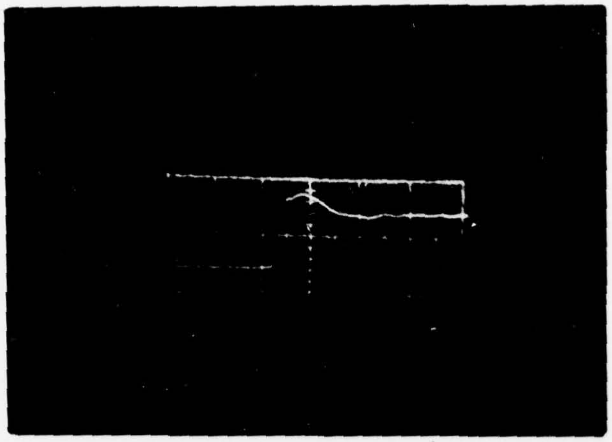
The data shown in Figure 7 were taken with ac-coupled transient feedback only; the quiescent reading beam voltage (and therefore the target diode bias) was left at the Tektronix-recommended value, namely 12.0 volts for that particular tube. We have not taken the next step of increasing the target bias and controlling on leakage current, due to limitations of time and effort during this contractual add-on. Nor have we been able to test the fix at higher levels than 2.5 rad, within the contractual period. There is every reason to believe, however, that the complete feedback scheme would allow the 7912 to operate properly at considerably higher radiation levels, producing significantly greater writing speed in the process.

SECTION 4
EVALUATION OF 519/VIDICON RECORDING

A separate task under this contract addition was to evaluate the performance of an alternative to the 7912 for CIRS recording, namely a normal phosphor-screen oscilloscope with its optical output recorded by a vidicon camera for transmission to the mesa. The Tektronix 519 oscilloscope was used for testing(rather than the more modern 7903 or 183) because of its risetime, writing speed, ruggedness, reliability, and availability in the DNA inventory. In short, the 519 would probably be chosen over any other oscilloscope (including the 7912) for fast downhole recording, if a sufficiently sensitive and radiation-resistant method could be found for transmitting its optical output to the mesa. A COHU model 4410/SIT (Silicon Intensified Target) vidicon was picked as having the necessary optical sensitivity, but nothing was known about its sensitivity to background gamma radiation. Tests were performed first of the 519 and vidicon as an optical combination (by comparison with film recording) and then of the radiation tolerance of the oscilloscope and vidicon separately, in order to evaluate this scheme for underground use.

4.1 Vidicon Optical Sensitivity

In order to compare the 4410/SIT vidicon with film recording, a 519 oscilloscope was used to record a single fast-rising transient, at a sweep speed of 2 ns/div. The input step was fast enough to display the risetime and writing speed limitations of the 519, namely 300 psec and 4 cm/ns. Figure 8 shows the result. Using a Tektronix C-51 camera with f/1.2 lens and Polaroid 410 film, the rise was just barely visible on the resultant single trace. By comparison, the SIT vidicon was able to resolve the rise easily, even with an f/1.4 lens rather than f/1.2, effective magnification of 0.8:1 rather than 0.5:1, and only one field of the video rather than the total integrated light output from the single trace. It is clear that



A. Vidicon recording of a single 2 ns/div. 519 oscilloscope trace, using a 4410-SIT camera at f/1.4. The photo is a single-field playback from the video tape recorder.

B. Film recording of the same trace, using Polaroid 410, ASA 10000 film and a C-51 camera at f/1.2.

Fig. 8 Comparison of Vidicon and Direct Camera Recording the SIT tube has significantly more sensitivity; and therefore can produce greater writing speed than is available with the best film recording, for any oscilloscope. Certainly the remote video readout is more suitable than film for use underground, so the only remaining question was that of radiation sensitivity, both for the SIT vidicon and for the oscilloscope itself.

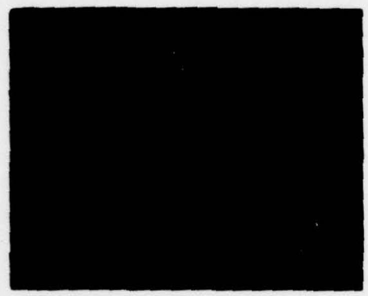
4.2 Radiation Tests of the 519

A laboratory 519 oscilloscope was operated under typical optical sensitivity conditions in the x-ray fluence from the 706 Febetron. Initial tests were made with standard recording, namely a C-51 camera at f/1.2 and Polaroid 410 film, and with no sweep operating. Even under these "initial setup" conditions, a distinct result was obtained, as shown in Figure 9A. At 0.15 rad (at the center of the CRT faceplate), the x-ray pulse produced an overall luminance of the entire field of view, plus a very bright spot on center. Auxiliary time dependent tests showed that the overall illumination followed a typical P-11 phosphor decay curve; but the center spot was much more persistent, lasting in some cases until high voltage was removed from the CRT. The persistent spot also remained on center for all values of CRT positioning voltage, and was completely absent for Febetron shots taken with no post acceleration voltage on the CRT, indicating that breakdown in the 20 kV post acceleration gap was responsible. By comparison, the overall illumination remained when all power was removed from the 519, as shown in Figure 9B, which was also taken at 0.15 rad. This level of direct phosphor excitation would perhaps be tolerable as a background if it were the only malfunction, but the degree of phosphor glow is directly proportional to radiation level and becomes intolerable at a slightly higher level. Figure 9C was also taken with no power on the 519, but at a radiation level of 0.5 rad.

