Center for Night Vision and Electro-Optics

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Comparison of Second and Third Generation Night Vision Goggles in Time-Limited Scenarios

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13. ABSTRACT (*Maximum 200 words*)
This report addresses eight nights of field testing which occurred at three sites (pine canopy, cluttered range, open meadow) in the Deschutes National Forest, OR, during May 1988. The primary objective of these field evaluations was to characterize changes in detection performance of second and third generation Night Vision Goggles. These changes were to be examined as a function of both allowed observation time and progressive user fatigue.

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Summary

The USACECOM Center for Night Vision and Electro-Optics (C2NVEO) has an ongoing effort to better characterize the performance differences between second and third generation image intensifiers. In early 1988, C2NVEO initiated an effort to evaluate use of second and third generation intensifiers in dynamic scenarios. The approach was to use static man-targets, but to allow the Night Vision Goggle (NVG) users limited amounts of time to detect the targets. The hypothesis was that as the allowed observation periods shortened, second generation NVG detection performance would degrade faster than its third generation counterpart. Three test sites were identified in the vicinity of the Central Oregon Test and Evaluation Facility (COTEF). These were classic examples of the pine canopy, cluttered vegetation, and open meadow terrains, respectively, and each had negligible artificial light contamination. The test data from two sites supported the test hypothesis. At both the pine canopy and open meadow sites, there were several instances where the second generation and third generation NVGs had essentially identical performance at the longer observation times. As the observation periods decreased, however, the second generation NVGs lost 35 to 45% of this performance, while the third generation NVGs lost 10% or less. The greatest degradation generally occurred as the observation period decreased from 4 to 2 seconds. Such trends were most dramatic at the pine canopy site, presumably because of its extremely low light levels. The cluttered site, on the other hand, showed no consistent trends, presumably because image contrast, not signal-to-noise, appeared to be the dominant factor in determining detection at that site. The overall results showed that the third generation NVGs detected 28% more targets. There were no significant differences in the number of false detections except at the cluttered site, where the second generation NVGs registered 155% more false detections.

Introduction

The USACECOM Center for Night Vision and Electro-Optics (C2NVEO) has been engaged in an ongoing effort to better characterize the performance differences between second and third generation image intensifiers. In early 1988, C2NVEO initiated an effort to evaluate intensifier use in dynamic scenarios, where the user does not have unlimited time to study and act upon the intensifier imagery. For starlight conditions in such instances, it has been suggested that the more noisy imagery associated with second generation intensifiers increases user task loading and decreases user performance. This aspect of intensifier performance has not been specifically addressed and quantified, however, due to the difficulty in staging and controlling dynamic scenarios for field tests.

In late 1987, C2NVEO conducted a series of field tests involving the performance of both second and third generation Night Vision Goggles (NVGs) utilizing various types of Coated Optical Components (COCs). Although these were static tests, the observers were allowed a limited (but non-taxing) period of time to observe the scene with the NVGs. It was noted that this concept could be extended by allowing the observers progressively shorter periods to observe a scene. Although the scene itself would remain static, the user would be under pressure to quickly assess the scene. Such is the case in typical combat situations, where the participants do not have the luxury of unlimited time to appraise their surroundings.

It was proposed that such a modified test be conducted at the Central Oregon Test and Evaluation Facility (COTEF). A site survey of the area concluded, however, that the most suitable sites were not on COTEF grounds, but were rather about 20 miles west in the Deschutes National Forest, OR.

This report addresses the eight nights of field testing which occurred at three sites in the Deschutes National Forest in early May 1988.

Section I

Field Test Description

Objective

The primary objective of these field evaluations was to characterize changes in detection performance of second and third generation NVGs. These changes were to be examined as a function of both allowed observation time and progressive user fatigue. It was hypothesized that as the user is allowed progressively less observation time or becomes increasingly fatigued, second generation's noisier imagery under starlight conditions would lead to a significantly greater degradation in detection performance.

Test Setup

Sites. The three test sites consisted of a pine canopy, a cluttered range, and an open meadow. These sites were all within a mile of each other in the Deschutes National Forest. Artificial light contamination at each of the three sites was found to be negligible (see Appendix). Specific site information is as follows:

- ***Pine Canopy.*** This was a flat, roughly rectangular area (approximately 65 x 20m), surrounded by evergreen trees. The ground had a thin covering of pine needles. The background for the targets generally consisted of tree trunks and the pine needle ground cover. There was a narrow (approximately 10m wide) opening to clear sky along the entire length of the range. See Figure 1.

- ***Cluttered Range.*** This was a fairly flat area of about 75 x 25m, which consisted of loosely spaced shrubs/evergreen trees and clump grasses. The background for the targets was generally tree trunks, shrubs, and pine branches. See Figure 2.

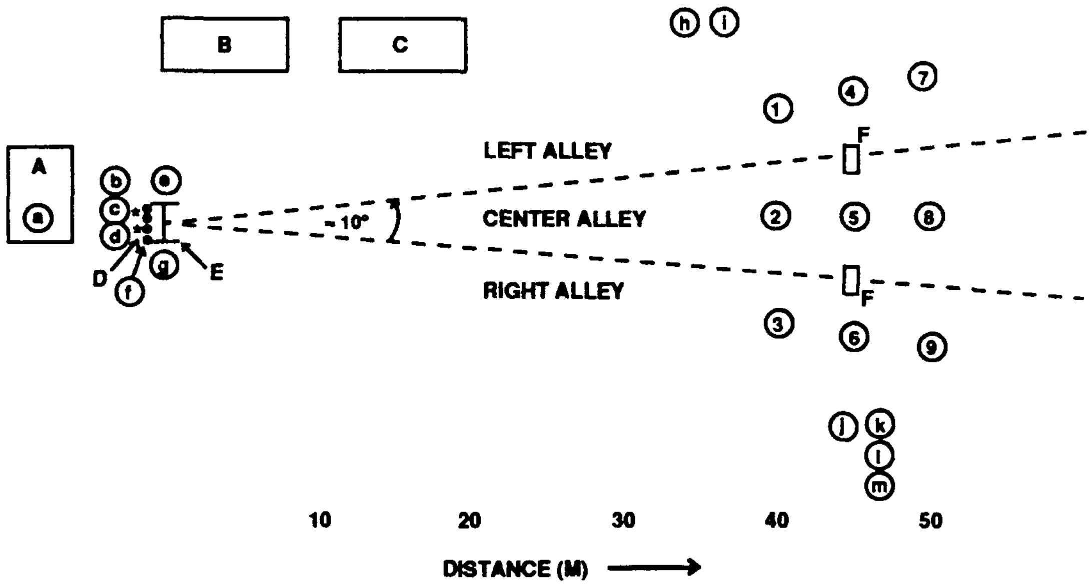
- ***Open Meadow.*** This was a fairly flat area in excess of 500 x 500m, which had been cleared in the recent past by a forest fire. The ground consisted of clump grasses, charred tree stumps, and patches of bare dirt. The background for the targets was mainly the grass/dirt ground covering. See Figure 3.

Figure 1. Canopy Site

Figure 2. Cluttered Site

Figure 3. Open Site

Range Layout. All three ranges were generally configured in the manner depicted in Figures 4 and 5. At one end of the range, the four observers sat closely together behind a shutter. From their viewpoint, the test range was divided into three "alleys" down which they could look; each "alley" comprised about 10 degrees of azimuth. The targets were placed within each alley at discrete distances from the observers. The common boundaries of the alleys were demarcated by 18 x 18 inch, 100% reflectance panels on tripods. These panels were generally placed 45 to 55m away from the observers. The test sequencer and test director operated a shutter to control the observation period for the observers. Each observer indicated his observations by pressing buttons on a remote panel box, which was connected by wire to a master data display box manned by the data manager. The latter and the timer, who directed the shutter movements, were stationed about 2m behind the observers. Apparatus for videotaping NVG imagery was placed directly behind the observers; its control center was located in a truck several meters back. The radiometric team was positioned off to the side of the test range, in an area judged to be similar in ambient conditions. When the targets were not occupying positions on the test range, they were stationed off to the side with the target manager, in an area where they were generally concealed from the observers. The two motorhomes used to transport personnel and equipment were placed behind or to the side of the videotaping control center.



PERSONNEL

- (a) = VIDEO ENGINEER
- (b) = TIMER
- (c) = DATA MANAGER
- (d) = TV CAMERA TECHNICIAN
- (e) = SEQUENCER
- (f) = OBSERVERS, 4 EACH (• • • •)
- (g) = TEST DIRECTOR
- (h) (i) = RADIOMETRIC PERSONNEL, 2 EACH
- (j) = TARGET MANAGER
- (k) (l) (m) = TARGETS, 3 EACH
- (1)-(9) = POSSIBLE TARGET POSITIONS, 9 EACH

EQUIPMENT

- A = VIDEOTAPING CONTROL CENTER
- B, C = SUPPORT MOTORHOMES, 2 EACH
- D = NVG TV CAMERAS, 2 EACH (* *)
- E = SHUTTER
- F = 100% REFLECTANCE PANELS, 2 EACH

Figure 4. Typical Range Layout

Figure 5. Observer End of Typical Range Layout

Test Methodology

General. This second generation/third generation comparison consisted of random presentations of static man-targets at three separate azimuths (i.e., the three "alleys") for each of three discrete distances. The targets were dressed in winter Battle Dress Uniforms (BDUs). The observers alternated between second generation and third generation AN/PVS-7 NVGs, and were allowed fixed periods of time to detect the targets; these observation periods ranged from 15 seconds down to 2 seconds. The purpose of these exercises was to ascertain if second generation, with its more noisy imagery, would degrade faster than third generation with regards to both missed and false detections as the allowed observation periods shortened. These exercises were conducted under no-moon conditions, with light levels generally in the 10^{-5} footcandle (fc) range (see Appendix).

All of these exercises were documented on videotape by E-OIR Measurements, Inc., using a system they specifically developed for this purpose. This system consisted of Silicon Intensifier Target (SIT) TV cameras optically coupled to the back ends of two AN/PVS-7 NVGs, which employed a second generation and third generation intensifier tube, respectively. The E-OIR system was capable of documenting typical intensifier imagery for ambient conditions ranging from twilight down to overcast starlight (see Figure 6).

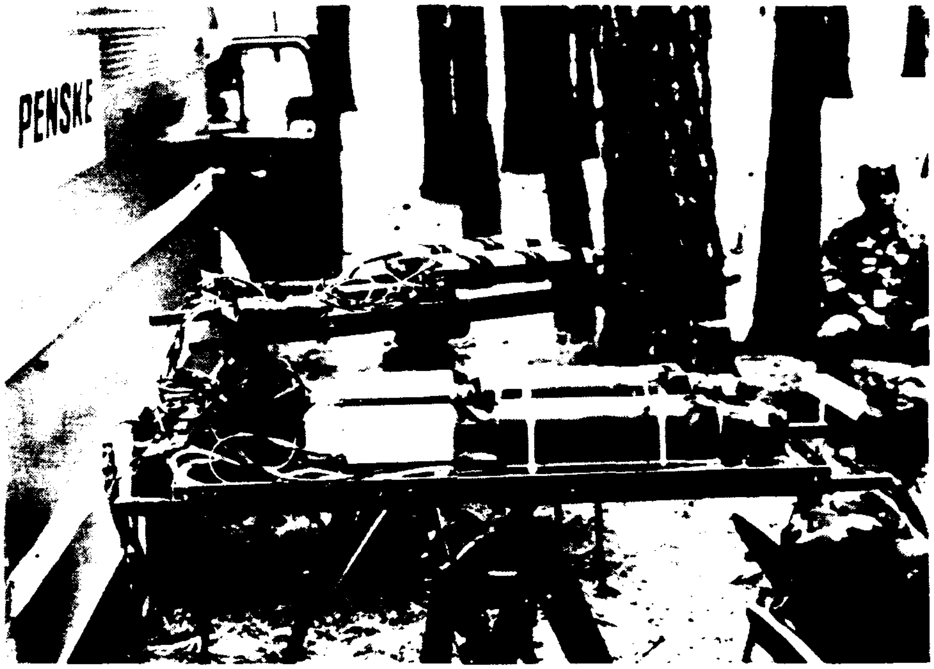


Figure 6. Intensifier/TV Systems

Procedure. Specific details of the test procedure are as follows:

1 The target personnel were National Guardsmen in winter BDUs. These personnel were placed at three discrete distances clustering around the 50% detection probability point, using 1987 AN/PVS-7 NVG field test data as starting points (nominally 40, 50, and 60m).

2 Up to three targets were placed at a given target distance. At each distance, the targets were uniformly spaced about 10 degrees apart, from the observers' standpoint. See Figures 7 and 8.

Figure 7. Close-up of Typical Target Setup

Figure 8. Typical Target Setup from Observer Perspective

3 The three azimuth locations for the targets were essentially the same from distance to distance. These were referred to as [observer's] "left," "center," and "right," and they corresponded to the three buttons on each observer's remote panel box. The observers were instructed to press the buttons corresponding to the azimuth locations of the targets they saw for a particular target presentation. This would input the data to the master LED display board manned by the data manager. After recording the data, he cleared the display and was then ready for another set of data.

4 A "trial" was defined as a particular presentation of targets to the observers. A set of 20 trials was defined to be a "sequence." A sequence's trials were evenly divided into presentations of 0, 1, 2, and 3 targets. These presentations were also evenly distributed among the three distances and the three azimuth locations. Target presentations were made according to a "master sequence," which was devised to be as unpredictable as possible to minimize observer guessing. (This sequence is shown in the Appendix.) At no time did any two targets occupy the same observer line of sight (i.e., the same azimuth location). Thirty targets were presented during each target sequence.

5 The target presentations were determined by the test sequencer, who directed the target manager via field radio to set up a particular trial from the master sequence. The target manager then sent target personnel to the appropriate locations, verified proper positioning by means of a third generation AN/PVS-7 NVG, and finally informed the sequencer of target readiness. The shutter operators then pivoted the plywood shutter down from in front of the observers so they could view the scene. The shutter operators also cued the test timer to begin timing the observation period with an LED stopwatch. Near the end of the observation period, the timer would begin a verbal countdown to cue the shutter operators for the raising of the shutter. The test videotapes verified that this procedure very effectively regulated the observation periods.

6 There were always four observers: three from the National Guard, and one from C2NVEO. Two observers started with second generation AN/PVS-7 NVGs, and the other two started with third generation AN/PVS-7 NVGs. (Laboratory characterization of these NVGs is detailed in the Appendix.) It was decided that these NVGs should not utilize Coated Optical Components (COCs). The four observers were initially exposed to a complete target sequence with 15 seconds observation time allowed for each trial. They were then exposed to sequences with progressively shorter observation times. A set of four sequences utilizing the four different observation periods (15, 7, 4, 2 seconds) was defined as a "target run." A target run accordingly consisted of 80 trials, involving 120 presented targets.

7 After the first target run, the observers switched generations of AN/PVS-7, and another target run was conducted. This allowed each observer to have equal time on each generation of AN/PVS-7.

Iterations to Test Methodology

Although this general type of field test had been previously performed at Fort A. P. Hill, VA, specific attributes of the Oregon test sites and personnel led to a number of modifications to the field test plan. The significant changes are listed below.

- It was originally planned that the entire test procedure would be repeated after the observers had used both generations of AN/PVS-7 NVG. This repetition would have enabled assessment of user fatigue effects on the comparative performance of the two NVG generations. The consistent inclement weather during the field test (cold, rainy, windy) persuaded the test director to retreat from this goal, in order to avoid a general mutiny of test personnel. Additionally, the consecutive night nature of the test (10 consecutive nights of testing had been scheduled) argued for the abbreviated procedure. As it was, the tests generally could not start until the end of astronomical twilight (approximately 2145 hours) and they generally lasted until about 0100 hours. This placed considerable demands on the National Guardsmen, especially those who had daytime responsibilities unrelated to the tests. Due to all of the above, the assessment of user fatigue effects had to be dropped from the test plan.

- Even the abbreviated schedule could not be completed every night. The first night at each site was primarily a shakedown exercise involving very limited data taking. On the middle night (when available), two target runs were made, but these runs did not necessarily have the full complement of four sequences each. Only on the last night at each site were two complete target runs made.

- The pine canopy site closely resembled sites at Fort A. P. Hill, VA, so relatively few procedural changes were required; the only major change was to reduce the target distances from 40, 50, and 55m to 40, 45, and 50m, respectively. The cluttered site, however, concealed the targets far more effectively than expected. Although the target distances were moved in from 35, 40, and 45m to 30, 35, and 40m, respectively, they still did not appear optimized; some target positions were still virtually undetectable. The open site had the opposite characteristic; despite the targets being ultimately moved out from 50, 60, and 70m to 110, 120, and 130m, respectively, the relatively high contrast and low clutter still made the targets too easy to see. At least one additional night at each of the two latter sites would have been required to optimize the target distances.

- The original plans were for ten consecutive nights of testing. This would have allowed three nights of testing at each of the three sites, with the tenth night available as a backup. As it turned out, the first night at the cluttered site was rained out. It was later decided, however, that the last day would be reserved for a daytime video of the equipment/personnel layout at each of the sites. Consequently, there were eight nights of field tests.

- After several nights of testing, it became apparent that the observers were beginning to learn portions of the master test sequence. It was originally thought that the NVG detection efficiency would introduce enough confusion for the observers that a pattern could not be gleaned; the tests had been set up so that these detection efficiencies would range around 50%. But it was belatedly recognized that the observers also spent significant time as targets, where they would go through many repetitions of the complete, exact sequence. Furthermore, the open site observers had virtually a 100% success rate on the first night, due to the targets being much too easy to detect. It was consequently decided that various permutations of the master sequence would be employed on each subsequent night (e.g., odd/even sequence ordering, backwards/forwards sequence ordering, starting points 1/4, 1/2, and 3/4 through the master sequence). This procedure stymied observer "pattern recognition," but maintained the same statistical distribution of targets.

Section II

Results

Test data is in terms of "false" and "true" detections. The master sequence alone was used to determine both of these quantities. It should be noted that there were some instances where, by mistake, the target presentation deviated from the master sequence. But the percentage occurrence of such deviations was judged to be so low as to be insignificant. Furthermore, such occurrences should have degraded second generation and third generation statistics equally. Additionally, it turned out to be extremely time-consuming to correct these occurrences in the computer data analysis program for the tests. This report's data is consequently not corrected for such occurrences.

Table 1 presents the rollup of data for the six nights when useful data was taken. Although there were eight nights of testing, the first nights at both the canopy and open sites yielded no useful data. The first canopy night was devoted to practice/troubleshooting. The first open site night had the targets much too close, yielding virtually a 100% observer success rate. The above, plus the rainout of the first night at the cluttered site, account for the two nights of useful data at each site that are found in Table 1.

Table 1 lists the numbers of true and false detections registered by the second and third generation NVGs on each of the six nights of useful data. Each generation's data is composed of the results of two different NVGs, where each NVG was used by one or two observers. The true detections are broken down by the three relative target distances of "short," "middle," and "long." Specific target distance measurements of a given night are listed in Table 2. The true and false detections are broken down by the allowed observation periods of 15, 7, 4, and 2 seconds. It should be noted that all four observation periods were not employed on every night. If a particular observation period was not utilized on a given night, a blank (--) occupies its position.

Table 1. Rollup of Detection Data

	FALSE DETECTIONS				TRUE DETECTIONS											
					Short				Middle				Long			
TIME (sec)	15	07	04	02	15	07	04	02	15	07	04	02	15	07	04	02
SITE																
Canopy																
(5-06-88)		*		*		*		*		*		*		*		*
2nd	7	2	5	1	31	16	27	13	13	8	9	6	2	2	3	1
3rd	3	9	1	2	38	16	40	20	33	15	32	13	22	9	15	4
Canopy																
(5-09-88)																
2nd	4	1	0	2	40	35	36	26	22	13	9	12	5	6	4	6
3rd	4	2	3	6	40	40	40	38	39	38	38	36	31	27	25	18
Cluttered																
(5-07-88)		*		*		*		*		*		*		*		*
2nd	10	2	4	0	39	17	34	18	28	14	32	13	27	11	23	11
3rd	3	0	6	2	36	17	40	17	35	16	38	18	24	12	27	13
Cluttered																
(5-10-88)																
2nd	18	9	6	7	37	33	33	26	30	25	23	24	21	20	12	15
3rd	1	6	2	2	39	40	34	35	39	33	34	31	26	23	20	16
Open																
(5-08-88)																
2nd	2	-	3	7	39	--	40	39	40	--	38	28	37	--	35	21
3rd	0	-	2	2	38	--	40	40	40	--	40	38	38	--	40	34
Open																
(5-11-88)																
2nd	1	2	2	0	40	40	39	39	40	38	38	34	39	37	35	35
3rd	0	2	2	2	40	40	40	40	40	40	40	38	40	36	38	36

Notes:

-- No data was taken at indicated point.

* Only one target sequence, with 20 possible target detections at each distance, was conducted for indicated night and observation period.

Unless otherwise specified, two target sequences with a total of 40 possible target detections at each distance were conducted for each observation period.

Table 2. Specific Target Distances

SITE	ACTUAL TARGET DISTANCES		
	Short	Middle	Long
Canopy			
5-06-88	40m	45m	50m
5-09-88	40m	45m	50m
Cluttered			
5-07-88	35m	40m	45m
5-10-88	30m	35m	40m
Open			
5-08-88	100m	110m	120m
5-11-88	110m	120m	130m

Table 3 lists each observer's true detection data for the night of most useful data at each test site. A corresponding listing of false detection data by individual observer may be found in Table 4.

Table 3. True Detection Data By Observer

5-09-88 Canopy Site

		2nd Gen					3rd Gen				
DISTANCE	PD	01	02	03	04	TOT	01	02	03	04	TOT
Short	15	10	10	10	10	40	10	10	10	10	40
	7	8	9	10	8	35	10	10	10	10	40
	4	8	9	10	9	36	10	10	10	10	40
	2	7	6	6	7	26	10	9	10	9	38
Middle	15	6	5	7	4	22	10	9	10	10	39
	7	2	2	6	3	13	10	8	10	10	38
	4	0	5	2	2	9	10	9	10	9	38
	2	3	2	5	2	12	9	8	10	9	36
Long	15	0	1	3	1	5	6	6	9	10	31
	7	0	0	3	3	6	7	3	8	9	27
	4	0	1	1	2	4	3	8	6	8	25
	2	0	2	2	2	6	3	7	7	1	18

5-10-88 Cluttered Site

		2nd Gen					3rd Gen				
DISTANCE	PD	01	02	03	04	TOT	01	02	03	04	TOT
Short	15	10	9	10	8	37	10	10	10	9	39
	7	8	8	10	7	33	10	10	10	10	40
	4	8	8	10	7	33	9	8	10	7	34
	2	8	5	9	4	26	10	9	9	7	35
Middle	15	10	6	9	5	30	10	10	10	9	39
	7	8	5	9	3	25	8	8	9	8	33
	4	9	4	8	2	23	9	8	10	7	34
	2	9	5	6	4	24	8	8	10	5	31
Long	15	7	5	7	2	21	7	9	8	2	26
	7	6	4	8	2	20	6	6	6	5	23
	4	3	1	8	0	12	7	5	5	3	20
	2	7	3	5	0	15	5	4	6	1	16

5-08-88 Open Site

		2nd Gen					3rd Gen				
DISTANCE	PD	01	02	03	04	TOT	01	02	03	04	TOT
Short	15	10	10	10	9	39	10	10	8	10	38
	7	--	--	--	--	--	--	--	--	--	--
	4	10	10	10	10	40	10	10	10	10	40
	2	10	9	10	10	39	10	10	10	10	40
Middle	15	10	10	10	10	40	10	10	10	10	40
	7	--	--	--	--	--	--	--	--	--	--
	4	9	10	9	10	38	10	10	10	10	40
	2	7	6	7	8	28	9	10	9	10	38
Long	15	10	10	8	9	37	9	10	10	9	38
	7	--	--	--	--	--	--	--	--	--	--
	4	8	7	10	10	35	10	10	10	10	40
	2	5	3	7	6	21	6	10	9	9	34

Notes:

PD	Observation period in seconds
01, 02, 03, 04	Observers #1 through #4
TOT	Total true detections
--	No trials conducted

Table 4. False Detections By Observer

		2nd Gen					3rd Gen				
Site	**PD**	**01**	**02**	**03**	**04**	**TOT**	**01**	**02**	**03**	**04**	**TOT**
Canopy	15	1	0	3	0	4	0	1	0	3	4
(5-09-88)	7	0	0	1	0	1	0	0	0	2	2
	4	0	0	0	0	0	0	0	0	3	3
	2	1	1	0	0	2	0	3	1	2	6
Cluttered	15	8	5	4	1	18	0	1	0	0	1
(5-10-88)	7	1	1	6	1	9	2	0	4	0	6
	4	1	1	3	1	6	1	0	0	1	2
	2	6	0	0	1	7	1	0	1	0	2
Open	15	0	0	0	2	2	0	0	0	0	0
(5-08-88)	7	--	--	--	--	--	--	--	--	--	--
	4	0	0	1	2	3	1	0	0	1	2
	2	0	1	4	2	7	1	0	0	1	2

Notes:

PD	Observation period in seconds
01, 02, 03, 04	Observers #1 through #4
TOT	Total false detections
--	No trials conducted

Section III

Analysis of Results

Overall Trends

A total of 2,520 targets were presented over the six nights of useful data. The third generation NVGs detected 2,146 (or 85%) of these targets, while the second generation NVGs detected 1,682 (or 67%) of the targets. In addition, the second generation NVGs registered 53% more false detections than the third generation NVGs (95 *vs.* 62). Both types of data can be combined into a single figure of merit ("FOM") by dividing the number of false detections by the number of true detections. Expressed as a percentage, this FOM is 5.6% for the second generation NVGs and 2.9% for the third generation NVGs. Such a low FOM indicates that random guessing was not a significant contributor to test results. This follows from the fact that for any randomly selected trial, there was a 50% probability that a target was presented in a given azimuth location ("alley"); therefore, purely random guessing would have resulted in the number of false detections being similar to the number of true detections (i.e., an FOM approaching 100%). The low second and third generation FOMs contraindicate this possibility.

Although the third generation NVGs invariably yielded more correct detections and generally yielded less false detections at each site, the relative differences in detection performance substantially varied from site to site. The overall results for each site are as follows:

SITE	TRUE DETECTIONS				FALSE DETECTIONS				FOM	
	2nd	(%)	3rd	(%)	2nd	(%)	3rd	(%)	2nd	3rd
Canopy	345	41%	667	79%	22	2.6%	30	3.6%	6.4%	4.5%
Cluttered	566	67%	663	79%	56	6.7%	22	2.6%	9.9%	3.3%
Open	771	92%	816	97%	17	2.0%	10	1.2%	2.2%	1.2%

NOTE: The true and false detection percentages were computed by dividing the respective detections by the 840 targets presented at each site.

Detection Capability vs. Allowed Observation Time

The prime objective of these field exercises was to test the hypothesis that as allowed observation time decreased, second generation NVGs would degrade in detection capability faster than third generation NVGs. The results from two of the three sites appeared to support this hypothesis. Specific discussion pertaining to each site is as follows:

Canopy Site. The most useful data was generated on the night of 9 May, when two complete target runs were conducted. Figure 9 presents a histogram layout of results. At the "short" target distance, there is no significant difference in detection performance for observation times of 15, 7, and 4 seconds; both NVG generations detected nearly 100% of the targets. At 2 seconds, however, the second generation NVGs detected only 65% of the targets, while the third generation performance remained essentially unchanged at 95%. All four observers registered virtually identical results in this regard.

A similar but less consistent trend appears for the "middle" target distance. Whereas the third generation detection performance remains at 90% or greater for all observation periods, second generation NVG detection performance falls by half in going from 15 to 7 seconds observation time (i.e., 55 to 33%). All four observers registered detection dropoffs at this point, but only two of these were substantial. Interestingly enough, no trends whatsoever appear for the 4 and 2 second observation periods; the variation from observer to observer is simply too great.

At the "long" target distance, third generation detection performance now appears to show a clear downward trend, falling from 78% at 15 seconds to 45% at 2 seconds. It should be noted, however, that a single observer (#4) accounted for most of this change; two others recorded much smaller dropoffs, while the fourth showed no change. Second generation detection performance showed no downward trend at all, but rather remained in the 10 to 15% range for all observation periods.

The 6 May canopy site data shows no clear trends in detection performance as a function of observation period. The following factors may account for this:

- Only 1.5 target runs were completed. Consequently, there were only two observers (not four) per generation for the 7 and 2 second observation periods.
- For both generations, the general detection performance was about 20% lower than on the succeeding canopy site night. The reasons for this are not clear.