Since no circumvention scheme seems possible for this direct faceplate phosphor response to high energy gamma rays, and since adequate

A. With power
at 0.15 rad.

B. Without power
at 0.15 rad.



C. Without power
at 0.5 rad.

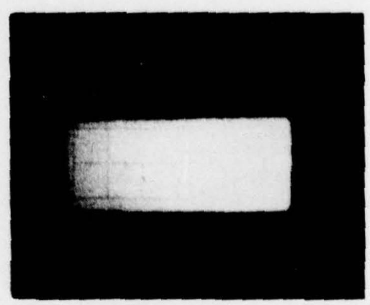


Fig. 9 Radiation Effects on the 519 Oscilloscope at 0.15 and 0.5 rad.

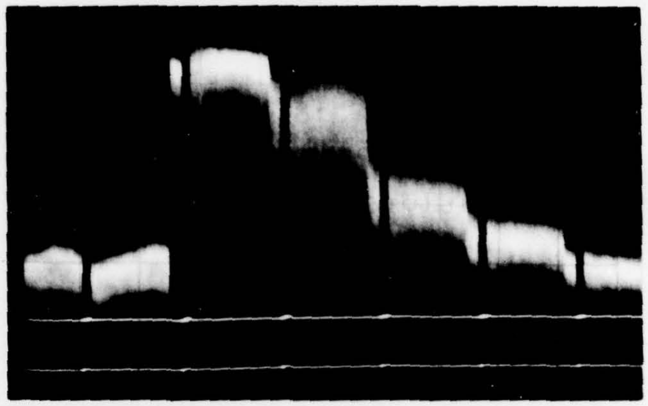
radiation shielding of the CRT in a 519 instrument would be awkward at best, we have concluded that background environments in the range of 0.1 - 0.5 rad constitute a fundamental limitation for the 519 in underground use. Furthermore, since all high speed oscilloscopes (except the 7912) use essentially the same P-11 phosphor, we would expect similar performance from other instruments such as the Tektronix 7903 and Hewlett-Packard 183.

4.3 Vidicon Radiation Sensitivity

Similar radiation tests were performed for a COHU 4410/SIT vidicon camera. In this case the optical conditions corresponding to Figure 8A were produced by operating the vidicon at full gain with the lens cap in place. We were looking for overall background brightness rather than an image, so the output waveform was displayed on a laboratory oscilloscope, as shown in Figure 10. About seven video fields are shown at 10 msec/div, with a full white signal corresponding to 3.5 divisions vertically. The radiation pulse occurred at 2.6 divisions from the left for both shots shown. At 50 mrad radiation level, the first video field was saturated, and recovery required about four fields. Even at a much lower level of 6 mrad, there was a significant overall background, which also persisted for a few fields. Evidence that the background whiteness was caused by direct target excitation (just as for the analogous 519 sensitivity) is provided by the downward step seen near the end of each video field in Figure 10A. When the reading beam reached the place on the target corresponding to the "zero time" position, the readout intensity decreased abruptly since all "later" locations had already been partially wiped off. This characteristic pattern continued for the entire wipedown process. In Figure 10B, the radiation pulse happened to occur during the retrace blanking between fields, so the step is not seen.

A non-intensified vidicon was also tested for radiation tolerance, even though previous measurements had shown that its optical sensitivity would not be adequate for use with a 519 at 2 ns/div, by about a factor of ten. The radiation sensitivity was also about a factor of ten less than that

A. At 50 mrad.



B. At 6 mrad.

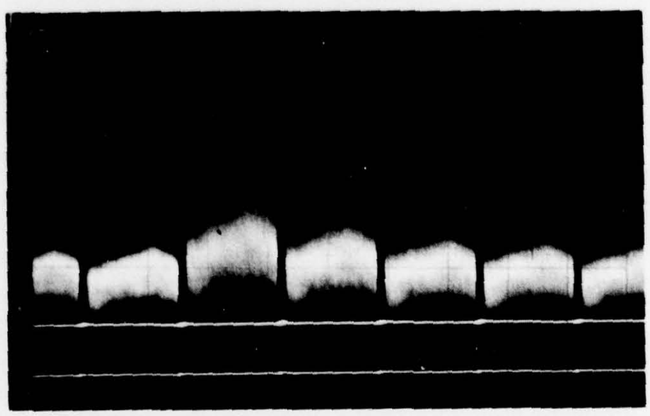


Fig. 10 SIT Vidicon Output at 6 and 50 mrad.

of the SIT tube, namely 0.1 - 0.5 rad required for partial to full background whiteness. Otherwise the behavior was the same as for the SIT tube, indicating some proportionality between optical and gamma-ray sensitivities.