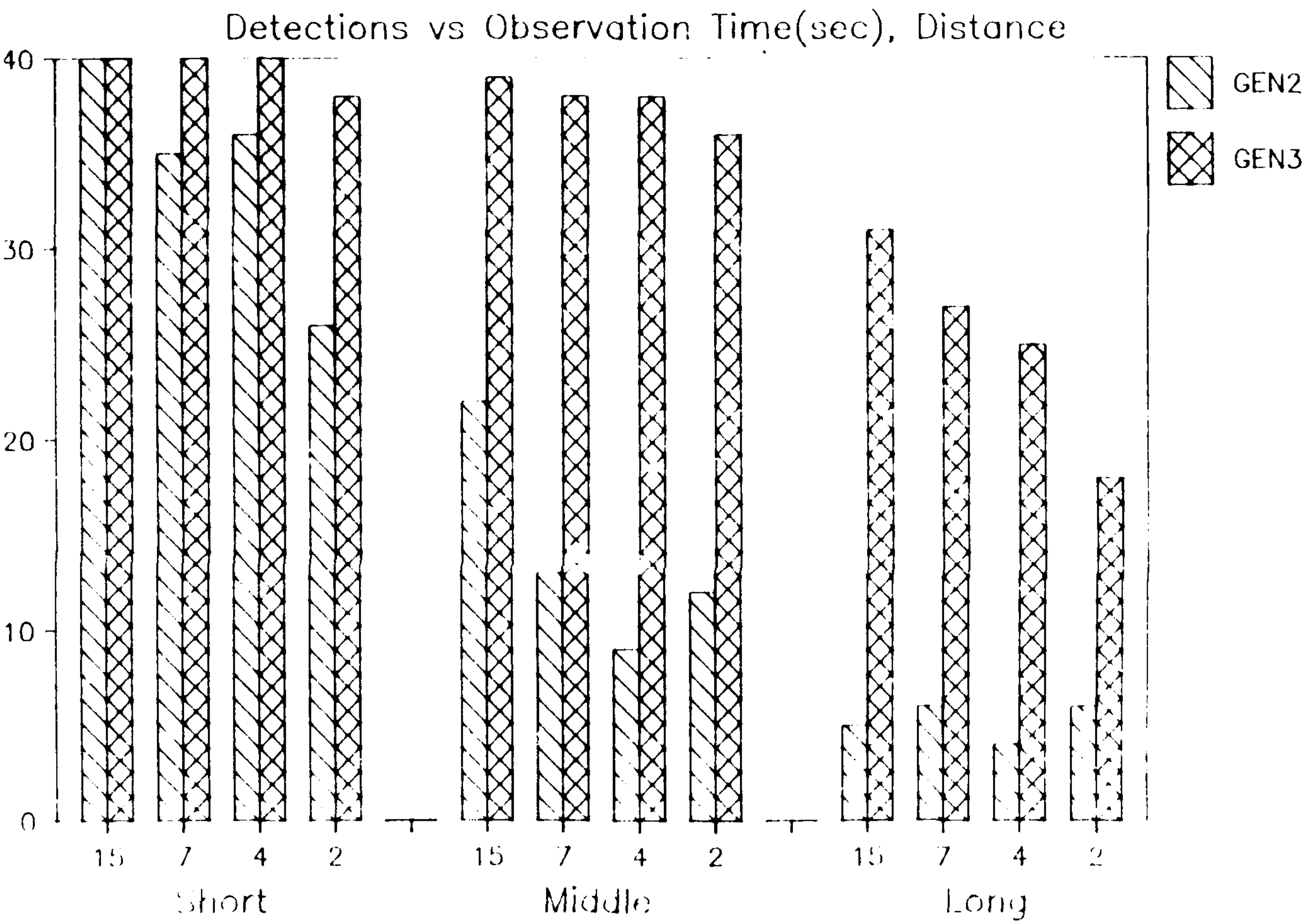


Figure 9. Histogram of Canopy Site (05/09/88)

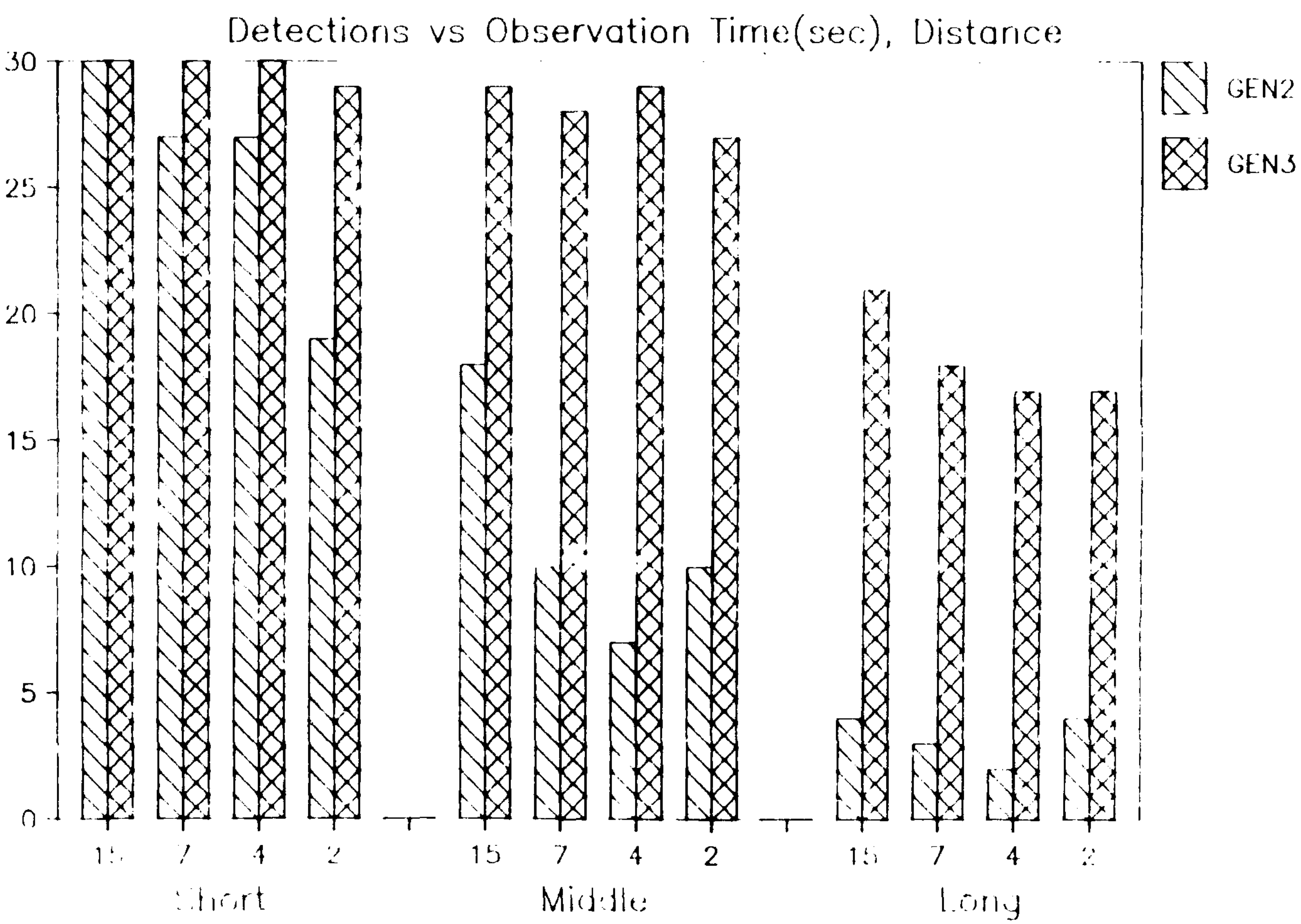


Figure 10. Histogram of Canopy Site (05/09/88) [Minus Observer #4]

Cluttered Site. The most useful data was generated on the night of 10 May. A histogram layout of the results is presented in Figure 11. At the "short" target distance, the data appears to show a trend similar to that at the canopy site. Whereas the third generation performance hovers in the 85 to 100% range for all observation periods, second generation detection performance falls from 93% at 15 seconds to 65% at 2 seconds. But it should be noted that while two observers' performances fell by half, the other two showed little or no change. A firm downward trend in detection performance is consequently not supported by these results.

The "middle" and "long" target distance data are also ambiguous regarding trends in detection performance. Both second and third generation appear to show downward trends in detection performance with decreasing observation period. But again, the observers were fairly equally divided between those who registered significant performance dropoffs, and those who registered little or no change. Consequently, these results also do not appear to warrant any assertions about trends.

On the 7 May night at the cluttered site, only 1.5 target runs were completed. This meant there were only two observers (not four) per generation for the 7 and 2 second observation periods. Moreover, since the first scheduled night at this site was rained out, 7 May was essentially a "shakedown" night where it was recognized that many test parameters would not be optimum. It is therefore not surprising that this night also exhibited no clear trends as observation periods decreased.

Open Site. The most useful data at this site was generated on the night of 8 May. A histogram layout of the results is presented in Figure 12. Although no sequences were conducted with the 7 second observation period, all four observers used each generation of NVG for the 15, 4, and 2 second periods. At the "short" target distance, both the second and third generation NVGs detected virtually 100% of the targets for all three observation periods. At the "middle" distance, both generations again detected virtually 100% of the targets for the 15 and 4 second periods. At 2 seconds, however, second generation dropped to 70% target detection, while third generation remained virtually unchanged at 95%; all four observers exhibited similar trends in this respect. At the "long" target distance, both generations were again in the 90% region for the 15 and 4 second periods. As before, second generation dropped to only 53% detection at the 2 second period, while third generation experienced only a minor drop to 85%. Three of the four observers registered significant drops in second generation detection for this observation period, while only one observer recorded a significant drop in third generation detection.

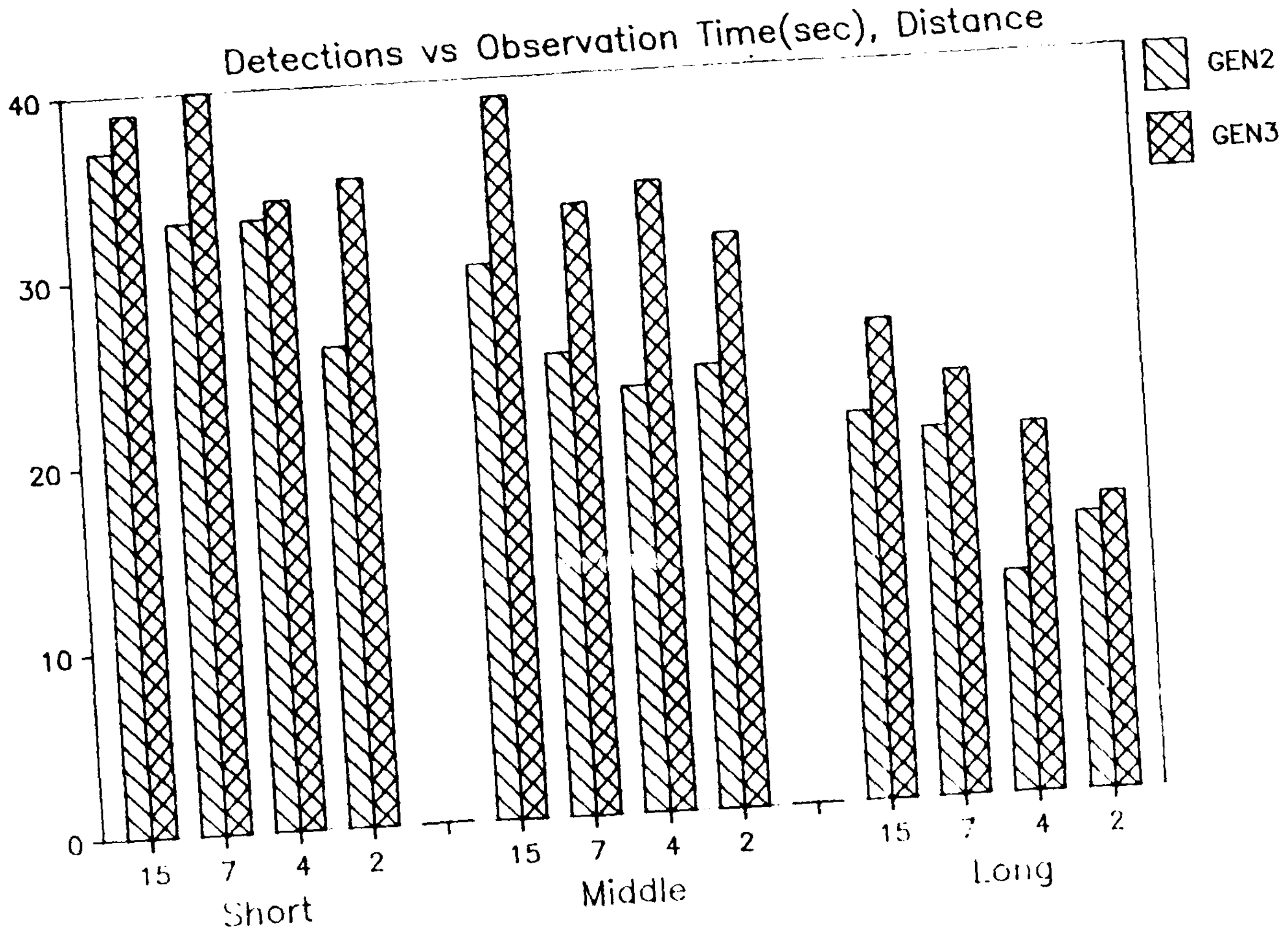


Figure 11. Histogram of Cluttered Site (05/10/88)

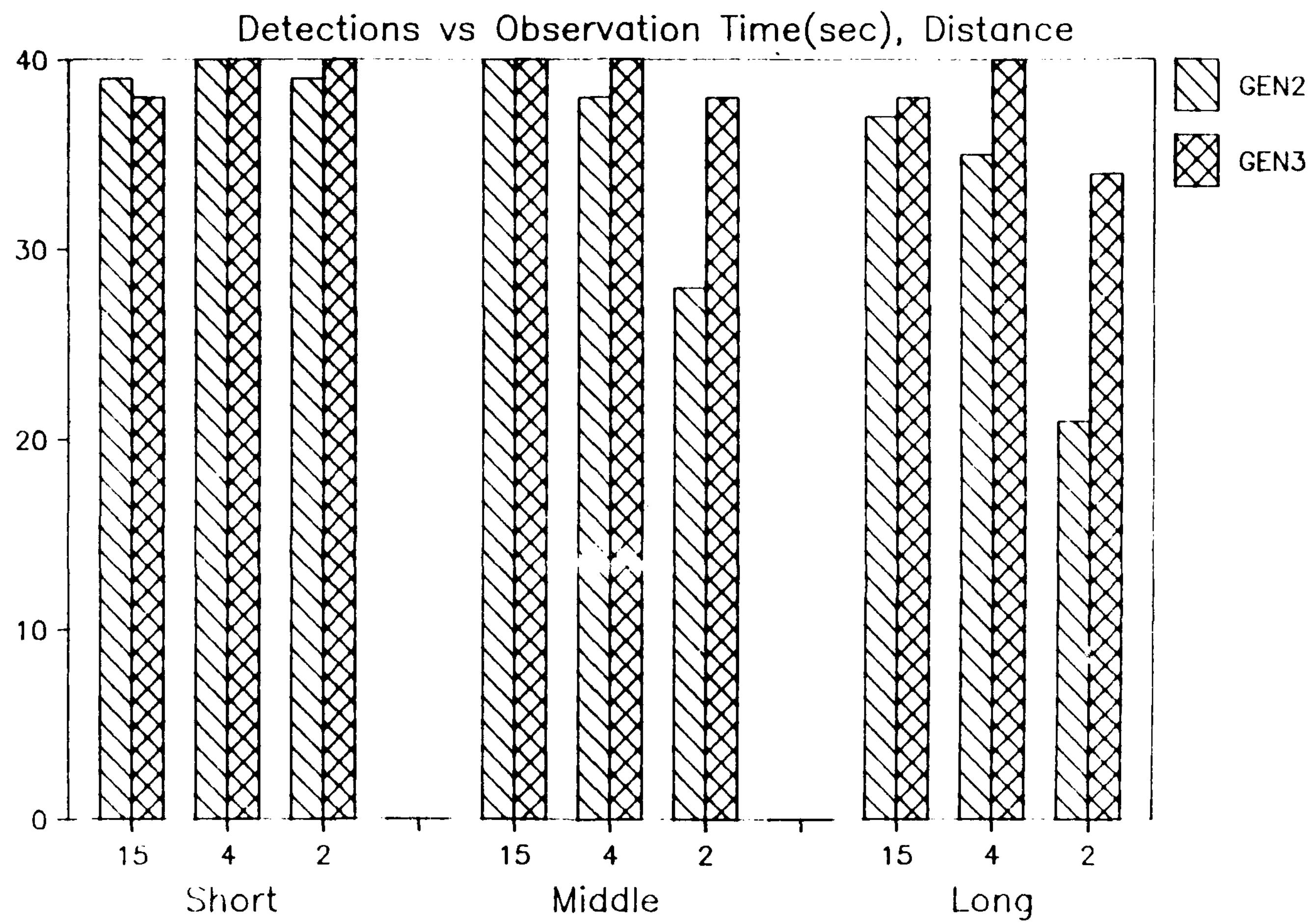


Figure 12. Histogram of Open Site (05/08/88)

The subsequent night at the open site (11 May) demonstrated no clear trends in target detection as the observation period decreased. The prime reason appears to be that the targets were simply too easy to detect. Most detection percentages were essentially 100%, with the lowest value being 85%. Consequently, it appears that there simply was not sufficient range in the results to show any trends. The reasons for the substantially higher detection percentages on this night are not at all clear. The target distances were 10 meters greater than on 8 May, and the variations in light level do not appear sufficient to account for it (see Appendix).

False Detections

As depicted in Table 4, the third generation NVGs generally registered less false detections than the second generation NVGs. It should be emphasized, however, that the false detections were also highly dependent upon human factors. One may observe, for example, that the largest number of false detections often occurred during the sequences with the **longer** observation periods (15 and 7 seconds). Although this may be an important relation, it is felt that to a large degree it is an artifact resulting from observer nervousness and inexperience; the tests always proceeded from longer to shorter observation periods. Additionally, Table 4 clearly indicates that the differences between individual observers were at times more significant than the differences between second and third generation NVGs. In other words, observers using the same generation NVG in nominally identical conditions often showed gross differences in the amount of false detections they registered. A contributing factor may have been target parallax. Each observer had a slightly different background for the targets, even though the four observers were seated within a 2 meter span. This effect was most noticeable at the cluttered site. Bearing in mind the above caveats, one can still draw several conclusions from the false detection data at each site:

Canopy Site. There do not appear to be any important differences between second and third generation NVGs regarding the amount of false detections at this site. While Table 4 (page 15) indicates that on 9 May the third generation NVGs registered twice as many false detections, this appears to be an artifact resulting from one particular observer. This individual (observer #4) started out that night with a third generation NVG, and was responsible for 10 of the 15 false detections recorded by all four observers using third generation NVGs. The impact of removing this observer's data from the overall 9 May results is reflected on the next page:

	FALSE DETECTIONS				
TIME (sec)	**15**	**07**	**04**	**02**	
Second generation	4	1	0	2	includes all four observers
Third generation	4	2	3	6	includes all four observers
Second generation	4	1	0	2	observer #4 removed
Third generation	1	0	0	4	observer #4 removed

It is apparent from the above that the false detections registered by observer #4 were so atypical in number and distribution that they skewed the overall results compiled from all four observers. It is plausible that nervousness accounted for this observer's unusual performance at the beginning of this night's test.

It is recognized that the respective false and true detection results registered by a given observer may not be separable. In other words, an observer's performance in one category may have a bearing on his performance in the other. Consequently, if a given observer's false detection data is removed as an anomaly, it makes sense to also remove his true detection data and reexamine overall results in that category. Performing this operation resulted in no significant changes to the trends described earlier. In fact, the trends were generally reinforced by this operation. This is illustrated by the histogram layout in Figure 10 (page 19).

Cluttered Site. For both nights at this site, the second generation NVGs were clearly associated with greater numbers of false detections. The more extensive 10 May data shows this trend for each observer, as indicated below:

	FALSE DETECTIONS				
TIME (sec)	**15**	**07**	**04**	**02**	**TOTAL**
Observer #1					
Second generation	8	1	1	6	16
Third generation	0	2	1	1	4
Observer #2					
Second generation	5	1	1	0	7
Third generation	1	0	0	0	1
Observer #3					
Second generation	4	6	3	0	13
Third generation	0	4	0	1	5
Observer #4					
Second generation	1	1	1	1	4
Third generation	0	0	1	0	1

It should be noted that observer #1 was fooled during his first sequence (2nd gen NVG, 15 sec) by a background clutter pattern bearing a remarkable resemblance to a standing man-target. But even if the eight false detections he registered for this sequence are removed from the above compilation, second generation NVGs still appear to be clearly associated with significantly more false detections.

Open Site. There were no significant differences in the number of false detections registered by the two generations on the night of 11 May. As stated previously, the targets were far too easy to detect on this night, for whatever reason. On the night of 8 May, however, the second generation NVGs registered three times as many false detections (12 *vs.* 4). The overall amounts of false detections are nevertheless considered to be too small to warrant any assertions about trends.

Section IV

Conclusions

1 The three field test sites are classic examples of the pine canopy, the cluttered scene, and the open range, respectively. The pine canopy featured extremely low scene illumination in conjunction with moderate target contrasts (approximately 30%). The cluttered site featured low scene illumination in conjunction with very low (approximately 10%) target contrasts. The open site featured low scene illumination in conjunction with relatively high (approximately 60%) target contrasts. The artificial light contamination was negligible at all three sites.

2 Target placement was fully optimized only at the pine canopy site. Target distances appeared to be nearly optimum at the cluttered site, but the azimuthal location of some targets could have been improved. For example, some targets were much harder to see than other targets at the <u>same</u> distance. At the open site, the target distances always appeared to be short of optimum.

3 At each of the three sites, the third generation NVGs detected more targets than the second generation NVGs. The third generation NVGs detected 93% more targets at the pine canopy, 17% more targets at the cluttered site, and 6% more targets at the open site. The ease of target detection at the open site may have obscured underlying trends in system performance.

4 At the cluttered site, the second generation NVGs recorded 155% more false detections than the third generation NVGs. This may have been related more to low image contrast than to noisier imagery, as discussed below. At the two other sites, there were no significant differences in the respective numbers of false detections.

5 The prime objective of these field exercises was to ascertain if, as allowed observation time decreased, second generation NVGs would degrade in detection capability faster than third generation NVGs. The results from two of the three sites appear to support this hypothesis. At both the pine canopy and open sites, there were several instances where the second and third generation NVG detections were essentially identical at the longer observation times. As the observation periods decreased, however, the second generation NVGs lost 35 to 45% of this performance, while the third generation NVGs lost 10% or less. The greatest degradation generally occurred as the observation period decreased from 4 to 2 seconds. Such trends were most dramatic at the pine canopy site, presumably because of its extremely low light levels. At the cluttered site, the second generation observers split fairly equally between those who registered significant detection drops with decreasing observation time, and those who registered little or no change. Third generation detection performance was generally more stable with decreasing observation time, but again there was significant variation among the observers. Consequently, the cluttered site results do not appear to support any assertions about detection performance as a function of observation time.

6 Image contrast, rather than signal-to-noise, appeared to be an overwhelmingly predominant factor in determining second and third generation NVG performance at the cluttered site. It is noted that the targets were set up at each site to span the 50% detection probability point. Consequently, cluttered site targets were three times as close as the high contrast open site targets, and were somewhat closer than the moderate contrast canopy site targets. Cluttered site irradiance levels, however, were similar to open site levels, which put them around six times higher than the canopy site levels. It follows from the above that image signal-to-noise was only a minor factor in determining detection performance at the cluttered site. The hypothesis that second generation NVG detection performance degrades faster than corresponding third generation NVG performance with decreasing observation time, however, was based purely on a signal-to-noise argument. It is therefore not surprising that the cluttered site results do not support this hypothesis.

Section V

Recommendation

The three sites utilized for this field test offer classic examples of three types of terrain found in battlefield scenarios. Each site is readily accessible, and each has negligible artificial light contamination. It is accordingly recommended that these sites be considered for any future field testing addressing performance differences between second and third generation NVGs.

References

1 R. Stefanik, *Night Sky Radiometric Measurements During Follow-On Evaluation Testing of AN/PVS-7 (A, B) at Fort Benning, GA*, AMSEL-NV-TR-0079, CECOM, C2NVEO, May 1989.

2 M. Vatsia, K. Stich, and D. Dunlap, *Night Sky Radiant Sterance from 450 to 2000 Nanometers*, Research and Development Technical Report, ECOM-7022, September 1972.

3 H. Pollehn, *Analysis of Field Tests Comparing Second and Third Generation Image Intensifiers* (Working Paper), CECOM, C2NVEO, July 1986.

4 RCA, *Electro-Optics Handbook*, Technical Series EOH-11, 1974.

Appendix

Figures

Section A-I
Master Sequence

Trial Number	Azimuth Location		
	Left	Center	Right
1	S	S	—
2	—	M	S
3	—	—	—
4	M	L	L
5	L	—	—
6	—	—	M
7	—	—	—
8	L	S	M
9	S	—	S
10	—	—	—
11	—	M	—
12	M	L	L
13	—	S	—
14	L	—	M
15	—	—	—
16	S	M	—
17	—	—	—
18	M	L	S
19	—	—	L
20	L	S	M

NOTES:

S Target presented at the "short" distance.
M Target presented at the "middle" distance.
L Target presented at the "long" distance.
— No target presented.

Section A-II
NVG Laboratory Characterization

Due to the extremely limited availability of nearly all the NVGs utilized in this field exercise, comprehensive laboratory evaluation of the systems and their tubes could not be performed. Consequently, it was decided that the laboratory evaluation would consist of both high light level and noise-limited resolution measurements of the systems. The former is measured after the target brightness is adjusted for maximum image sharpness. The latter is measured at an extremely low target brightness where the tube's relative signal-to-noise ratio is the primary determinant of the maximum resolution that can be observed.

The high light level resolution was measured at a target brightness of 2.6×10^{-3} footlamberts, which roughly corresponds to full moon conditions; this was the highest brightness attainable in the laboratory setup. The noise-limited resolution was measured at a target brightness of 1.0×10^{-5} footlamberts, which roughly corresponds to low starlight conditions. In each case, the target consisted of a back-illuminated 1951 Air Force Resolution Chart having 100% contrast black bars on a bright background.

Serial No. NVG Type	Tube Generation	High Light Level Resolution (cyc/mr)*	Noise-Limited Resolution (cyc/mr)
01043 "B"	Second	0.754	0.299
00040 "A"	Second	0.847	0.336
00033 "A"	Third	0.950	0.423
00044 "A"	Third	0.847	0.377

NOTES:

* cycles per milliradian

"B" AN/PVS-7B NVG

"A" AN/PVS-7A NVG

Section A-III
Radiometric Characterization

The only way to completely characterize the irradiance during field testing of image intensifiers is to perform a spectroradiometric scan over the spectral region of interest. This would generate data in terms of power per unit wavelength. Unfortunately, spectroradiometric equipment of the required sensitivity was not available for this field test.

The most readily available equipment was photometric, and as such was designed to measure scene illumination in terms of the brightness to the human eye. The typical unit is the "footcandle (fc)," which is defined as one incident lumen (photopic radiation) per square foot. The spectral sensitivity of the human eye, however, is vastly different from that of either the second or third generation image intensifier. Second generation's spectral sensitivity extends from the near-ultraviolet to the near-infrared. Third generation's spectral sensitivity, in contrast, has little or no component in the violet to blue-green region. The majority of its response lies in the near-infrared region, where there is far more natural night sky energy than in the visible region. Consequently, photometric characterization is intrinsically incomplete when used in conjunction with image intensifiers. Furthermore, it can be quite misleading when one is comparing second *vs.* third generation intensifiers in the presence of artificial light contamination. Such contamination is deliberately concentrated in the visible region, where second generation is generally more sensitive than third generation. The degree of advantage that this would confer to second generation over third generation cannot be ascertained from photometric information alone.

In order to more completely characterize night sky irradiance, the Image Intensifier Engineering Team devised a measurement setup utilizing three photometers. (See "Spectral Data Acquisition and Computations" in Stefanik's report.[1]) The first operates as a standard photometer, but the other two were modified so as to have a second generation spectral response and a third generation spectral response, respectively (see Figure A-1).

Figure A-1. Photometric/HN2/HN3 Measurement System

The outputs of the two modified photometers can be analyzed in order to yield a normalized irradiance for second generation (HN2) and third generation (HN3). The normalized irradiances are a measure of the incident radiation in the two respective passbands. These values are normalized such that the photopic illuminance (fc), HN2, and HN3 all have the same numerical value (7.39×10^{-5}) for a natural moonless night sky. The natural moonless night sky spectral distribution was defined as the average of the Vatsia, et al, data.[2]

The usefulness of the normalized second and third generation irradiances may be illustrated by the following:

- If the moonless night sky irradiance were natural (i.e., no artificial light), the numerical value of HN2 would equal that of HN3. The third generation intensifier would yield a substantially better signal-to-noise (S/N) characteristic than the second generation intensifier, by virtue of the former's much higher sensitivity.

- If the night sky irradiance were artificially contaminated with photopic-efficient lighting (i.e., more power in the visible region), HN2 would be greater than HN3. The S/N characteristic for the second generation intensifier would thereby be closer to that of the third generation intensifier. This would tend to yield a smaller performance difference than the previous condition. (See "Parameters Affecting Image Intensifier Performance" in Pollehn's working paper.[3])

The general nature of the irradiance at each field test site can be depicted by two dimensional plots utilizing combinations of the HN2, HN3, and photopic (fc) data. In the first type of plot, both the HN2 and HN3 readings are divided by the corresponding photopic (fc) readings. The horizontal and vertical axes are then defined to be HN3/fc and HN2/fc, respectively. Each set of measurements is accordingly represented as a point whose coordinates are (HN3/fc, HN2/fc).

Such points can then be compared to points resulting from characteristic distributions of radiation, both natural and artificial. Comparing the measurement points to the "reference" points can give one an understanding of the general distribution of night sky radiation. Refer to Figure A-2. Proceeding out from the origin, one first finds "M," which stands for "mercury lamp." This radiation is heavily concentrated in the blue, so the x- and y-axis values are well less than unity. One next finds "S," which stands for "sodium lamp." This lamp's radiation has major peaks in the red and near-infrared, which result in higher x- and y-axis values than those for mercury lamps. One next finds "F," which signifies "flat distribution," or equal values of energy for all wavelengths. The corresponding x- and y-axis values are somewhat less than one, since Vatsia's baseline night sky has a heavier concentration of near-infrared radiation. One next finds "V," which marks the unity coordinates (by definition) of the baseline distribution of radiation measured by Vatsia, et al.[2] The next-to-last symbol is "R," which stands for the estimate of average night sky irradiance given in the RCA Electro-Optics Handbook.[4] The final symbol "B" denotes the distribution of radiation associated with a 2856K blackbody, which is the standard for all laboratory measurements.

Figures A-2, A-3, and A-4 present the radiometric data generated at the canopy, cluttered, and open sites, respectively. In these two dimensional plots, each point signifies a single measurement from a set of five measurements consisting of the four cardinal directions plus vertical. The measurements are identified by night, but are not broken down by direction. Data from all directions, however, is included in each plot.

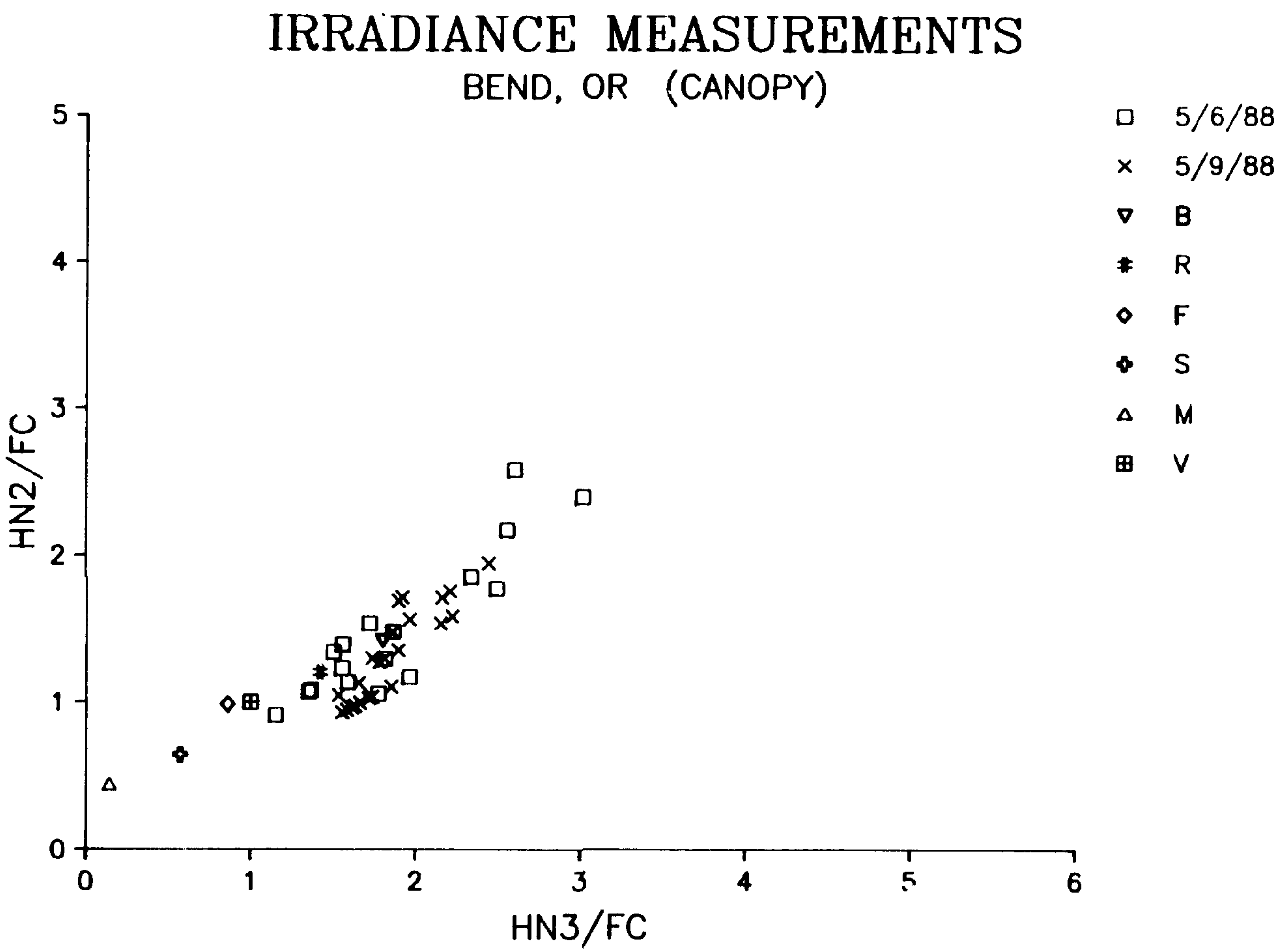


Figure A-2. Canopy Site, HN2/fc *vs.* HN3/fc

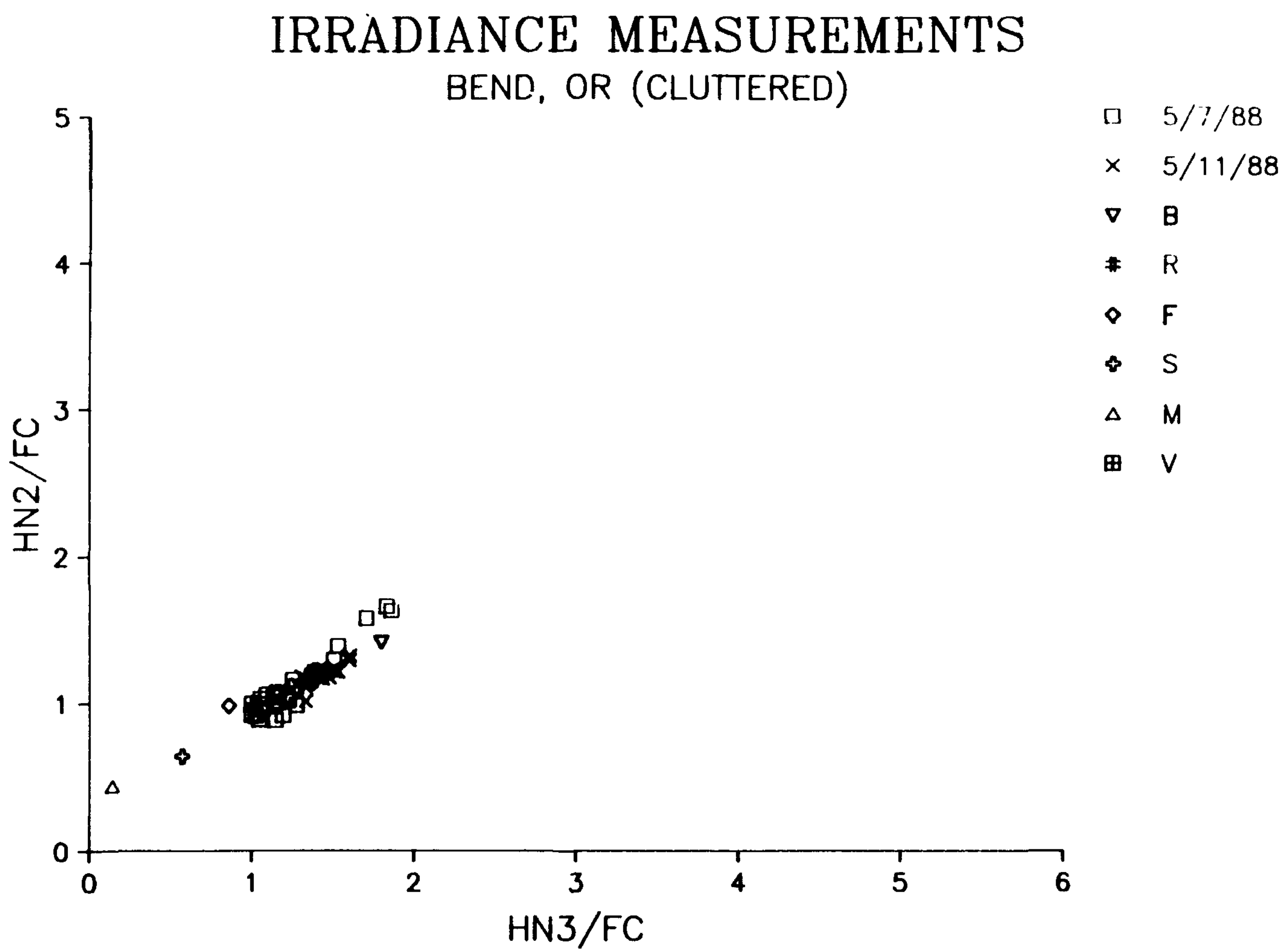


Figure A-3. Cluttered Site, HN2/fc *vs.* HN3/fc

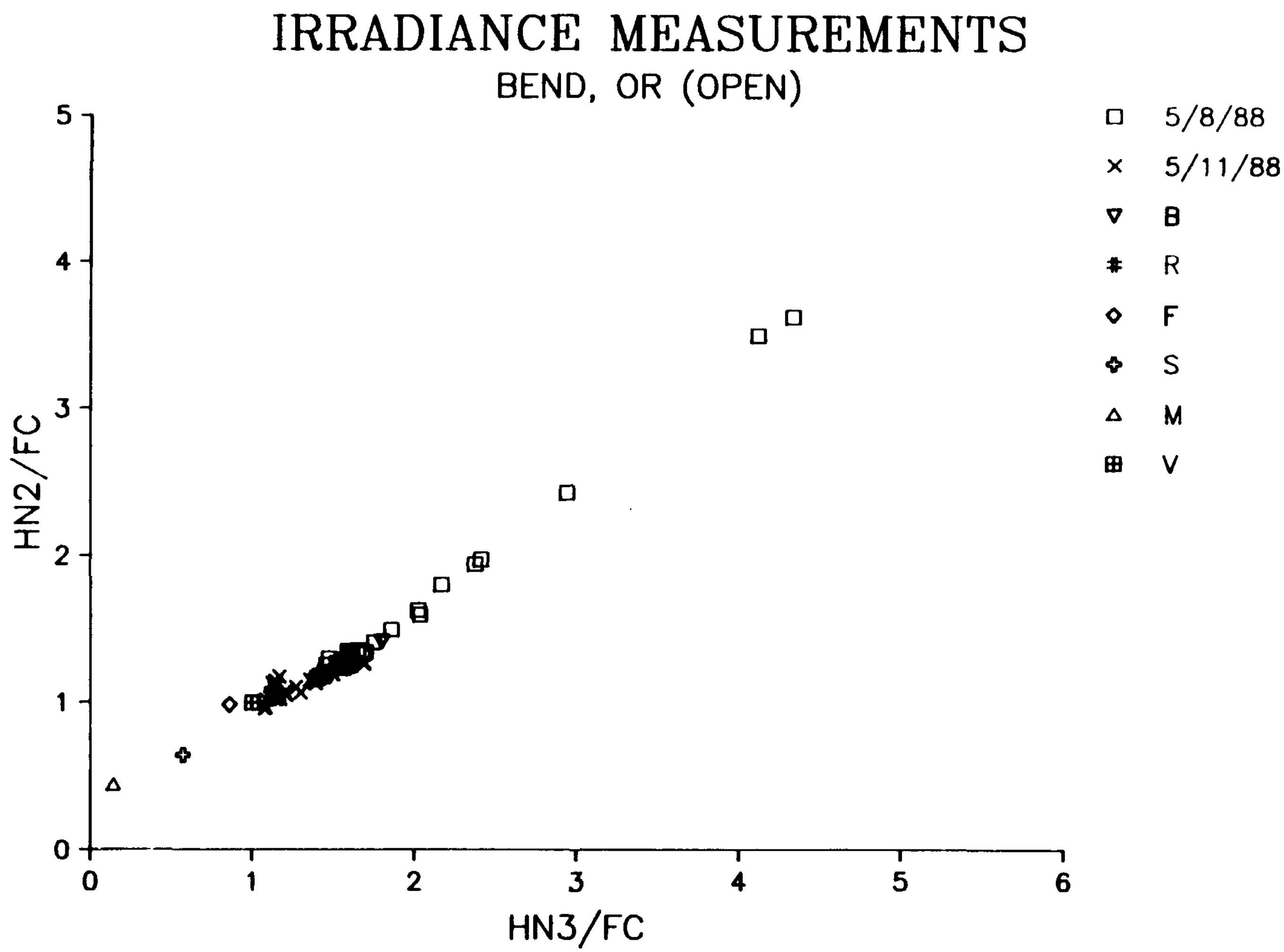


Figure A-4. Open Site, HN2/fc *vs.* HN3/fc

Even a cursory examination of these three plots indicates that there was little or no artificial contamination. The data points for all three sites lie far away from the mercury or sodium lamp positions, and in fact indicate a substantially higher near-infrared component than the Vatsia distribution. For the cluttered site, the points cluster in the "V" to "B" region. For the canopy site, the points tend to loosely cluster around the blackbody distribution ("B") point. This large near-infrared component probably resulted from the greater incidence of multiple reflections off trees and foliage which one would expect in a canopy environment.

The open site data presents an interesting disparity in results between the two nights of testing. The 5/11/88 data is strongly clustered in the "V" to "B" region, similar to the cluttered site data. The 5/8/88 data, however, indicates periods during which the near-infrared component was even more predominant than at the canopy site. This "infrared burst" is considered in more detail at the conclusion of this section.

The second type of plot has a horizontal axis consisting of the photopic value (fc), with the corresponding value of either HN2/fc or HN3/fc as the vertical axis. Refer to Figure A-5. The letter symbols are as previously defined; but now each symbol identifies a horizontal line, rather than a single point as before. The Vatsia distribution line, which would intersect the vertical axis at its unity value, is not separately indicated here because of its close proximity to the flat distribution ("F") line. Each field test site has two corresponding plots—the first being HN2/fc *vs.* fc, and the second being HN3/fc *vs.* fc. As before, each plot presents the data points from the five directions, identified by the particular night.

Figures A-5 through A-10 present the data generated in this format for the canopy, cluttered, and open sites, respectively. These graphs clearly indicate that each site had fairly consistent values of photopic radiation. The canopy site had values clustering in the 8 to 12 x 10^{-6} fc range, while the values for the cluttered site clustered in the 6 to 9 x 10^{-5} fc range. The open site values, except for the "infrared burst," clustered in the 7 to 10 x 10^{-5} fc range. These graphs also indicate that there was no consistent relationship between a given photopic value and the corresponding measurements of HN2 and HN3. Here is another graphic demonstration of the limited value of using photometers to characterize conditions for image intensifiers, even in the absence of artificial light contamination.