4.4 Summary

It appears that vidicon rather than film recording of fast oscilloscope traces can generally be a useful tool in any reasonably benign environment. If the background radiation level is below 10 mrad total prompt dose, a SIT vidicon and 519 oscilloscope (or 7903 presumably) can produce more writing speed than film recording, and perhaps compete with a 7912. If ultimate writing speed is not required, a 519 and non-SIT vidicon combination will operate satisfactorily up to about 0.1 rad prompt dose, in situations where the long-term environment may make film recording inconvenient or impossible. However, it appears that no normal phosphor-screen oscilloscope (with either film or vidicon readout) can approach the radiation hardness available with the 7912, and required for CIRS recording.

SECTION 5
CONCLUSIONS

Long cables have traditionally been used between detectors and recorders in underground testing, in order to protect the recorders from the tunnel environment. The resulting limit to overall measurement resolving time has been accepted as a necessary part of the protection, since there are practical limits to coaxial cable size and compensation.

The thesis and objective of the LPARL CIRS work has been to reach a level of recording system performance which is not available through long cables, by solving the problems associated with operating in the hostile tunnel environment, close to the signal source. It was expected from the beginning that a great deal of "hardening" would be required; with respect to power source and electrical isolation, temperature, humidity, dust and dirt, as well as electromagnetic pulse and gamma-ray backgrounds. After some two years of laboratory effort, two underground test events, and the usual trial and error process, it appears that all the necessary testing and fixing have been accomplished. A hardened CIRS-7912 can record data in the several gigahertz regime (namely with risetimes approaching 100 psec) because it has essentially no input cable degradation; it can survive and function reliably in the environment found within a few meters of typical fast detectors.

A summary of the "tunnel survivability" specifications of the hardened CIRS, as tested and proven, thus serves as a suitable conclusion for the developmental work.

Power Source and Electrical Isolation

The CIRS derives all its power (and that for input detectors as well) through the single video output cable. There are no connections to ground or power sources in the tunnel. Similarly, all signal grounds are made only to the isolated shield of the output cable.

Ambient Temperature

The cooling system is self-contained, circulating tunnel air through a heat exchanger. The 7912 internal circuitry temperature is maintained $\pm 1^{\circ}C$ for ambients up to $39^{\circ}C$, and held within allowable limits up to $54^{\circ}C$ ambient.

Humidity, Dust and Dirt

The chambers are hermetically sealed, and filled with clean dry gas (80% He, 20% SF_6) maintained slightly above ambient pressure, thus achieving complete isolation from the tunnel environment.

Electromagnetic Pulse Background

All circuitry is double shielded, since the 7912 chassis is insulated from the outer shell of the CIRS. The detectors are similarly insulated inside a double-walled shielding box, and the detector-CIRS signal cables are double-shielded triax. Deriving all power from the mesa makes possible this complete isolation in the tunnel.

Radiation Background

Proper operation of the hardened (but unshielded) 7912 has been demonstrated at the highest radiation level we have achieved in the laboratory, namely 3 rad total dose. This sets a lower limit to the malfunction threshold, which (by coincidence) is about equal to that encountered in the LPARL alcove on MIGHTY EPIC. We expect about a factor of two higher background on DIABLO HAWK, namely about 6 rad, so some shielding will be required. A reasonable safety margin of 5-10 (0.3 - 0.6 rad at the CRT target matrix) will require a gamma-ray attenuation of 10-20. The gamma-ray spectrum is difficult to estimate in such a scattered and already-shielded geometry, but shielding cannot be less effective in any spectrum than at the 2-3 MeV minimum, where the mean free path is 25-30 gm/cm^2 for any shielding material. This gives a maximum of about 75 gm/cm^2 as the thickness required to achieve an attenuation of 10-20. So 30-40 cm (1-1.5 ft) of sandbags, or 7 cm (3") of lead then constitutes a very conservative estimate of the shielding required to achieve a safety margin of 5-10 in DIABLO HAWK.

The overall conclusion, then, is that a sandbagged "vault" at the rear corner of the LPARL alcove will assure that the CIRS will not malfunction in the DIABLO HAWK radiation background. This assurance is with an acceptable safety margin, since the bare 7912, as modified, will operate properly up to levels at least within a factor of two of the ambient expected, and perhaps to much higher levels.

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