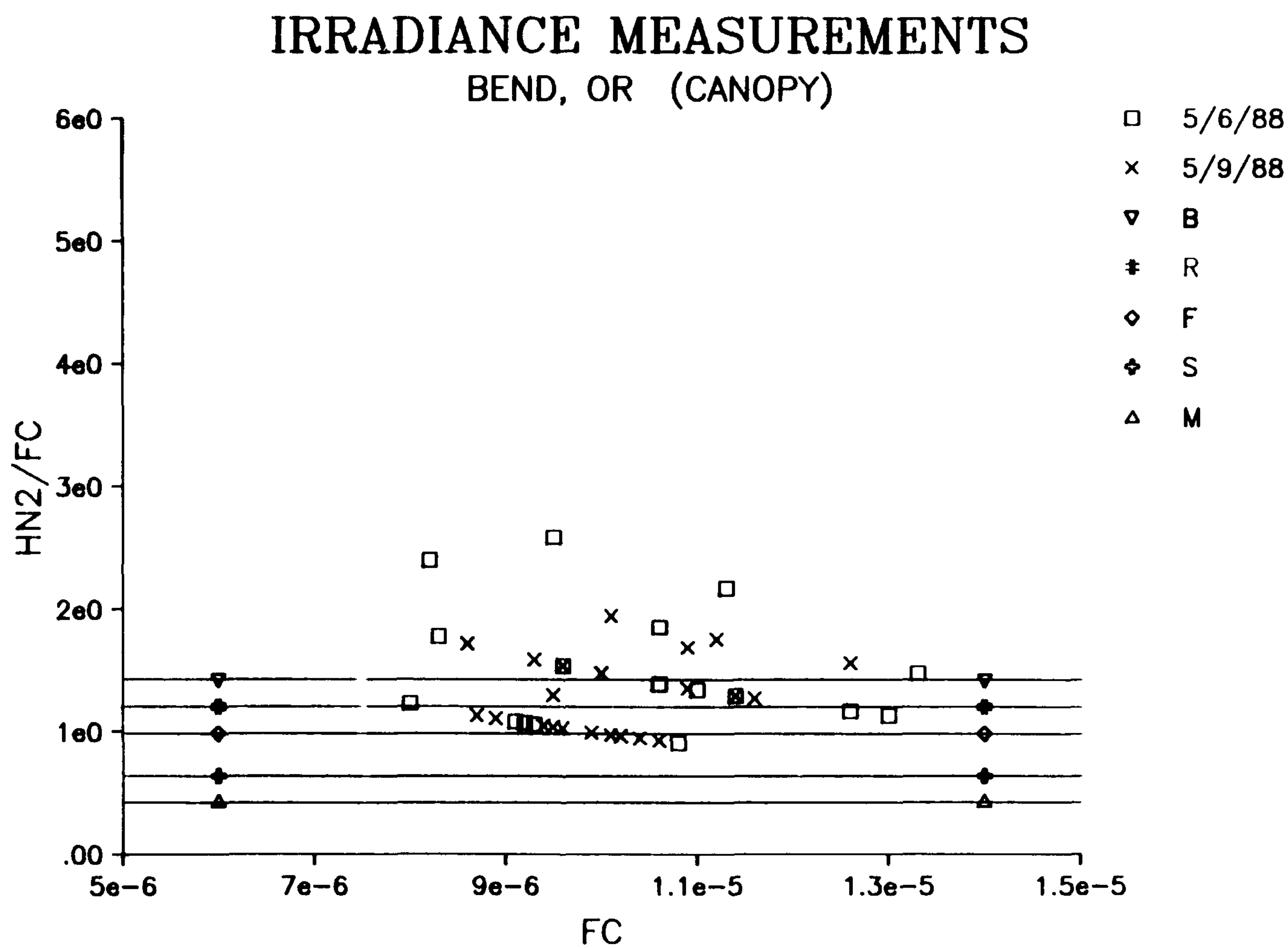


Figure A-5. Canopy Site, HN2/fc *vs.* Photopic

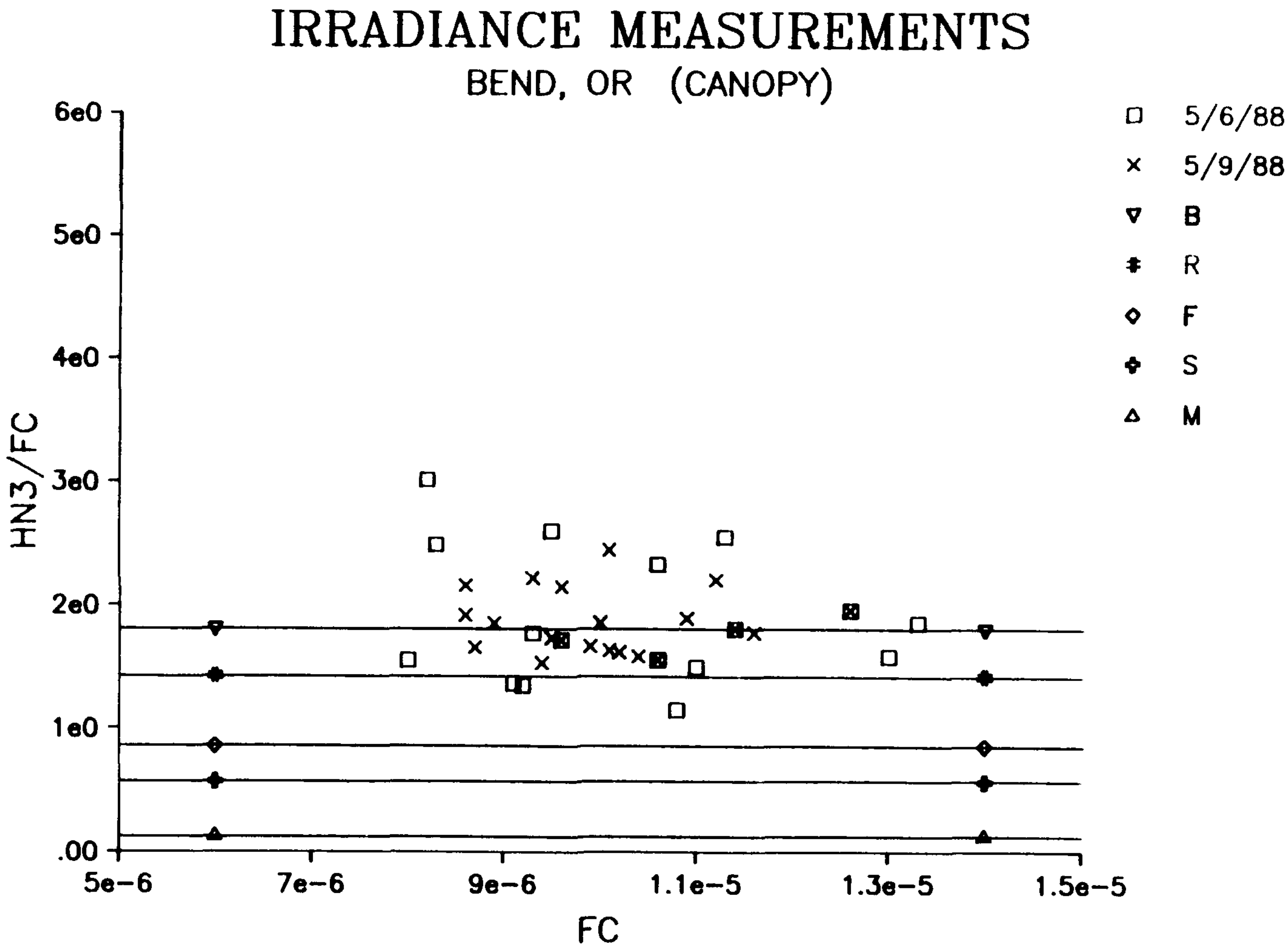


Figure A-6. Canopy Site, HN3/fc *vs.* Photopic

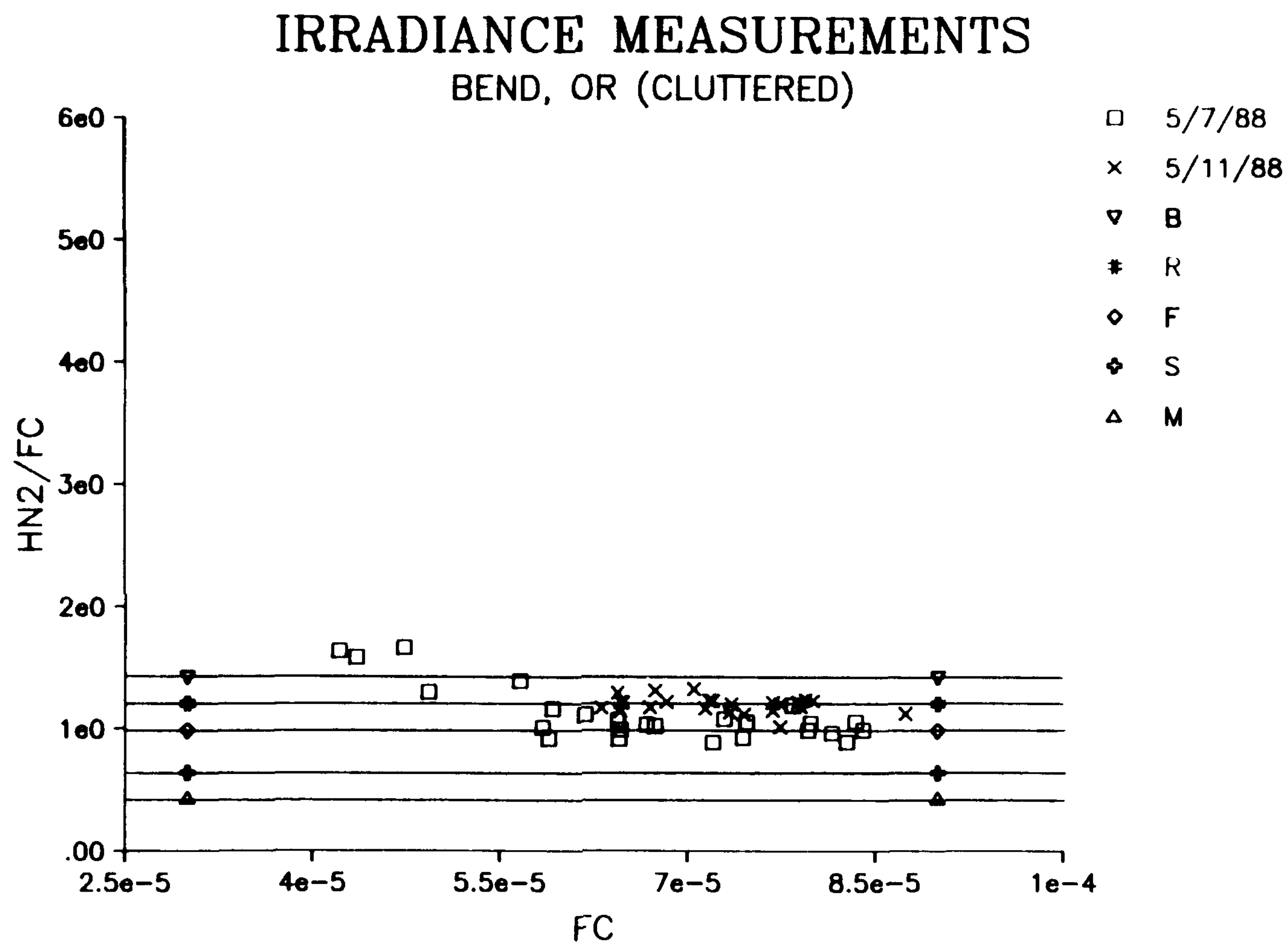


Figure A-7. Cluttered Site, HN2/fc *vs.* Photopic

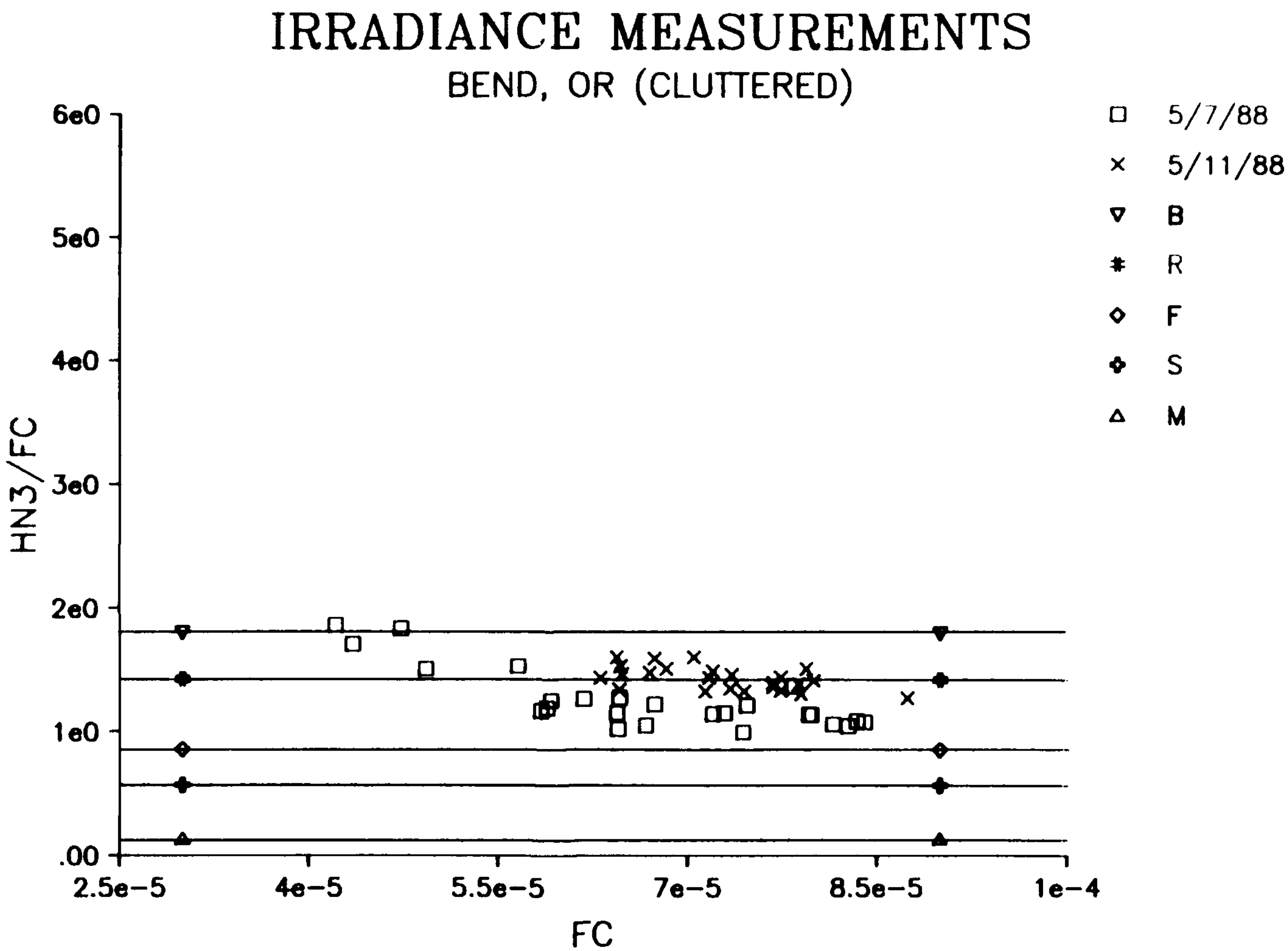


Figure A-8. Cluttered Site, HN3/fc *vs.* Photopic

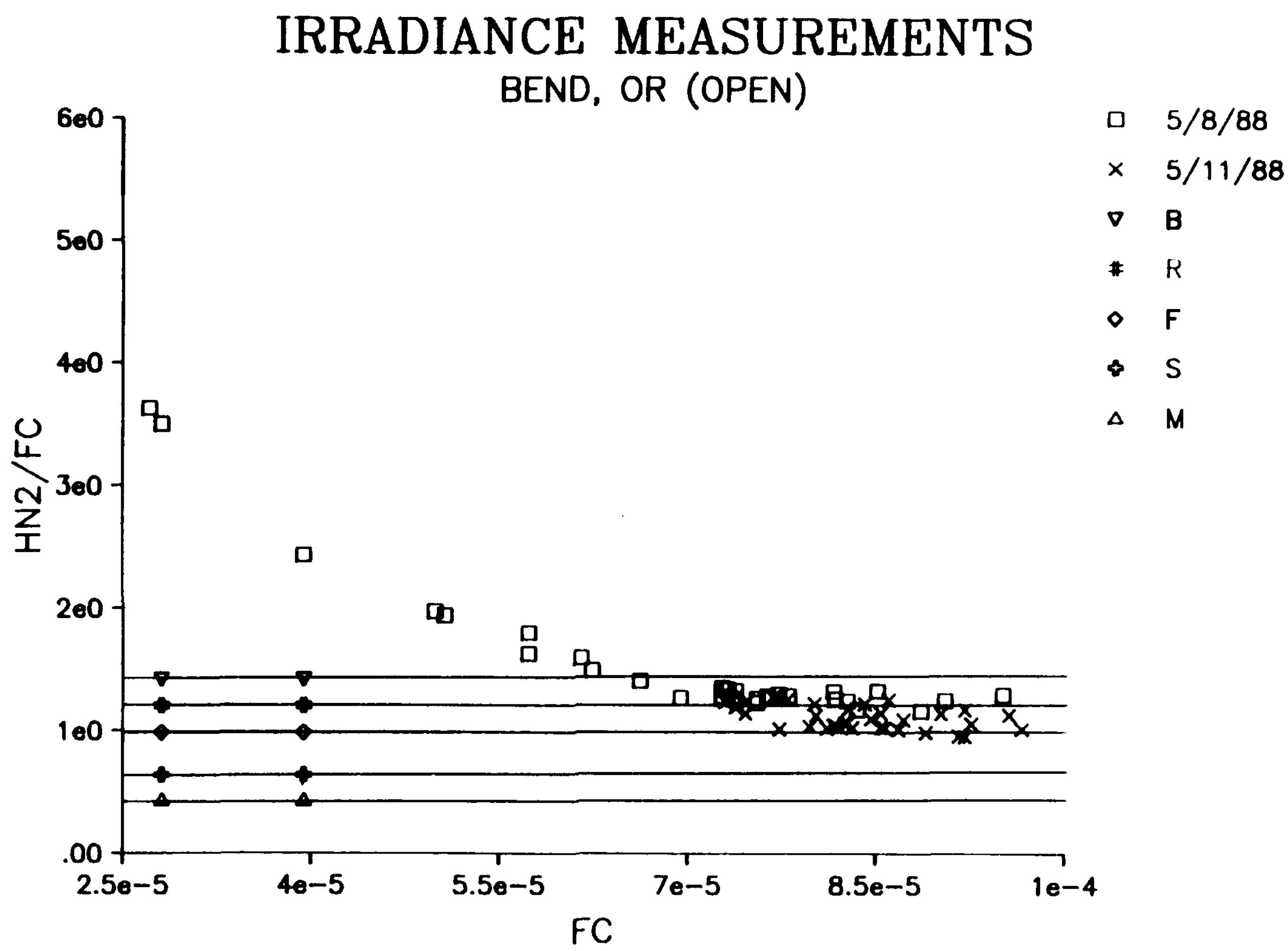


Figure A-9. Open Site, HN2/fc *vs.* Photopic

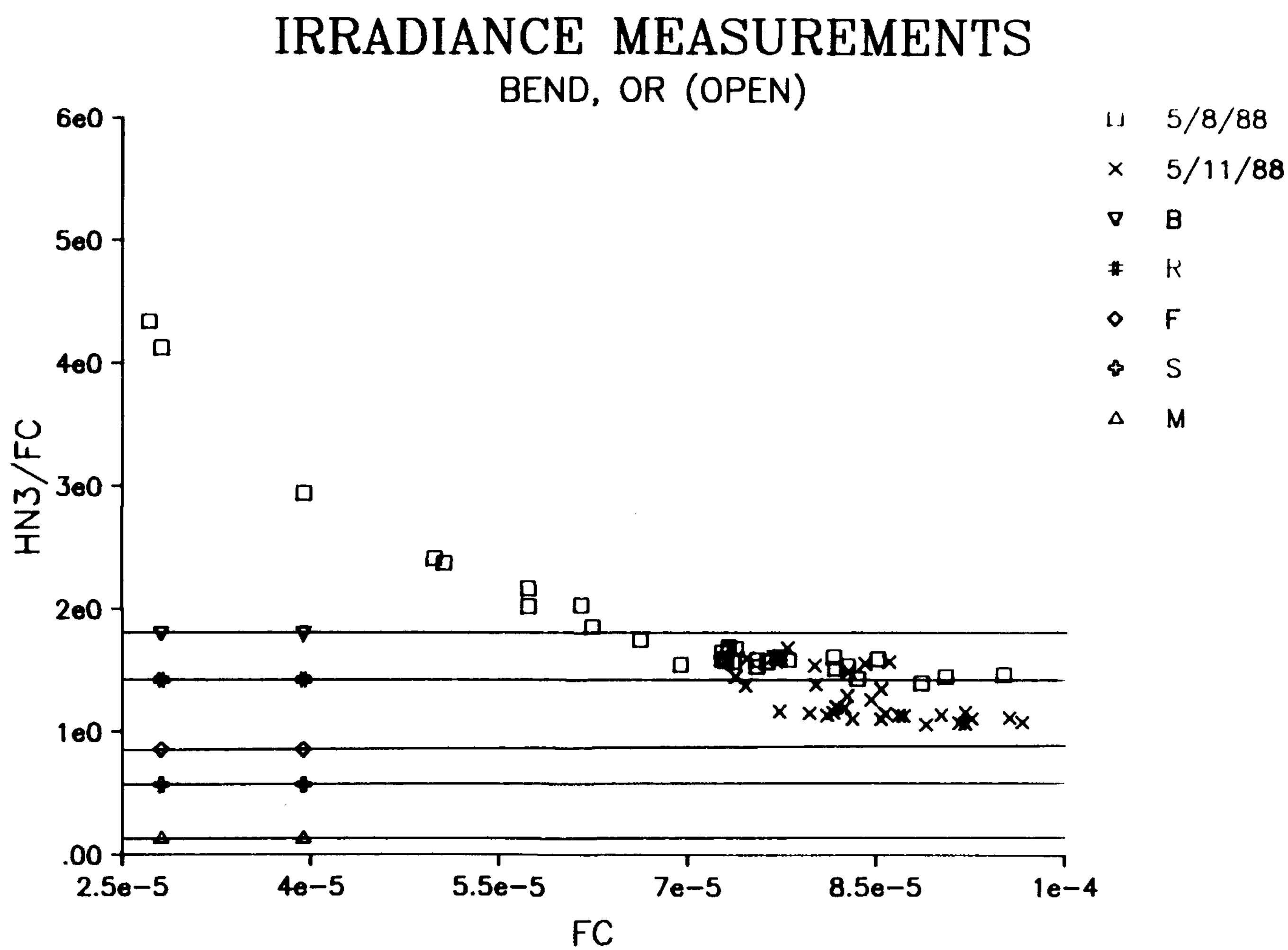


Figure A-10. Open Site, HN3/fc *vs.* Photopic

One unexpected trend indicated by these graphs was that the open site radiation generally had a greater near-infrared component than the cluttered site, even though the latter had more foliage. Moreover, late on the night of 5/08/88, there was an "infrared burst" at the open site. Actually, this was more a case of the HN2 and HN3 values staying basically the same over a period where the photopic values fell by a factor of three (9 to 3 x 10^{-5} fc). It is noted that during this period, a "bright" cloud over the nearby town (Sisters) dispersed and was replaced by "dark" clouds which obscured some stars. In any case, there was no significant difference in the NVG detection statistics for Run #1 conducted at the high photopic levels *vs.* Run #2 conducted at the low photopic levels (see pages A-30 through A-35, Specific Sequence Results, OP08 (Run#1) *vs.* OP09 (Run #2)). This is further reinforcement for the argument that NVG performance is a function of HN2/HN3, not photopic levels.

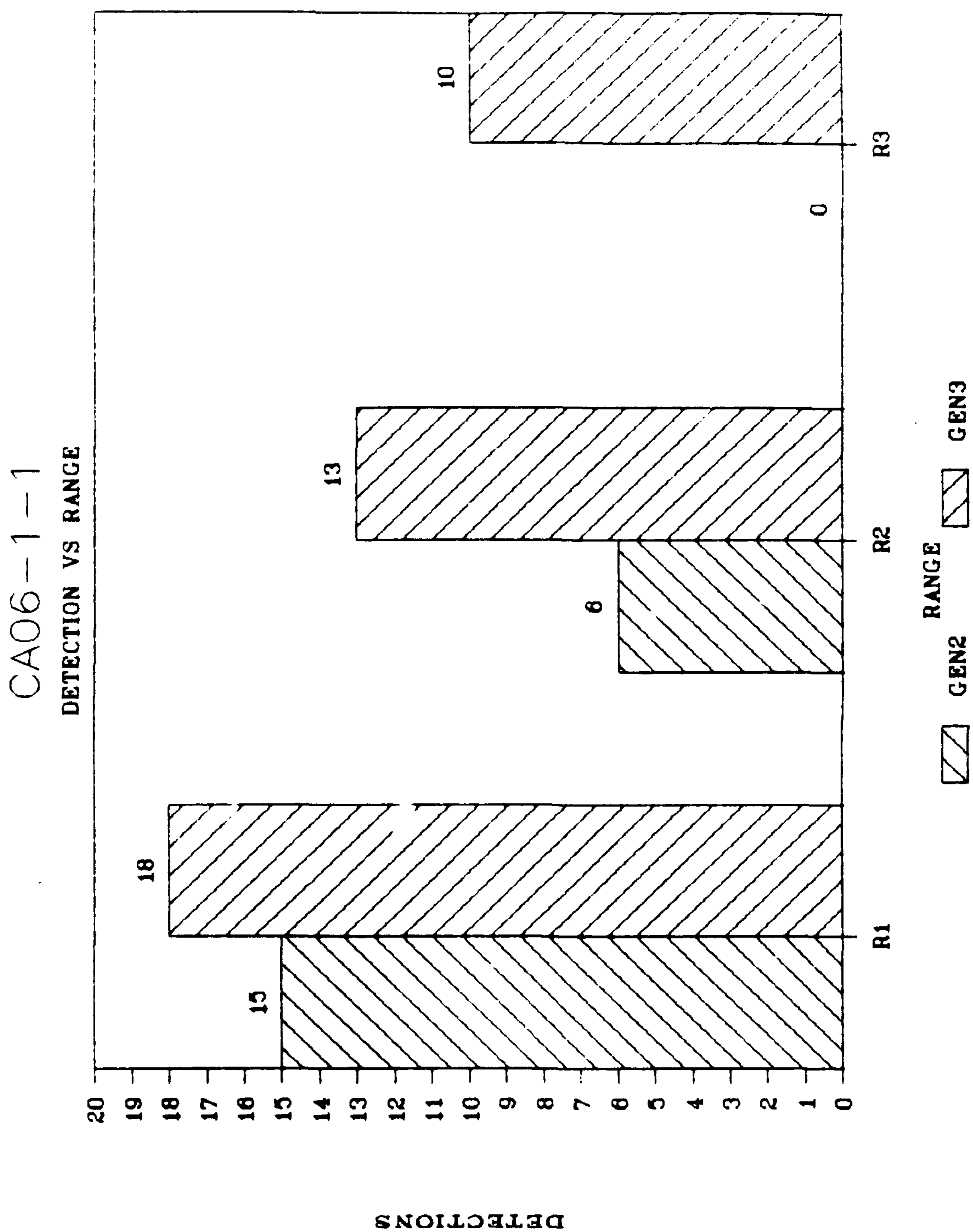
Section A-IV
Specific Sequence Results

This section presents the detections recorded for the second generation NVGs and the third generation NVGs for each of the sequences where useful data was taken. Each histogram layout has an identifier of the following format:

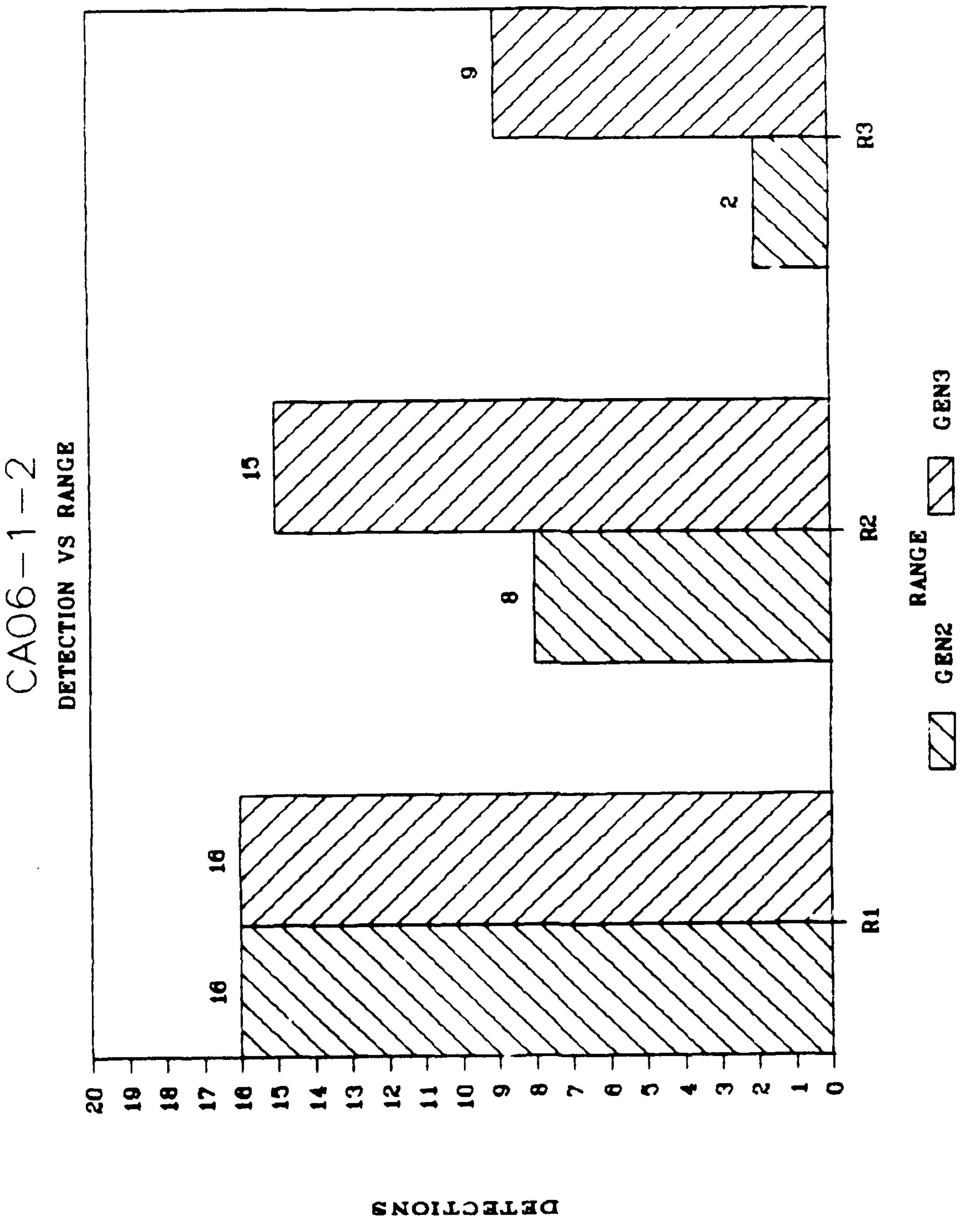
AAXX-Y-Z

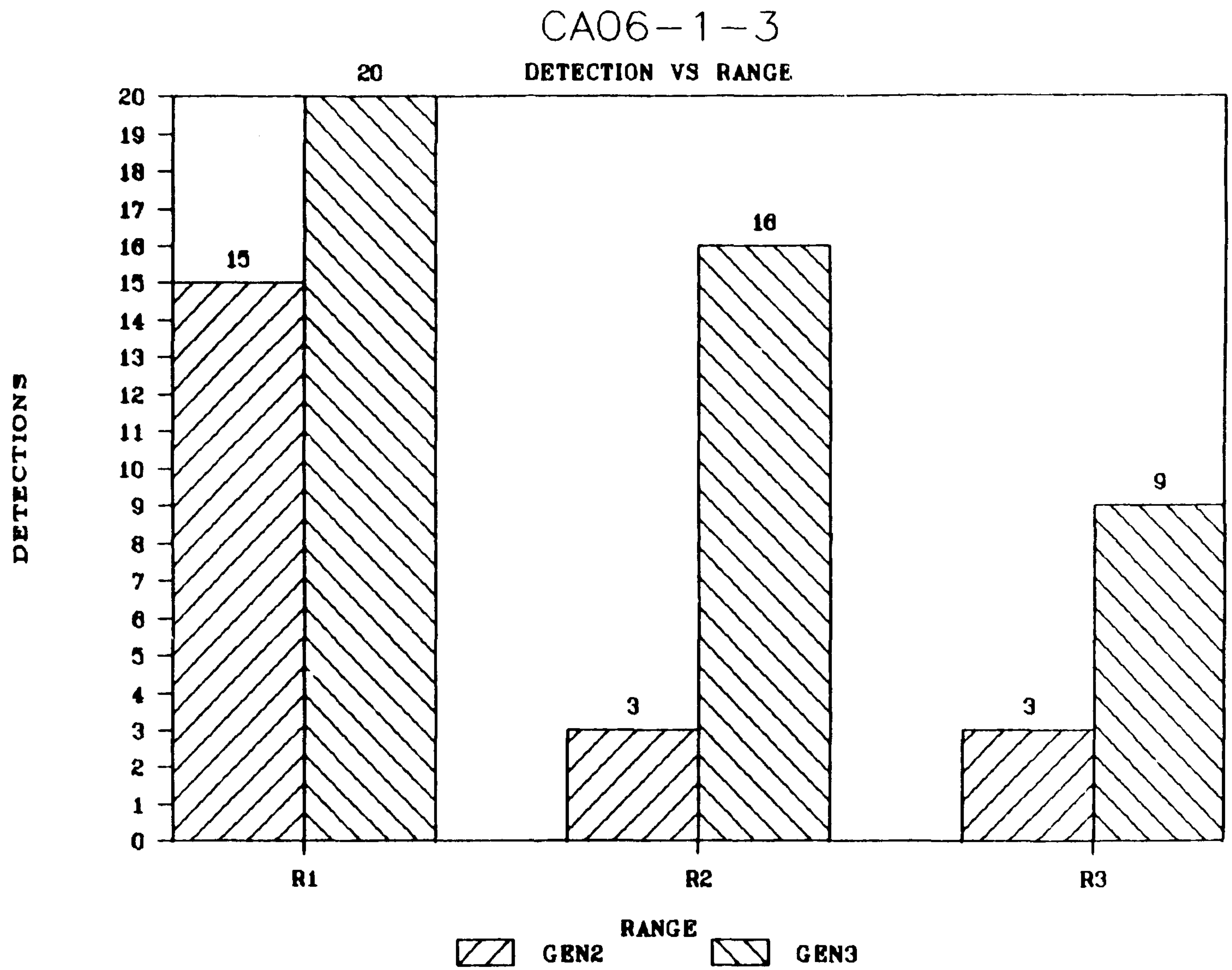
The first two symbols (AA) are letters denoting the specific test range, where "CA" denotes the canopy site, "CL" denotes the cluttered site, and "OP" denotes the open site. The next two symbols (XX) are numbers denoting the day in May 1988 during which the given sequence was conducted. The next symbol (Y) is a number denoting the particular run of which the given sequence was a part. The last symbol (Z) is a number identifying the allowed observation period for the sequence in question; the 15 second period is denoted by "1," the 7 second period by "2," the 4 second period by "3," and the 2 second period by "4."

On each histogram, "R1," "R2," and "R3" correspond to the "short," "middle,"and "long" target distances, respectively, as defined in Table 2 (page 13) of the report.



CA06 — 1 — 1
DETECTION VS RANGE
DETECTIONS
RANGE
R1
R2
R3
15
18
6
13
0
10
GEN2
GEN3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20


CA06-1-2
DETECTION VS RANGE
DETECTIONS
RANGE
R1
R2
R3
16
16
8
15
2
9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
GEN2
GEN3


CA06-1-3
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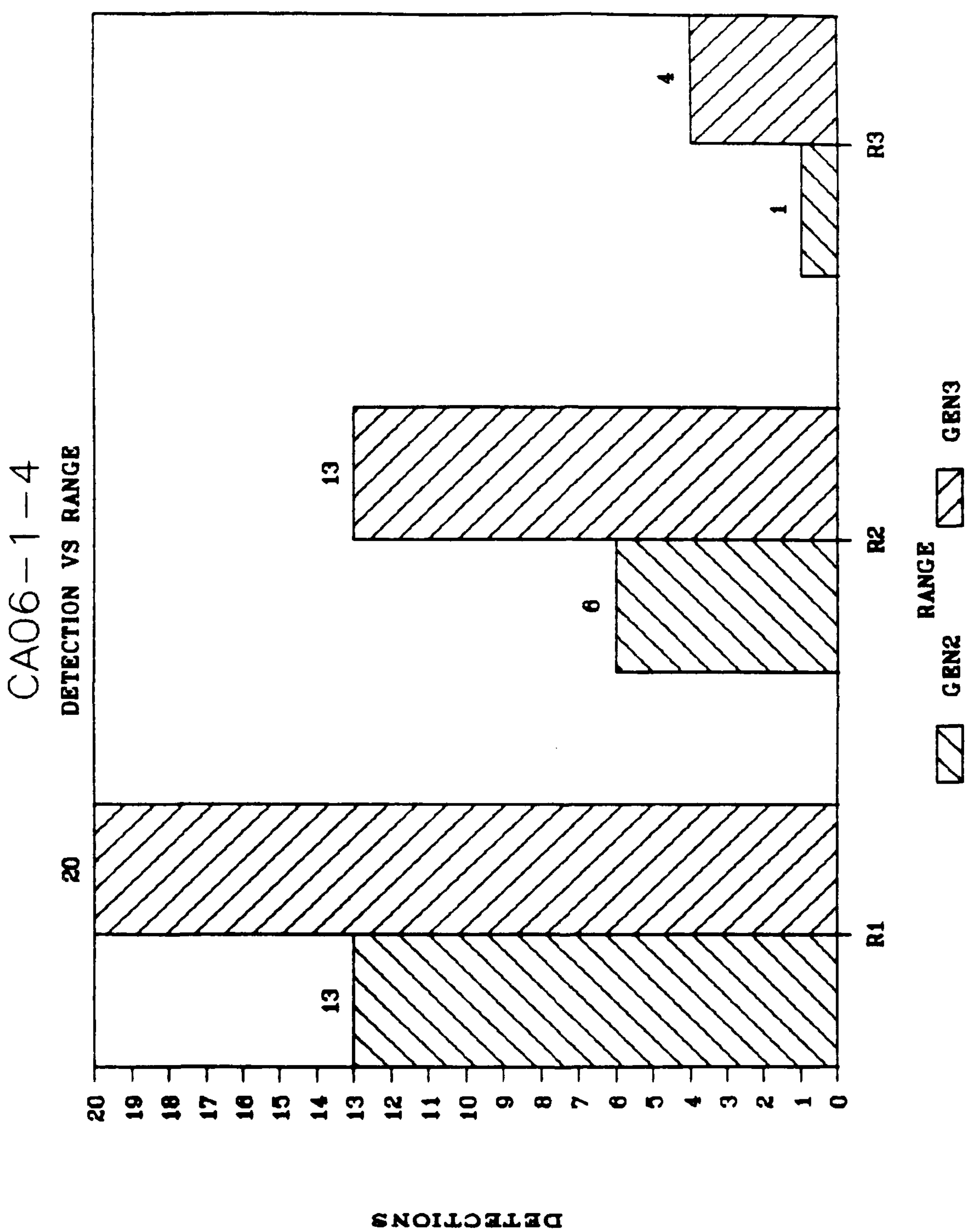
R3
RANGE
GEN2
GEN3



CA06-1-4
DETECTION VS RANGE
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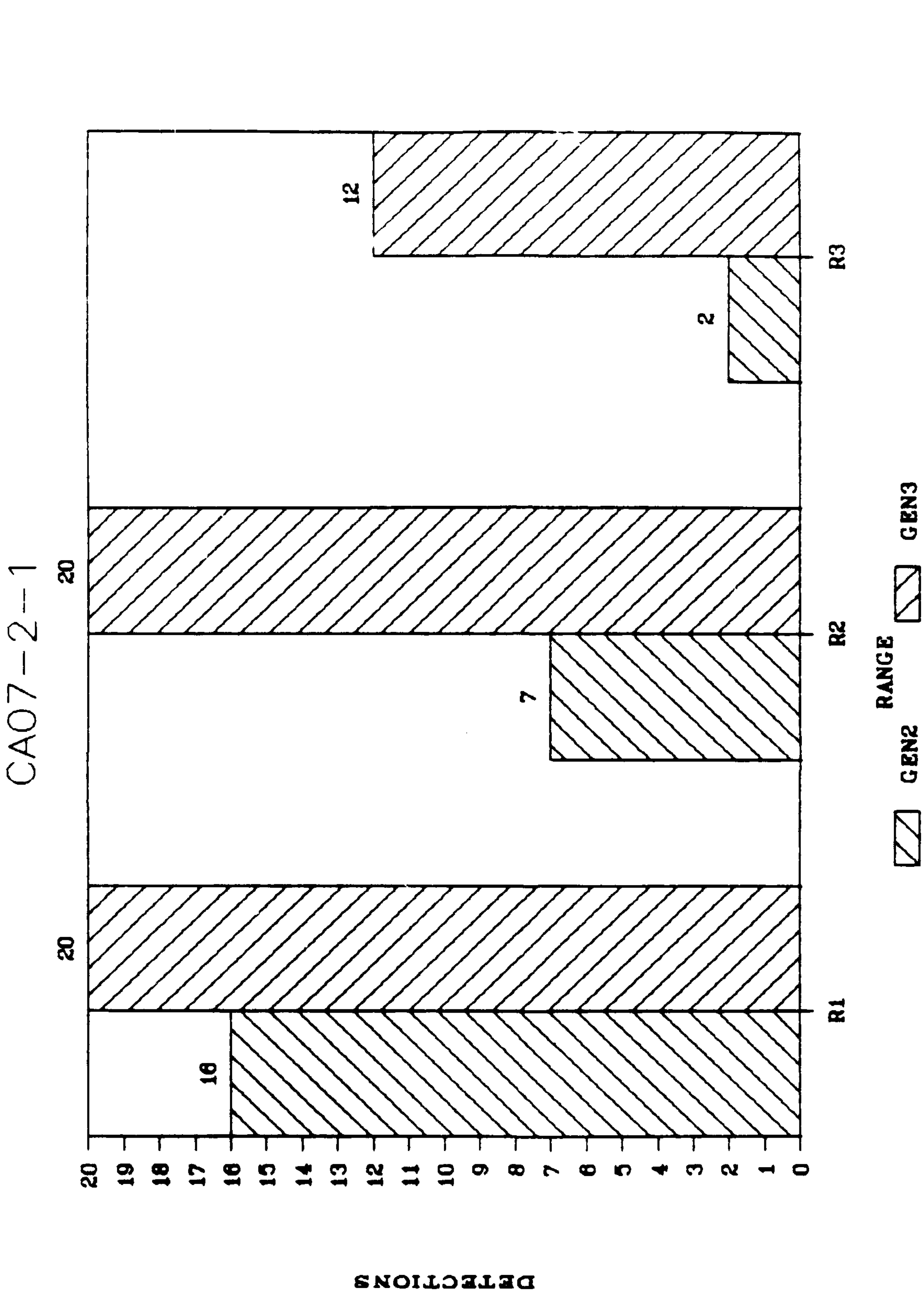
R1
R2
R3
RANGE
GEN2
GEN3


CA07-2--1
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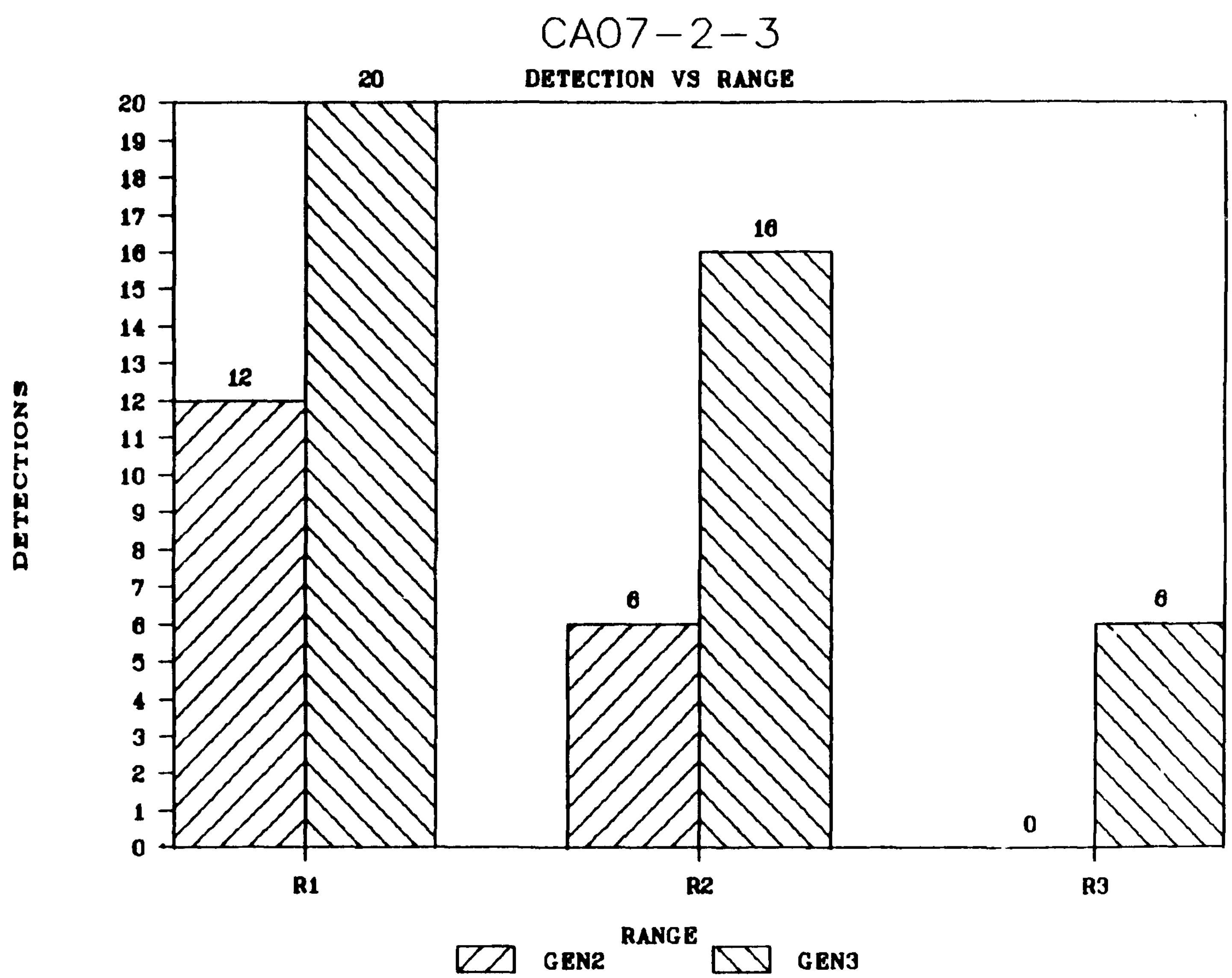
R1
R2
R3
RANGE
GEN2
GEN3



CA07-2-3
DETECTION VS RANGE
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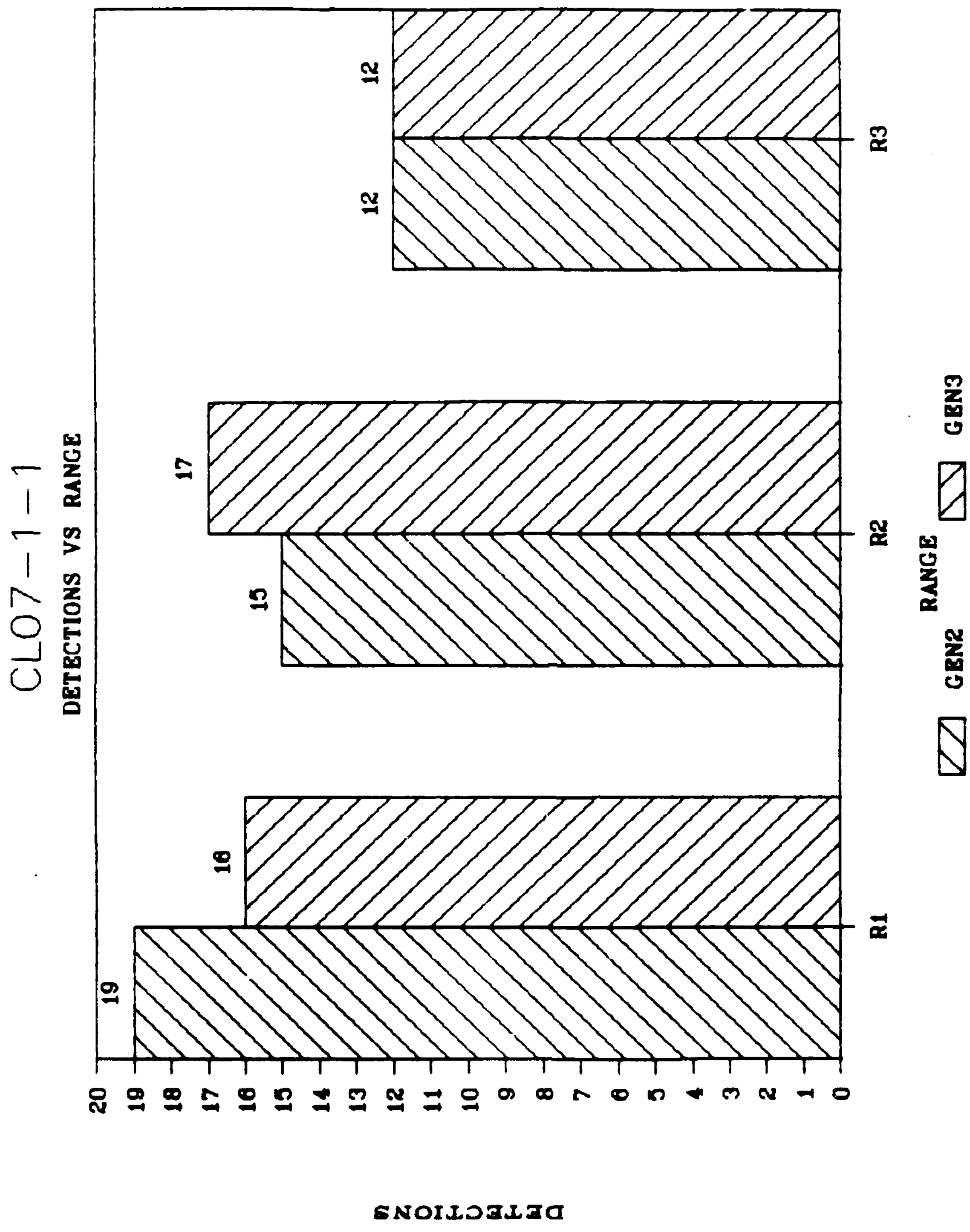
R1
R2
R3
RANGE
GEN2
GEN3



CL07 — 1 — 1
DETECTIONS VS RANGE
DETECTIONS
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R3
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12
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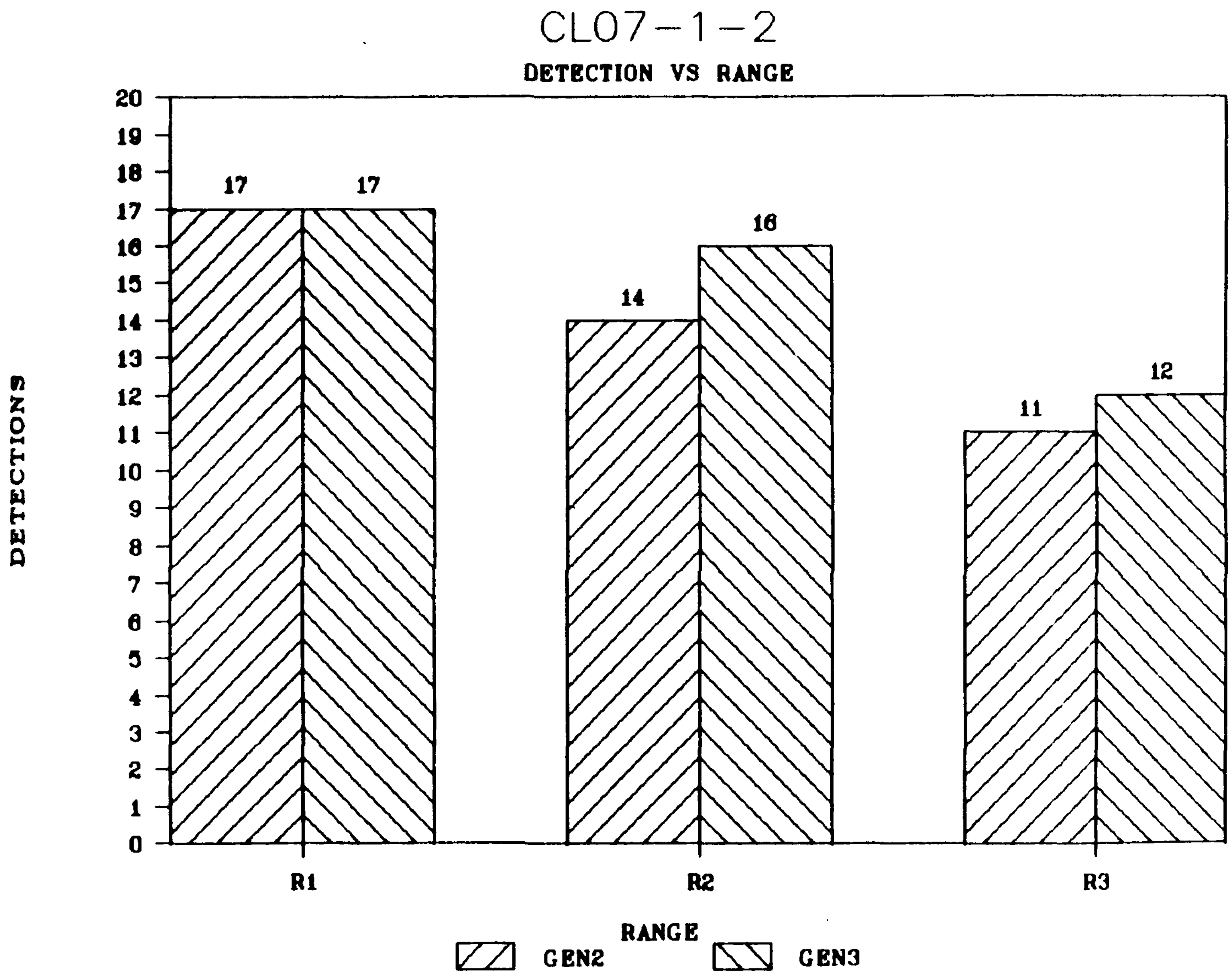
GEN3


CL07-1-2
DETECTION VS RANGE
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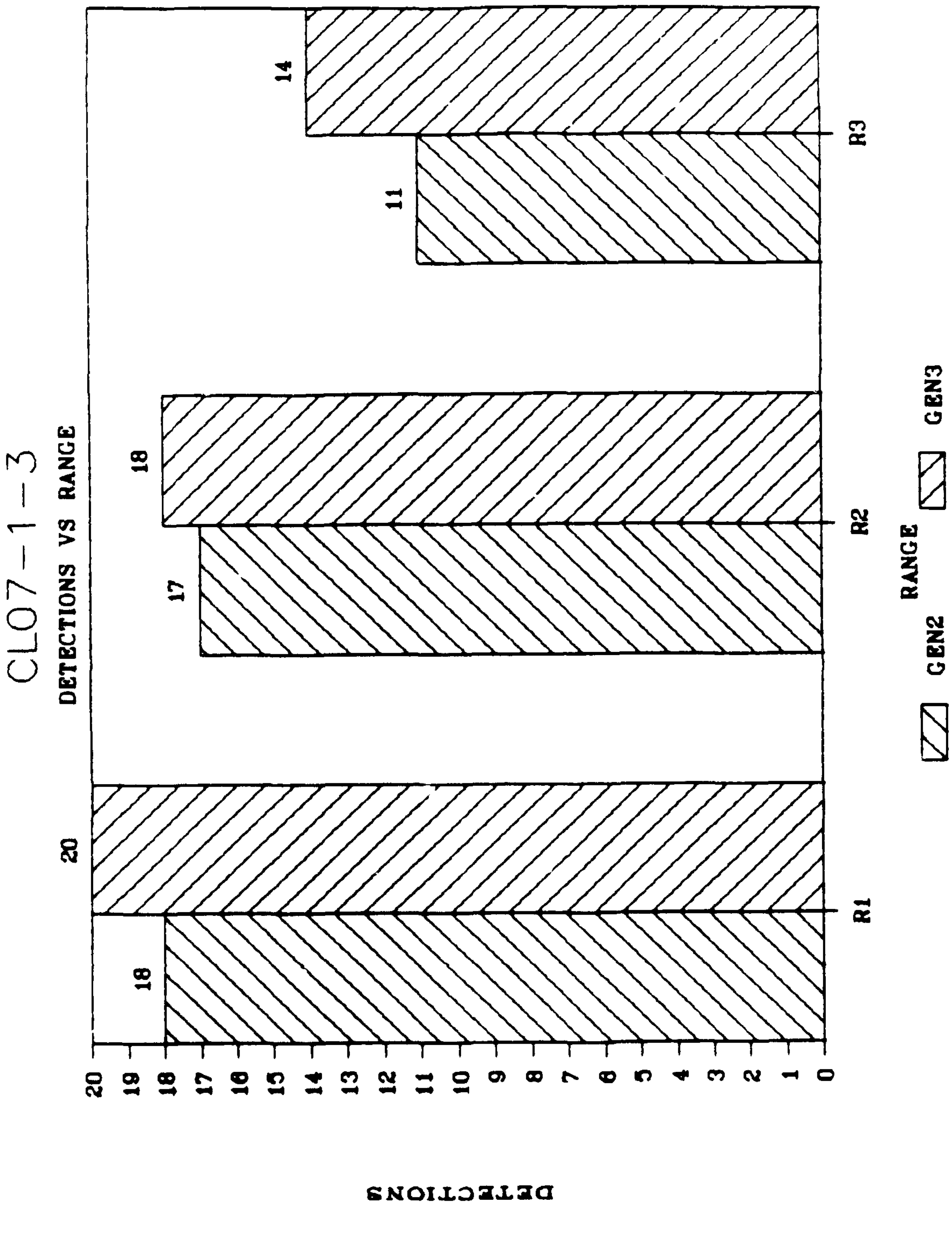
R1
R2
R3
RANGE
GEN2
GEN3


CL07-1-3
DETECTIONS VS RANGE
DETECTIONS
RANGE
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R2
R3
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11
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GEN2
GEN3
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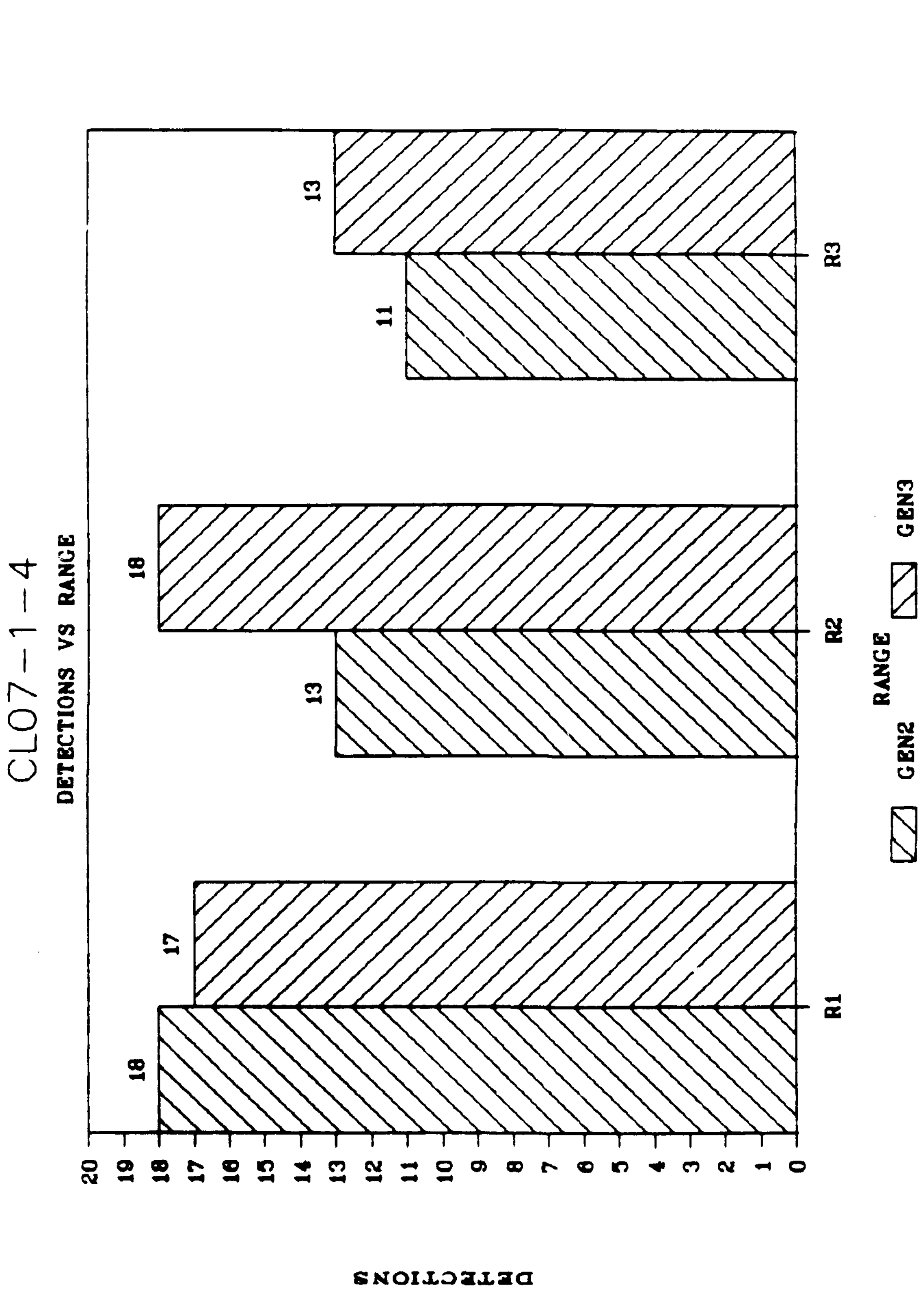
CLO7 - 1 - 4
DETECTIONS VS RANGE
DETECTIONS
RANGE
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R2
R3
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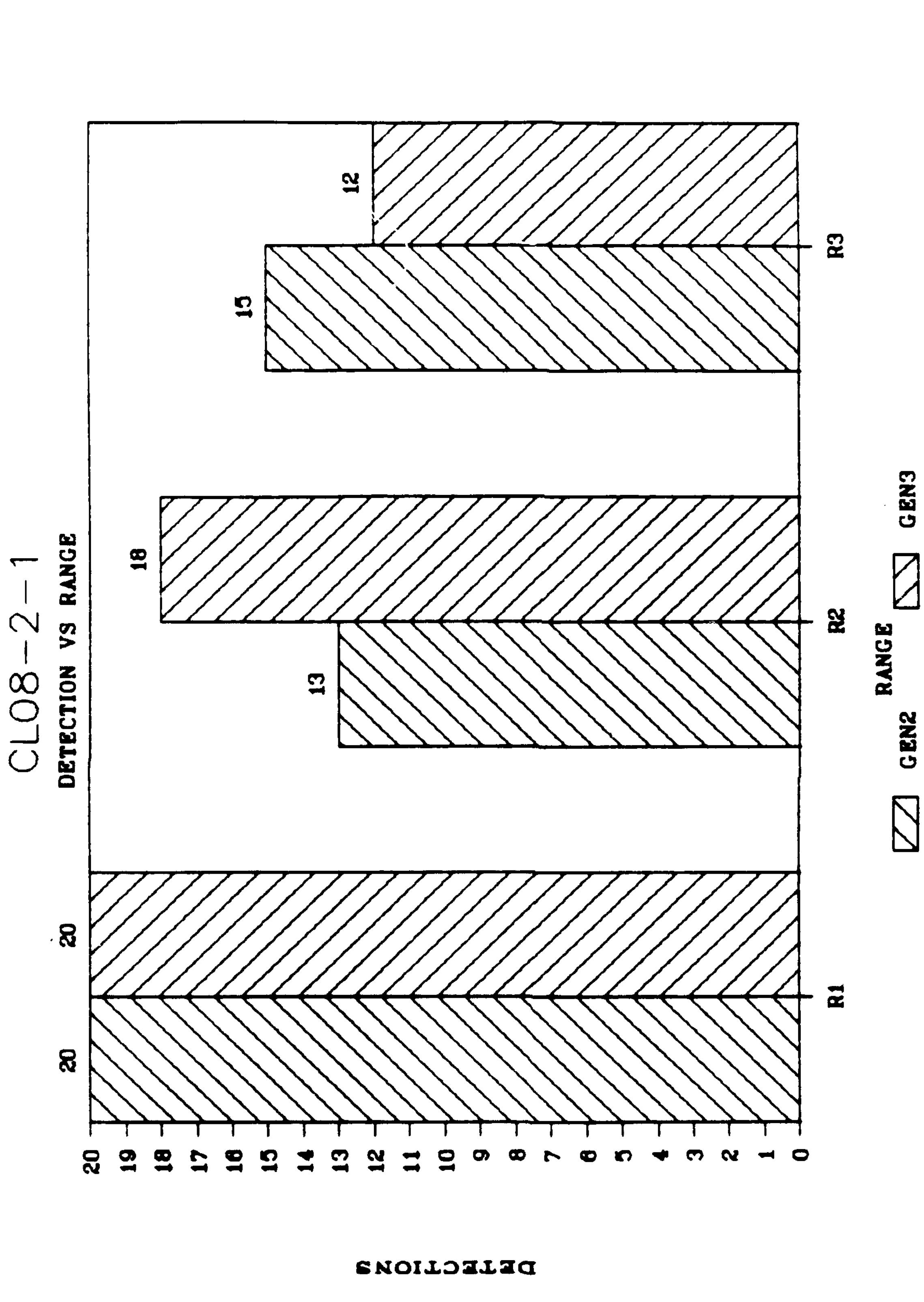
GEN2
GEN3



CL08-2-1
DETECTION VS RANGE
DETECTIONS
RANGE
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R2
R3
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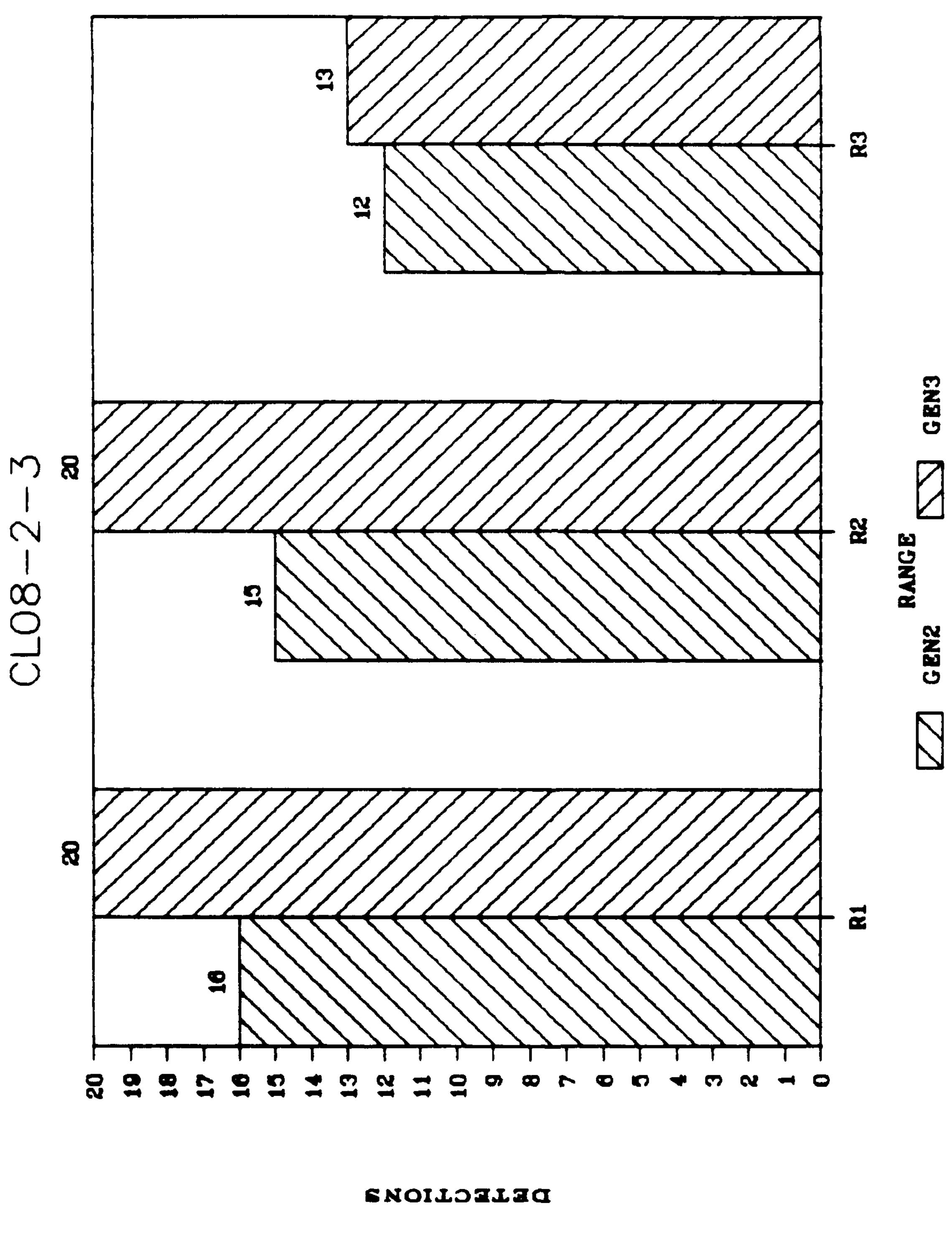
GEN2
GEN3


CL08-2-3
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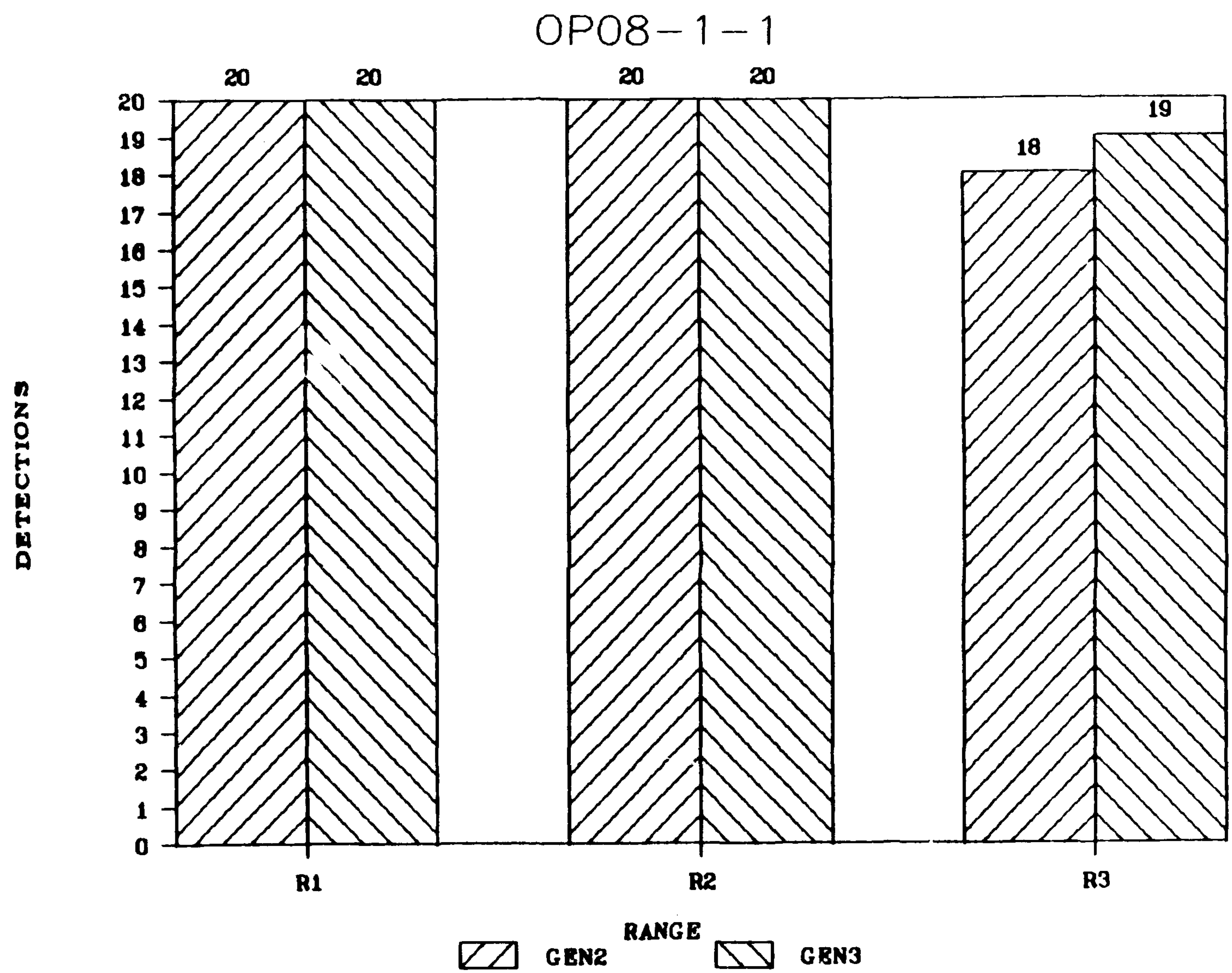
DETECTIONS
R1
R2
R3
RANGE
GEN2
GEN3


OP08-1-1
DETECTIONS
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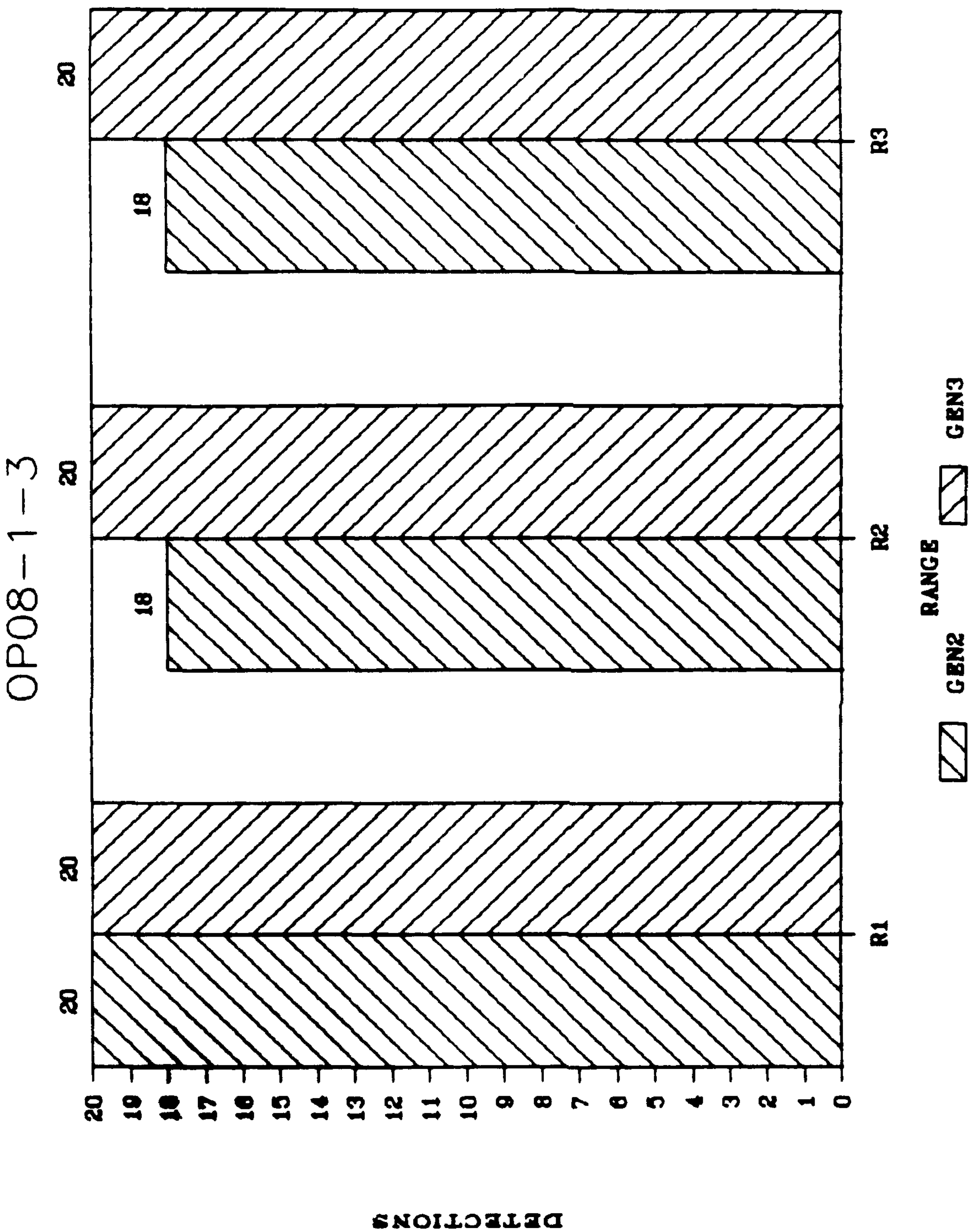
R1
R2
R3
RANGE
GEN2
GEN3


OP08-1-3
DETECTIONS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
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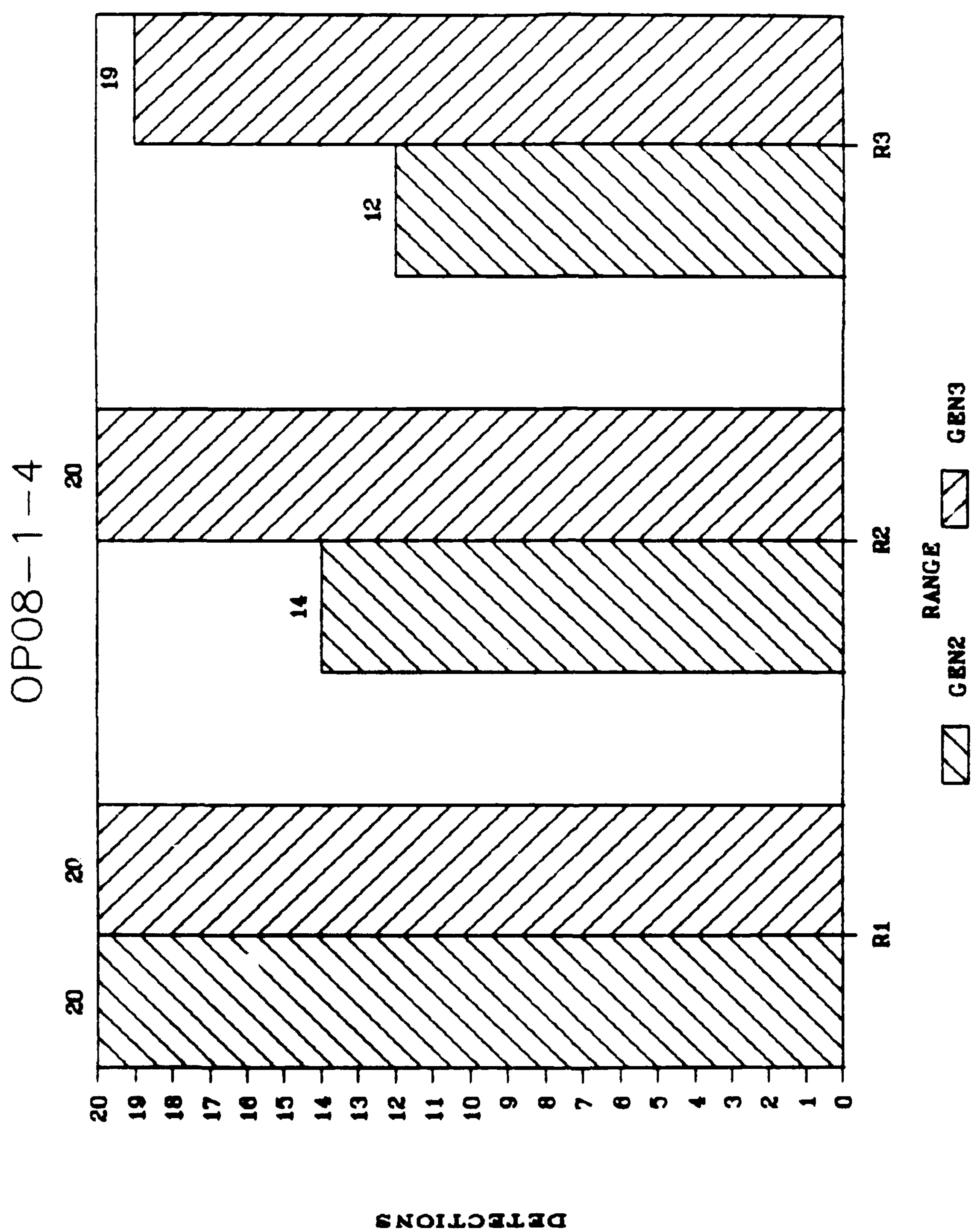
R1
R2
R3
RANGE
GEN2
GEN3


OP08-1-4
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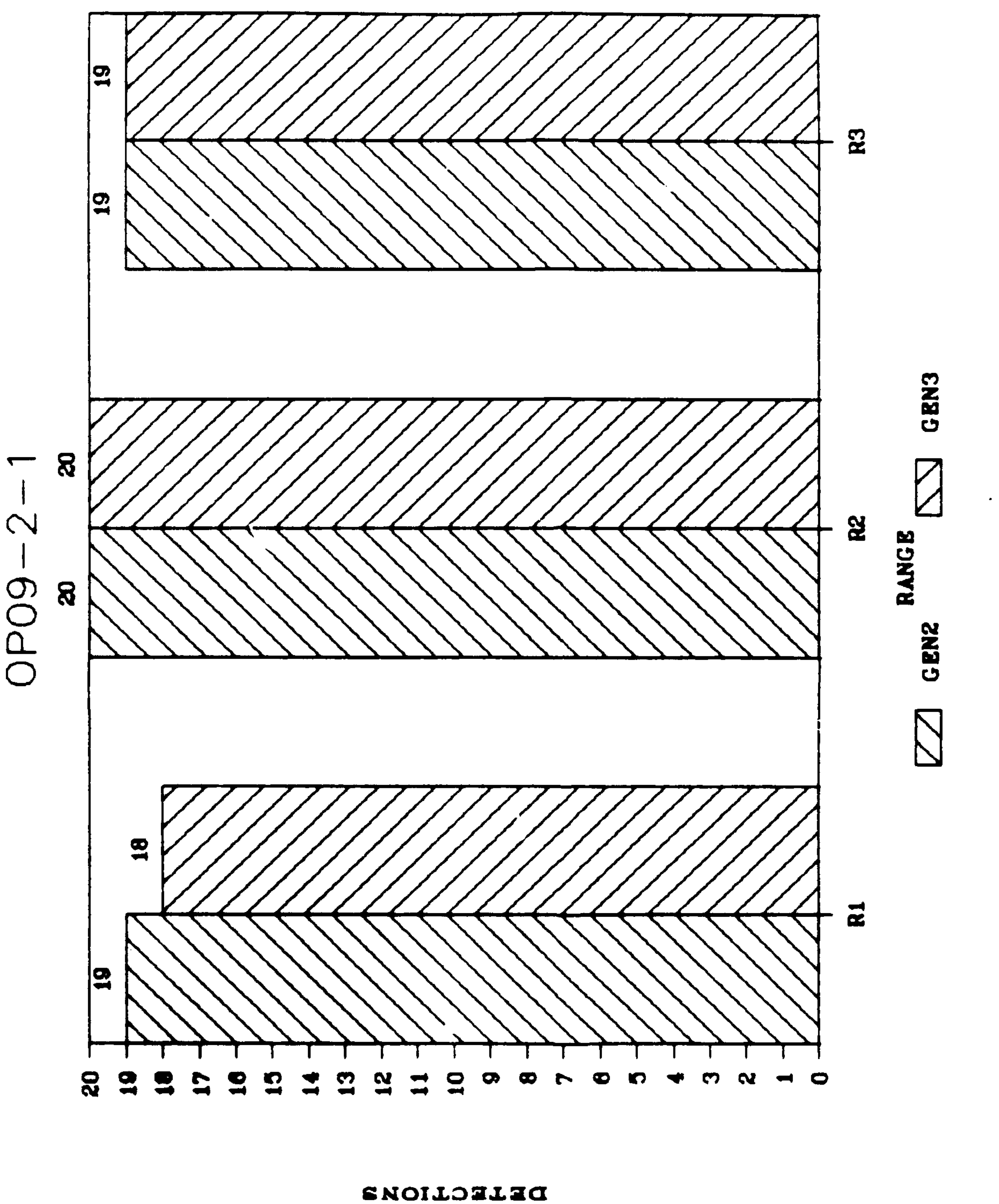
R1
R2
R3
RANGE
GEN2
GEN3


OP09-2-1
DETECTIONS
RANGE
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R3
GEN2
GEN3
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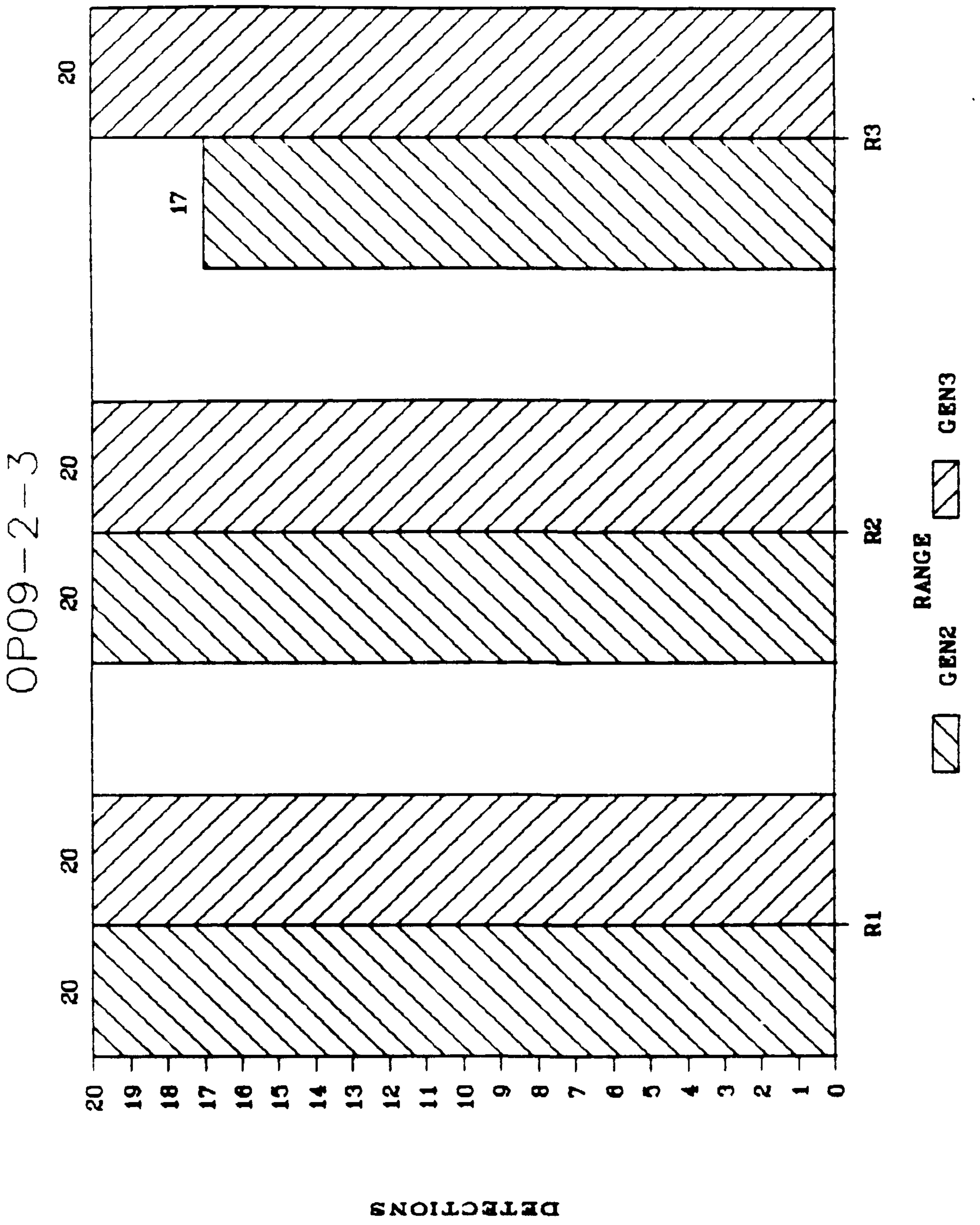

OP09-2-3
DETECTIONS
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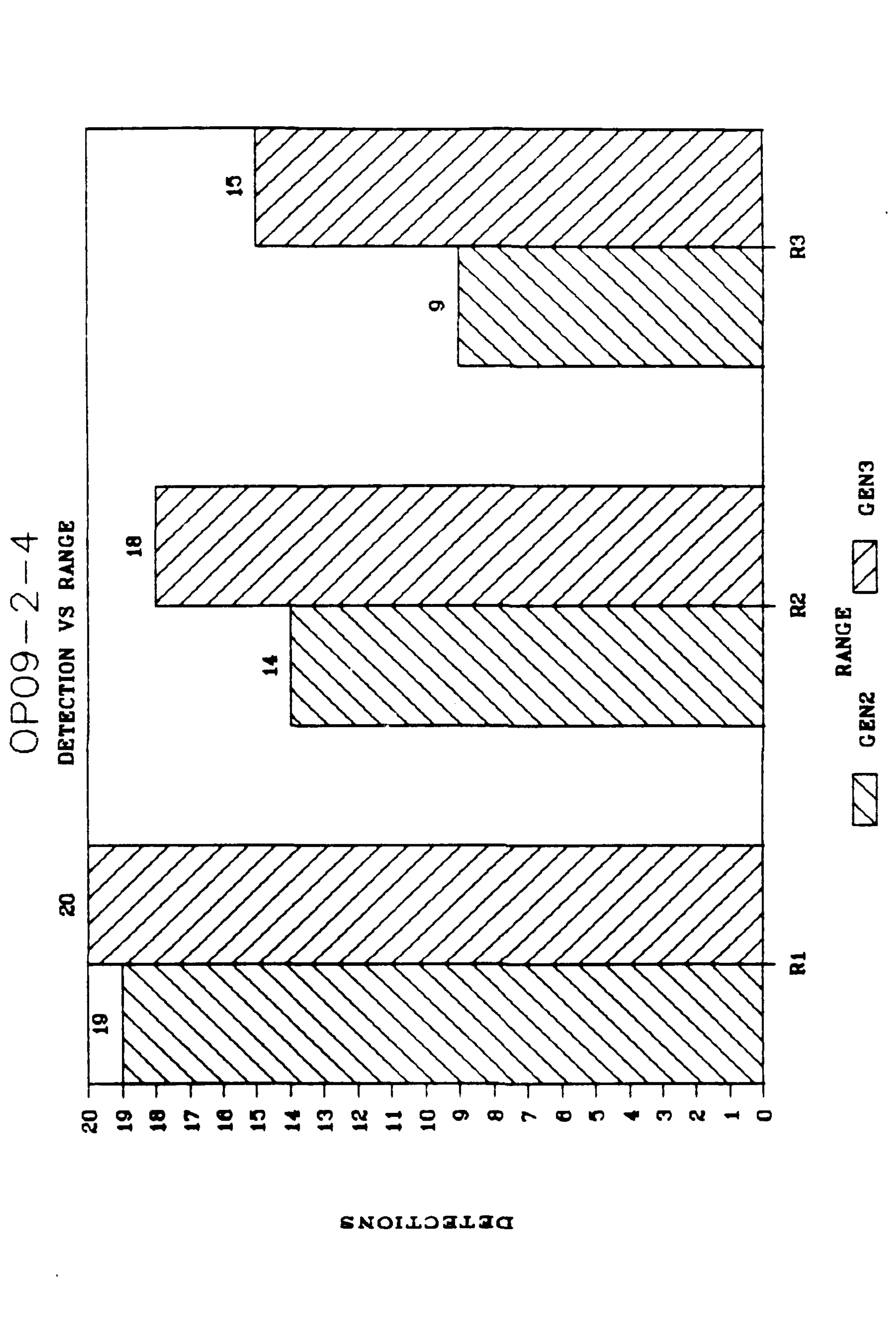
GEN2
GEN3


OP09-2-4
DETECTION VS RANGE
DETECTIONS
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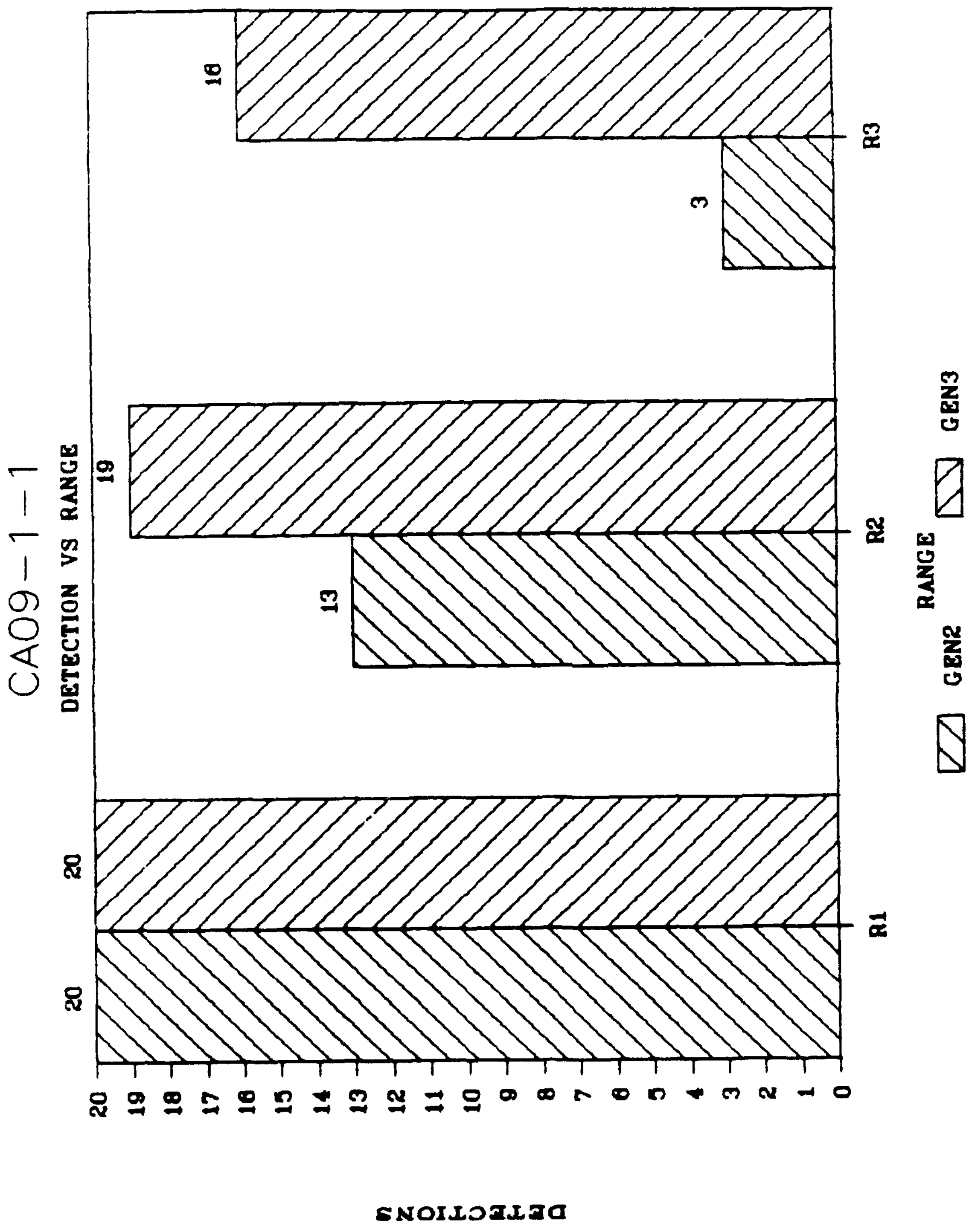
R1
R2
R3
RANGE
GEN2
GEN3


CA09 — 1 — 1
DETECTION VS RANGE
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R1
R2
R3
RANGE
GEN2
GEN3
DETECTIONS
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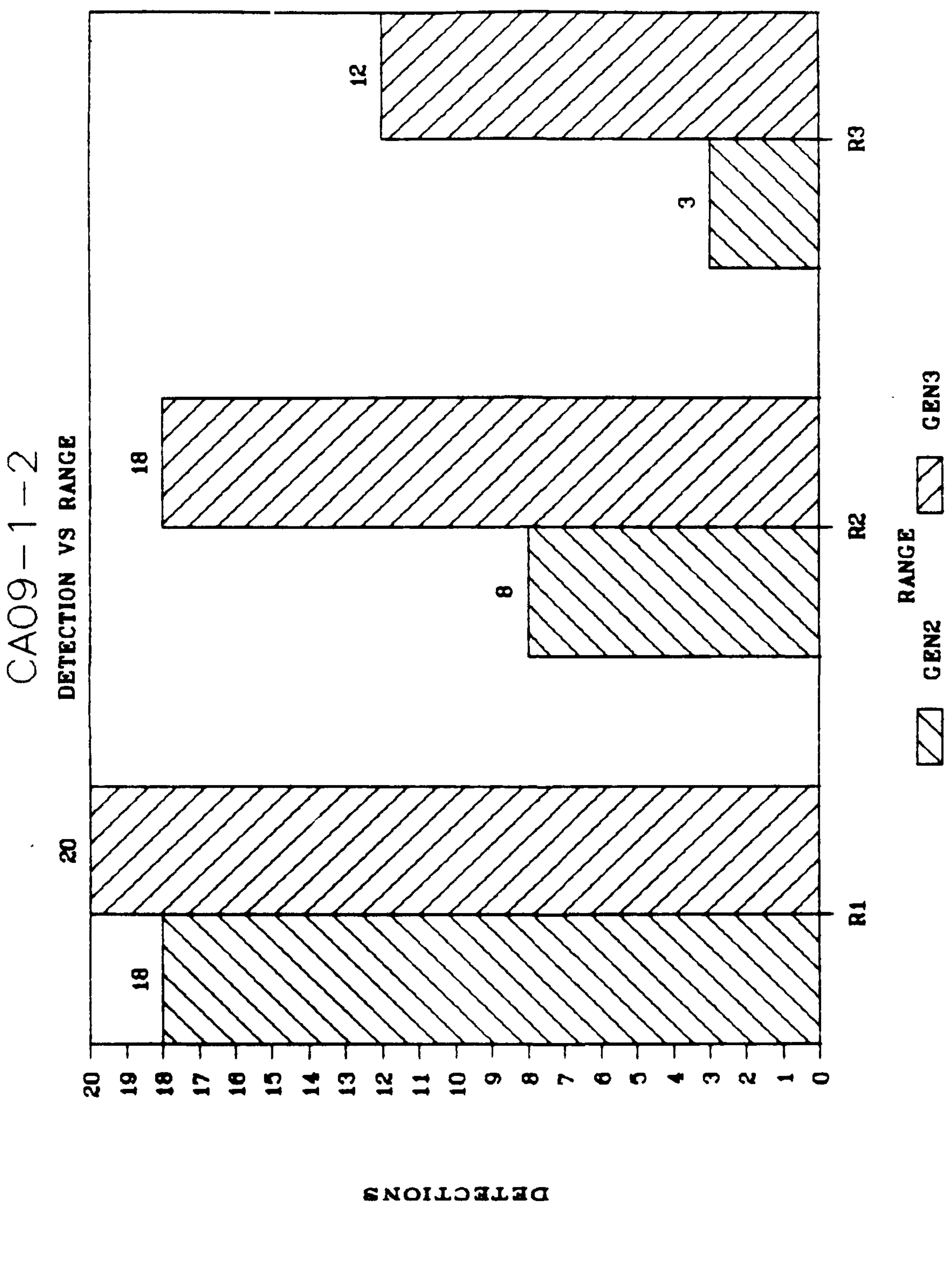
CA09-1-2
DETECTION VS RANGE
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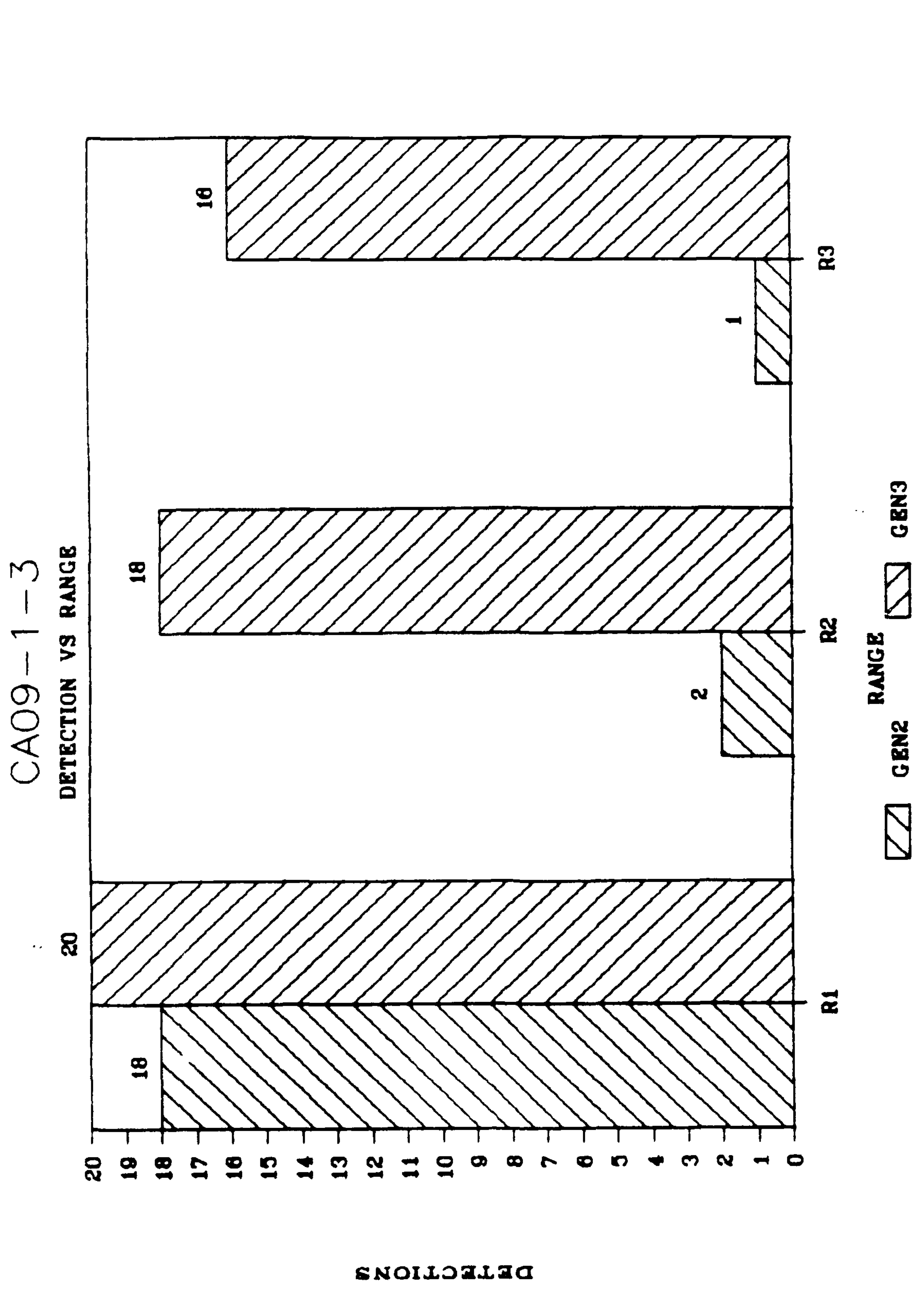
R1
R2
R3
RANGE
GEN2
GEN3


CA09 — 1 — 3
DETECTION VS RANGE
DETECTIONS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
18
20
R1
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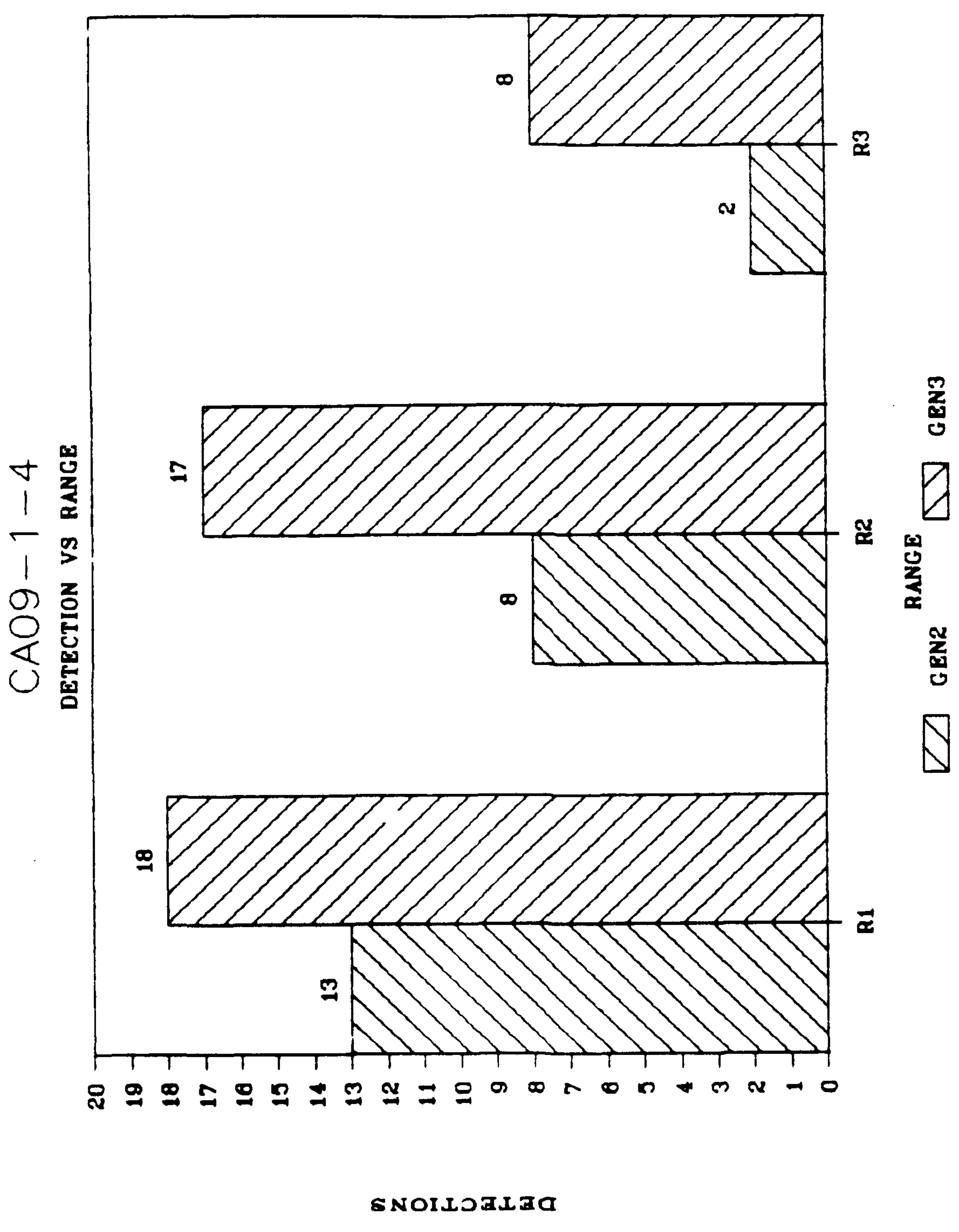
R2
1
16
R3
RANGE
GEN2
GEN3



CA09 – 1 – 4
DETECTION VS RANGE
DETECTIONS
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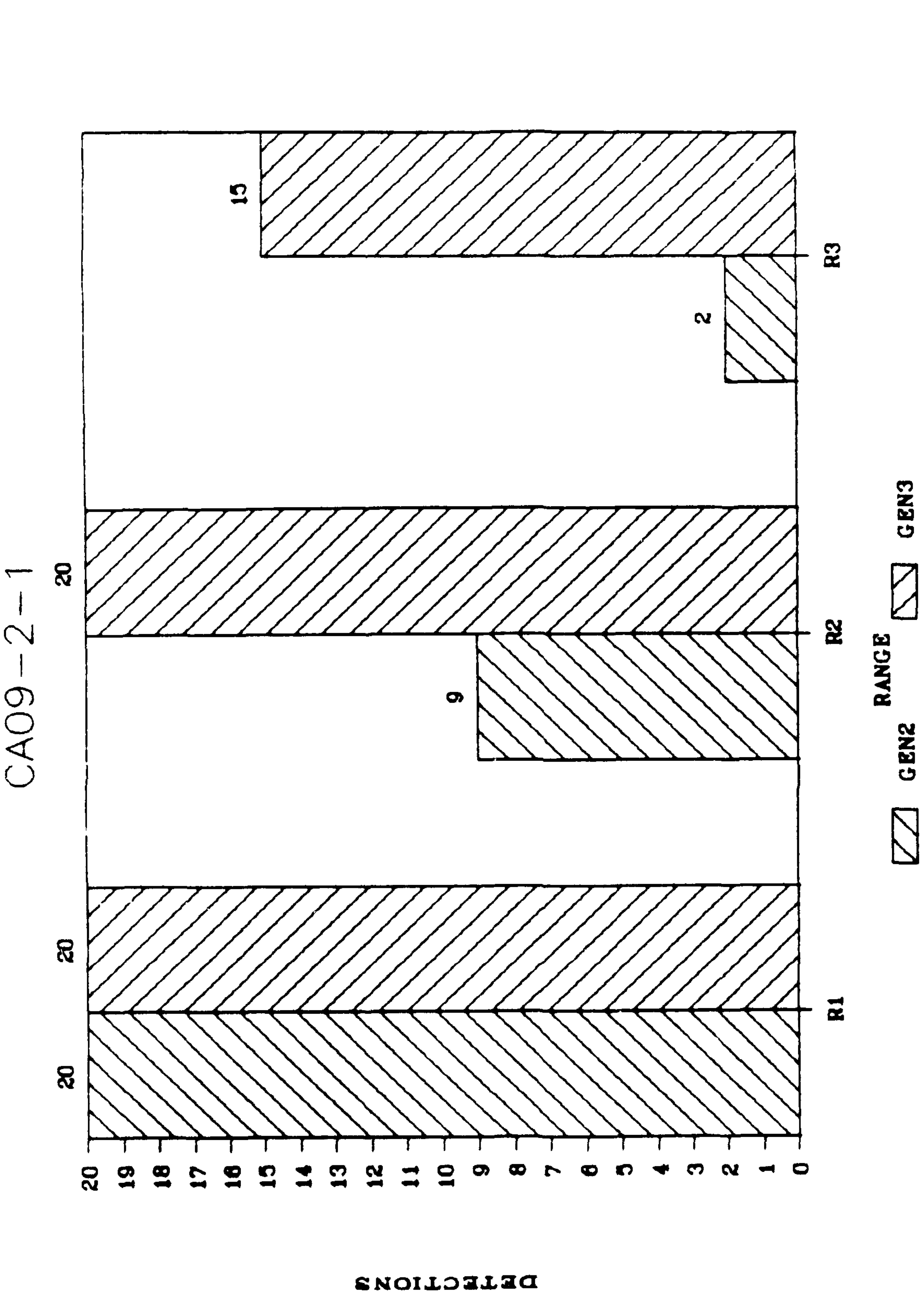
R1
R2
R3
RANGE
GEN2
GEN3


CA09-2-1
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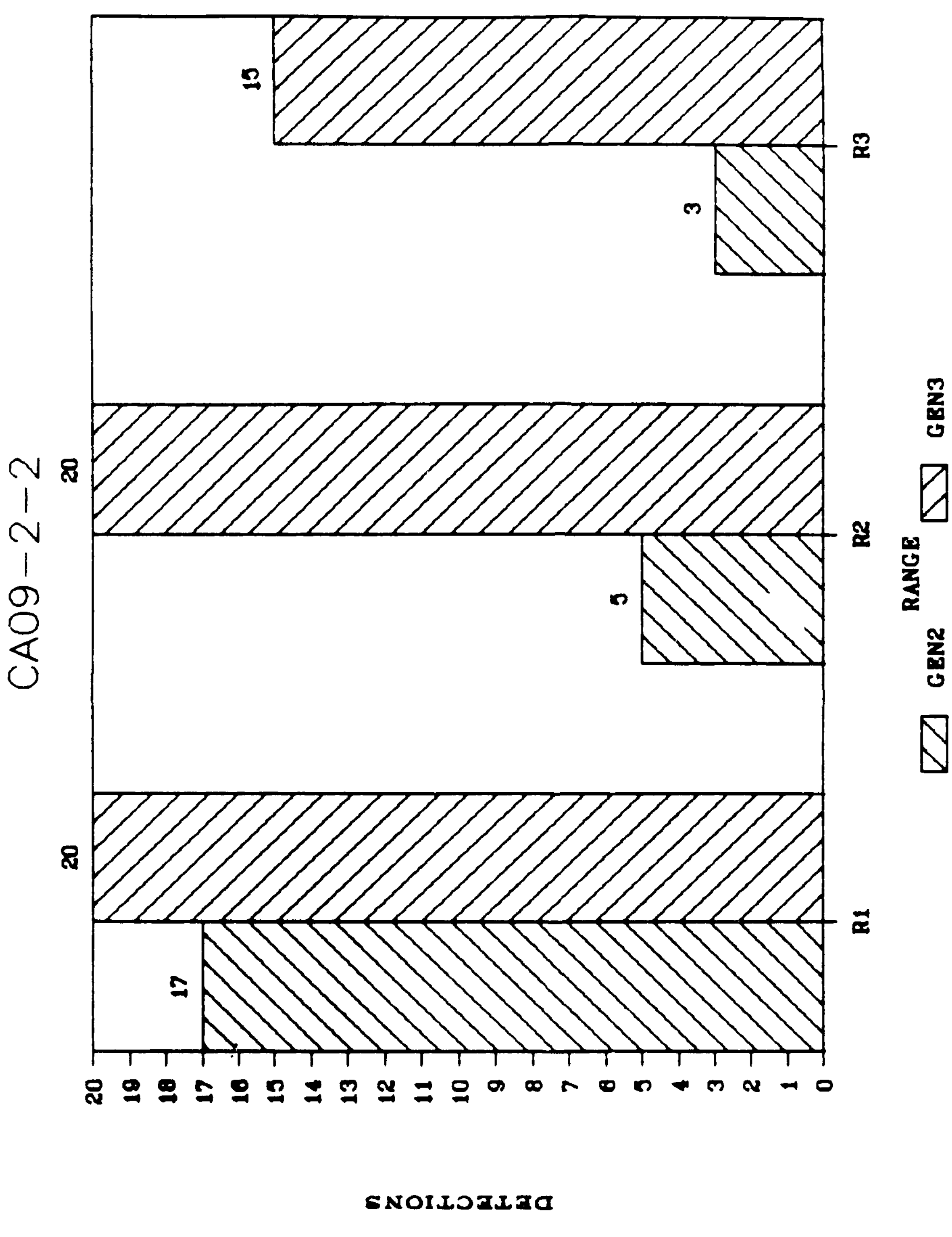
R1
R2
R3
RANGE
GEN2
GEN3


CA09-2-2
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R2
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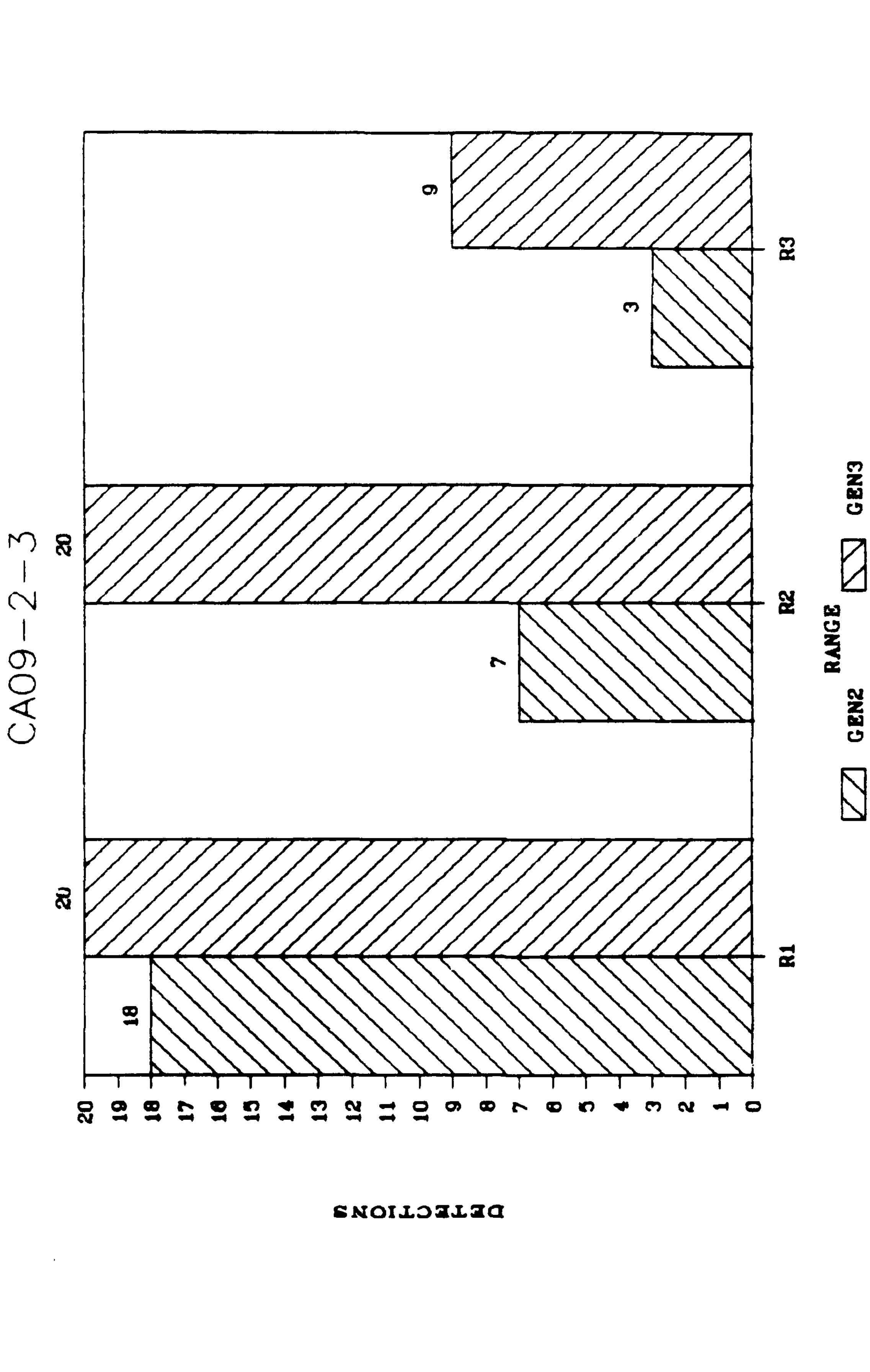
RANGE
GEN2
GEN3


CA09-2-3
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R1
R2
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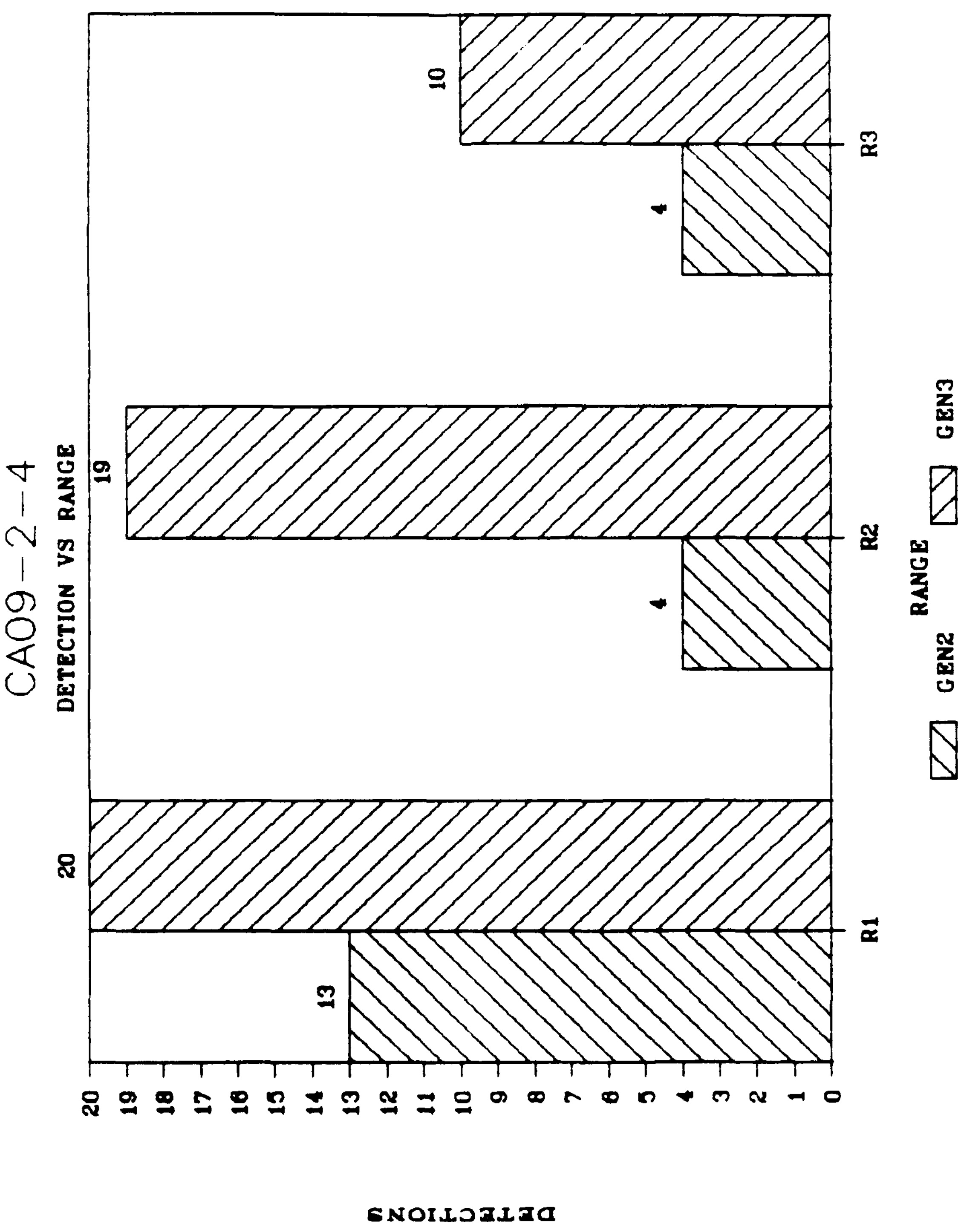
RANGE
GEN2
GEN3


CA09 - 2 - 4
DETECTION VS RANGE
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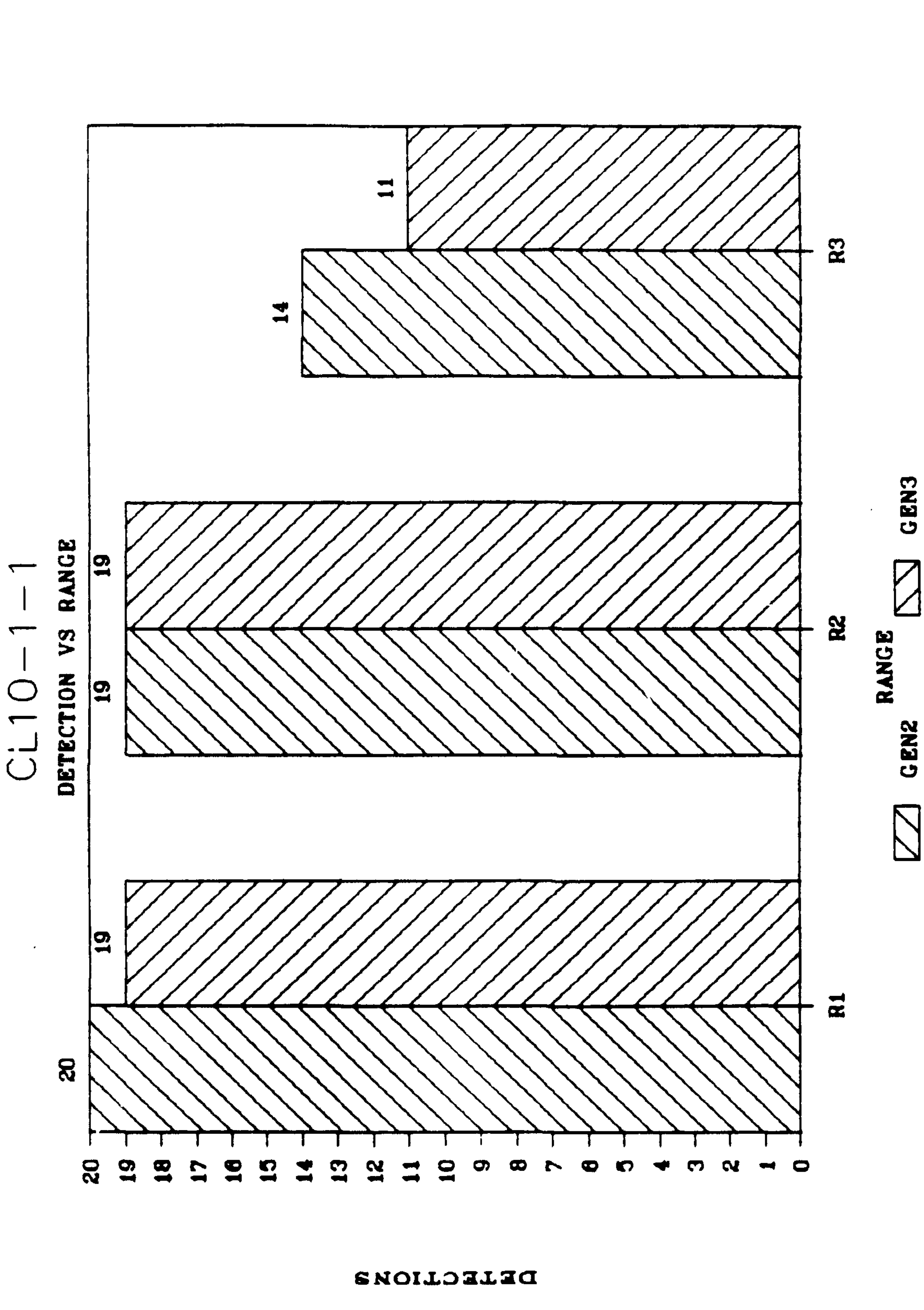
RANGE
GEN2
GEN3



CL10-1-1
DETECTION VS RANGE
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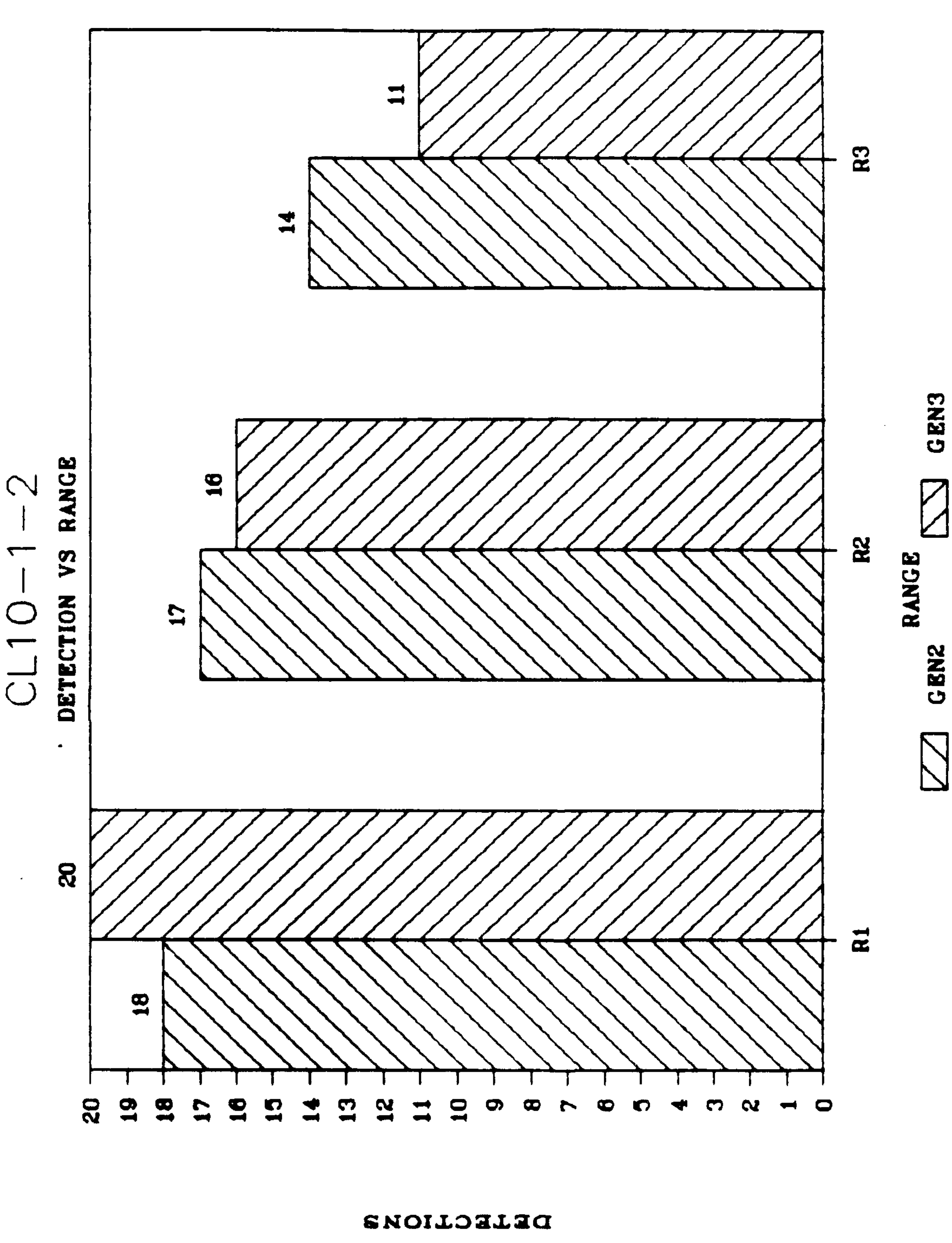
R1
R2
R3
RANGE
GEN2
GEN3



CL10-1-2
DETECTION VS RANGE
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R3
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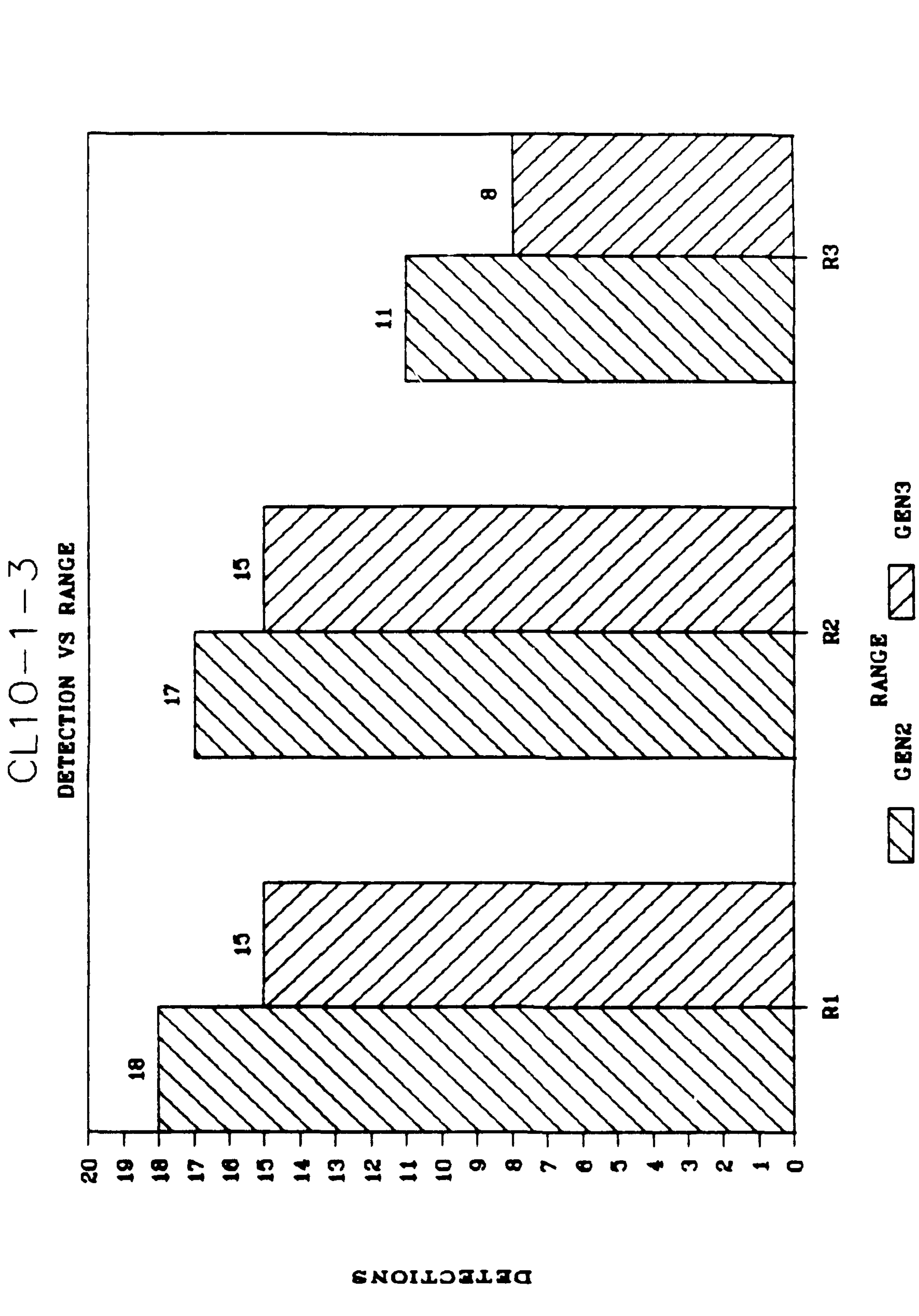
GEN3


CL10-1-3
DETECTION VS RANGE
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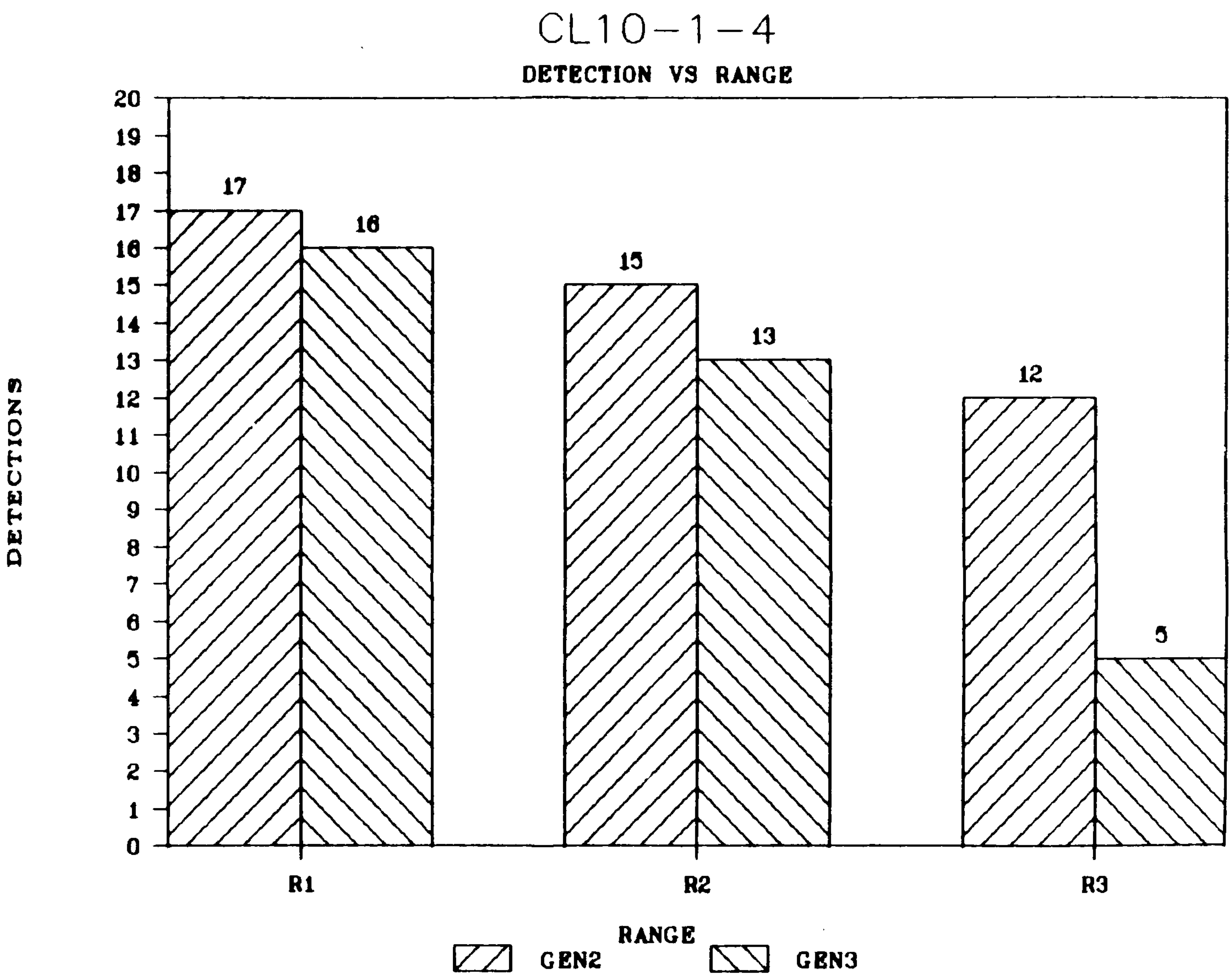
R1
R2
R3
RANGE
GEN2
GEN3


CL10-1-4
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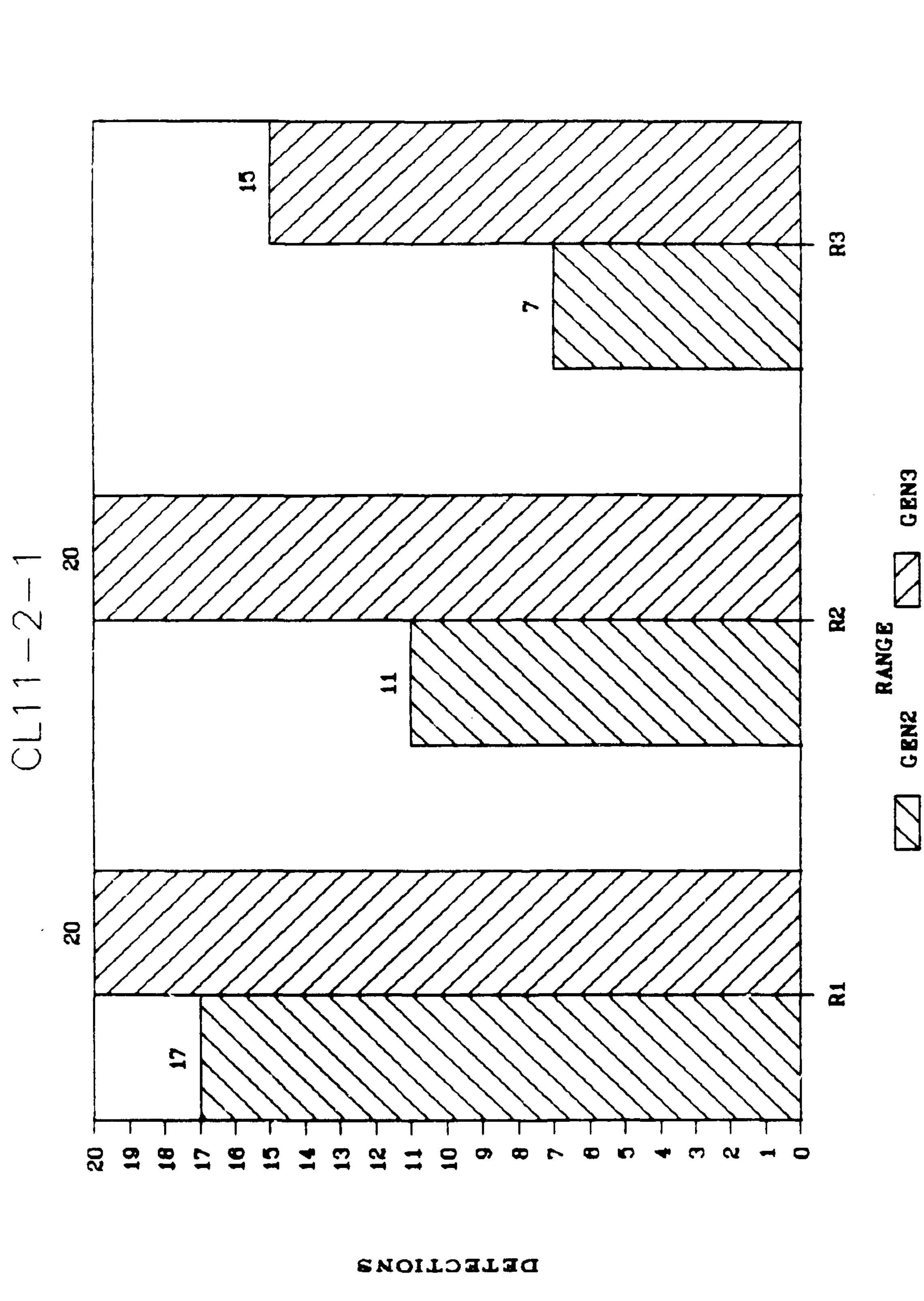
R1
R2
R3
RANGE
GEN2
GEN3



CL11-2-1
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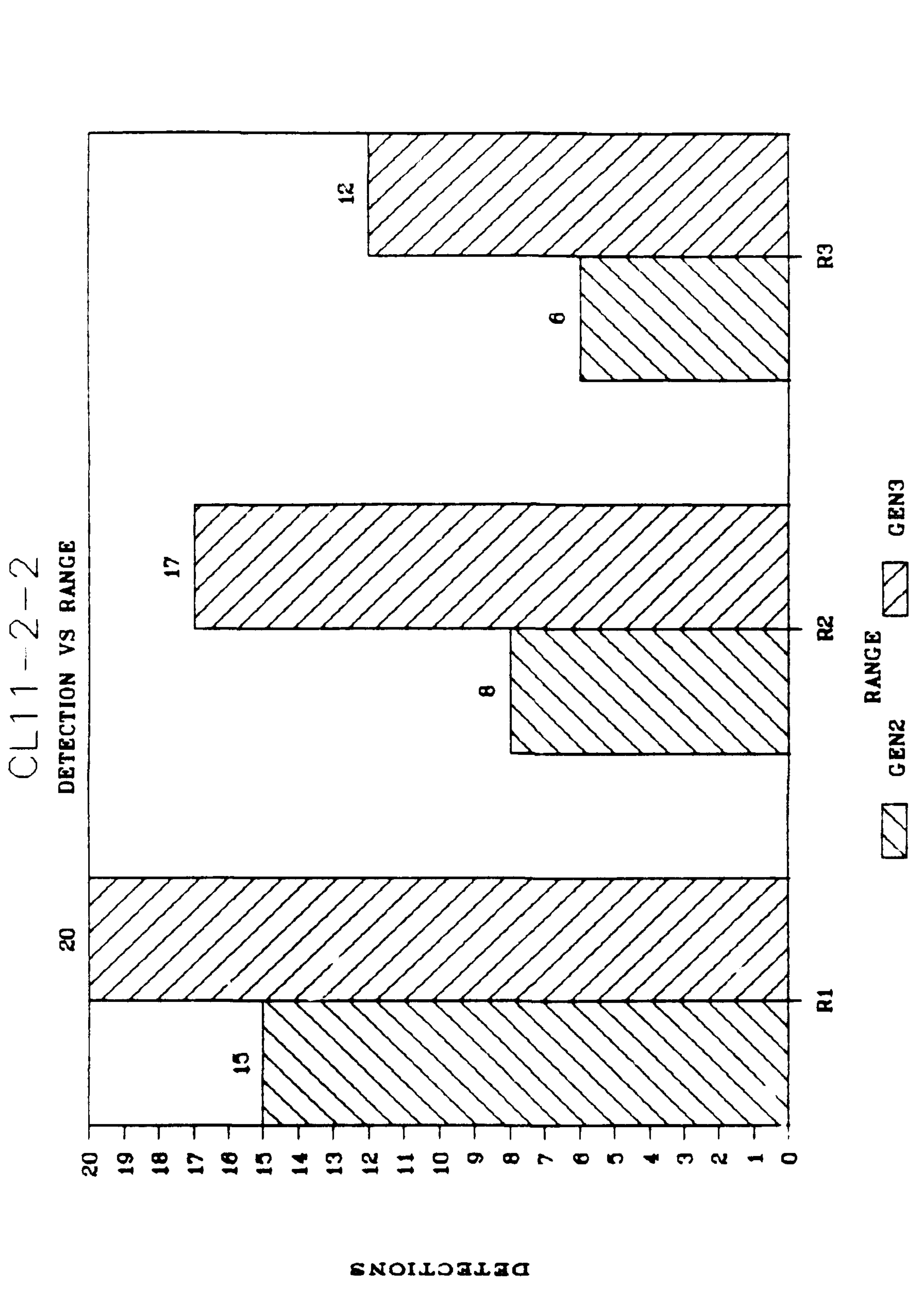
R1
R2
R3
RANGE
GEN2
GEN3


CL11-2-2
DETECTION VS RANGE
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GEN2
GEN3
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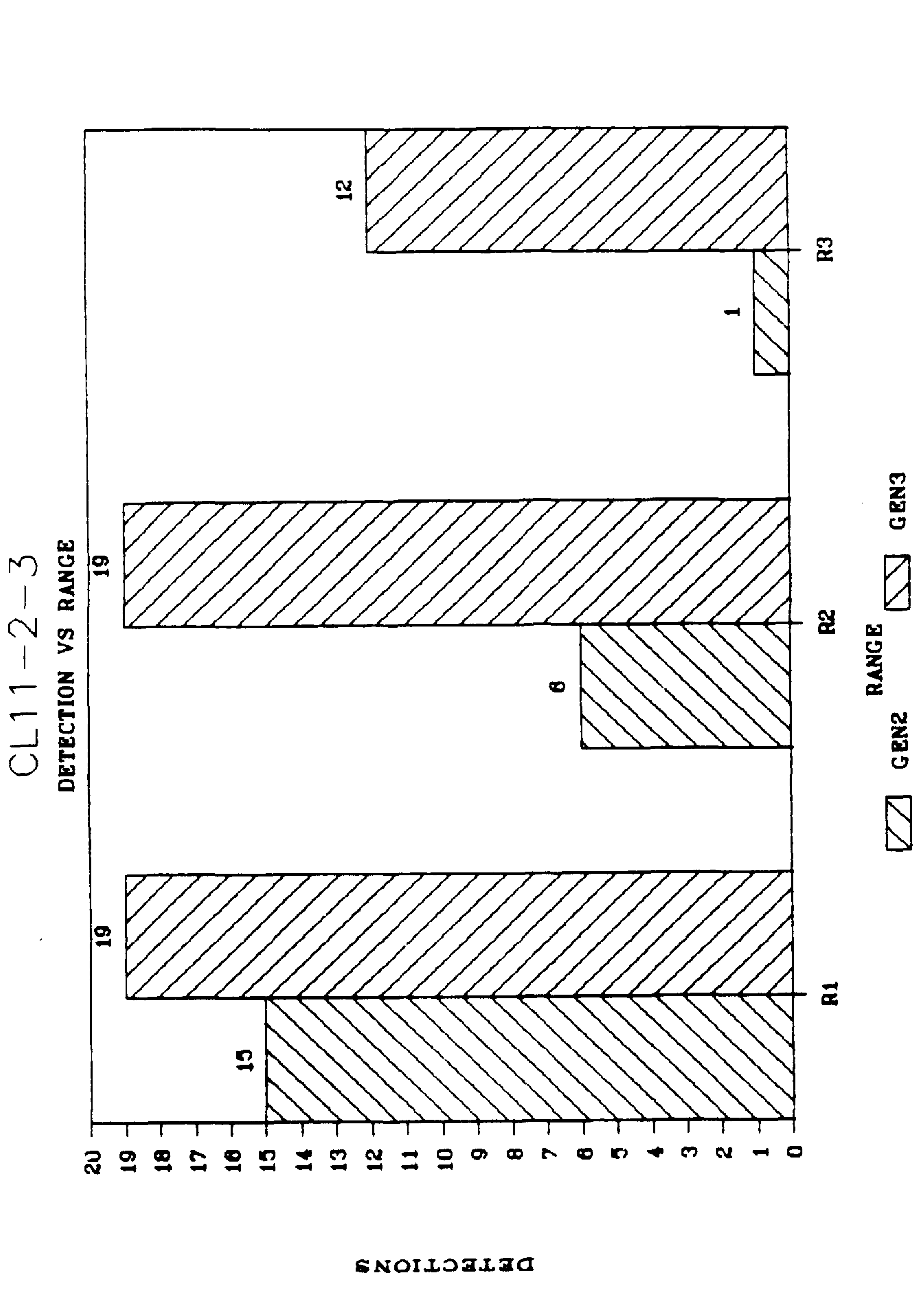

CL11-2-3
DETECTION VS RANGE
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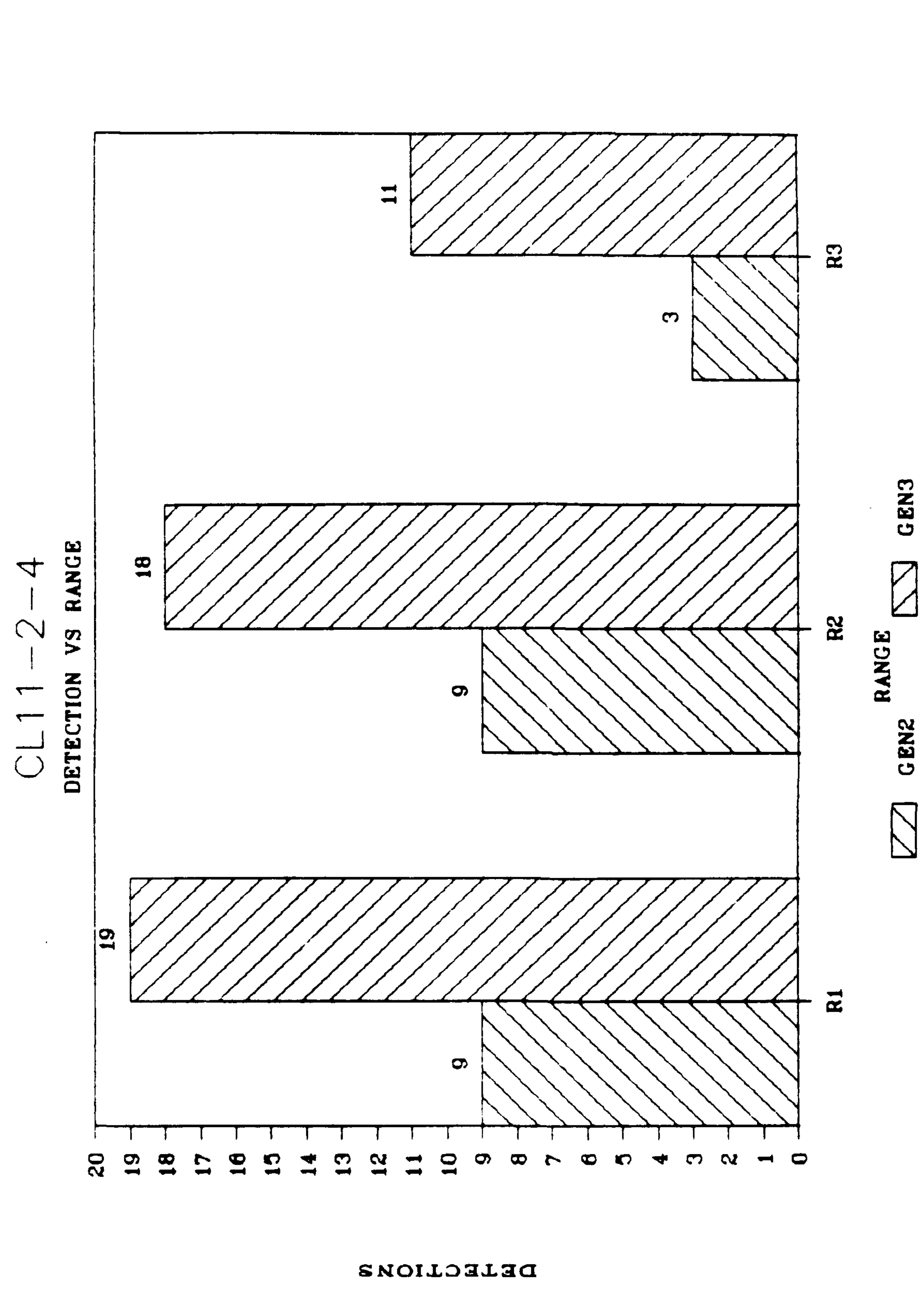
GEN2
GEN3


CL11 – 2 – 4
DETECTION VS RANGE
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R1
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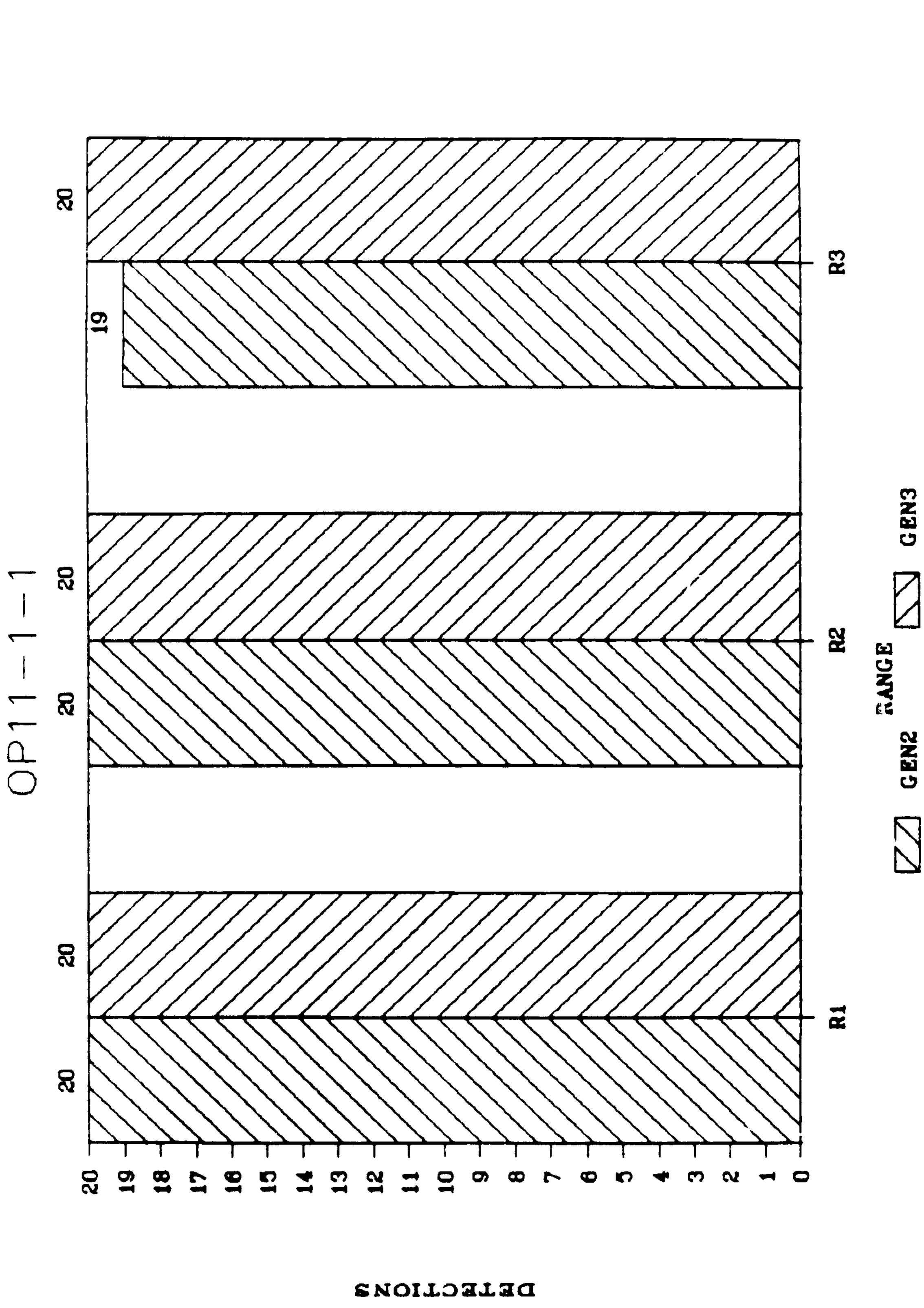
R3
RANGE
GEN2
GEN3



OP11 — 1 — 1
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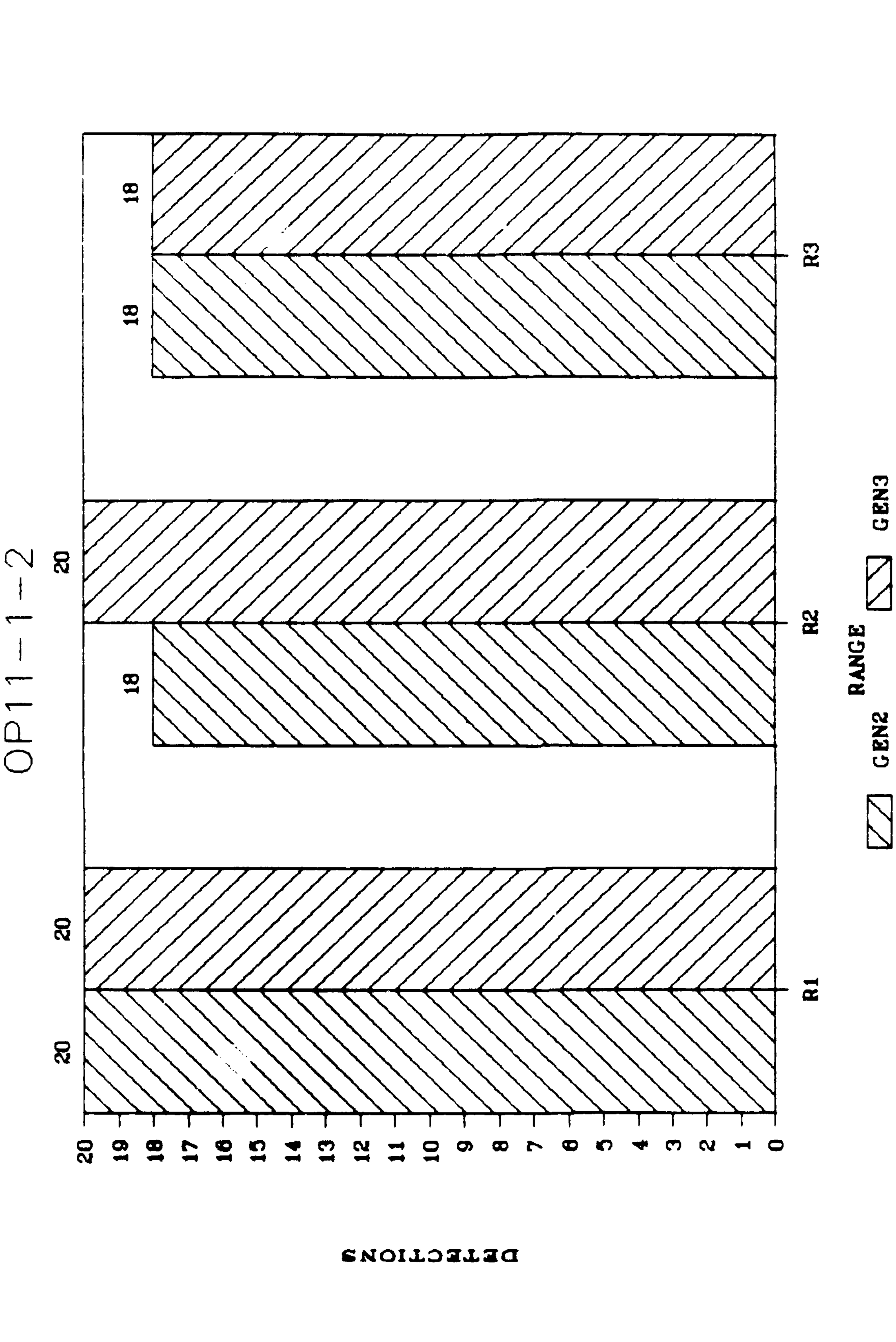
RANGE
GEN2
GEN3


OP11 — 1 — 2
DETECTIONS
RANGE
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GEN3
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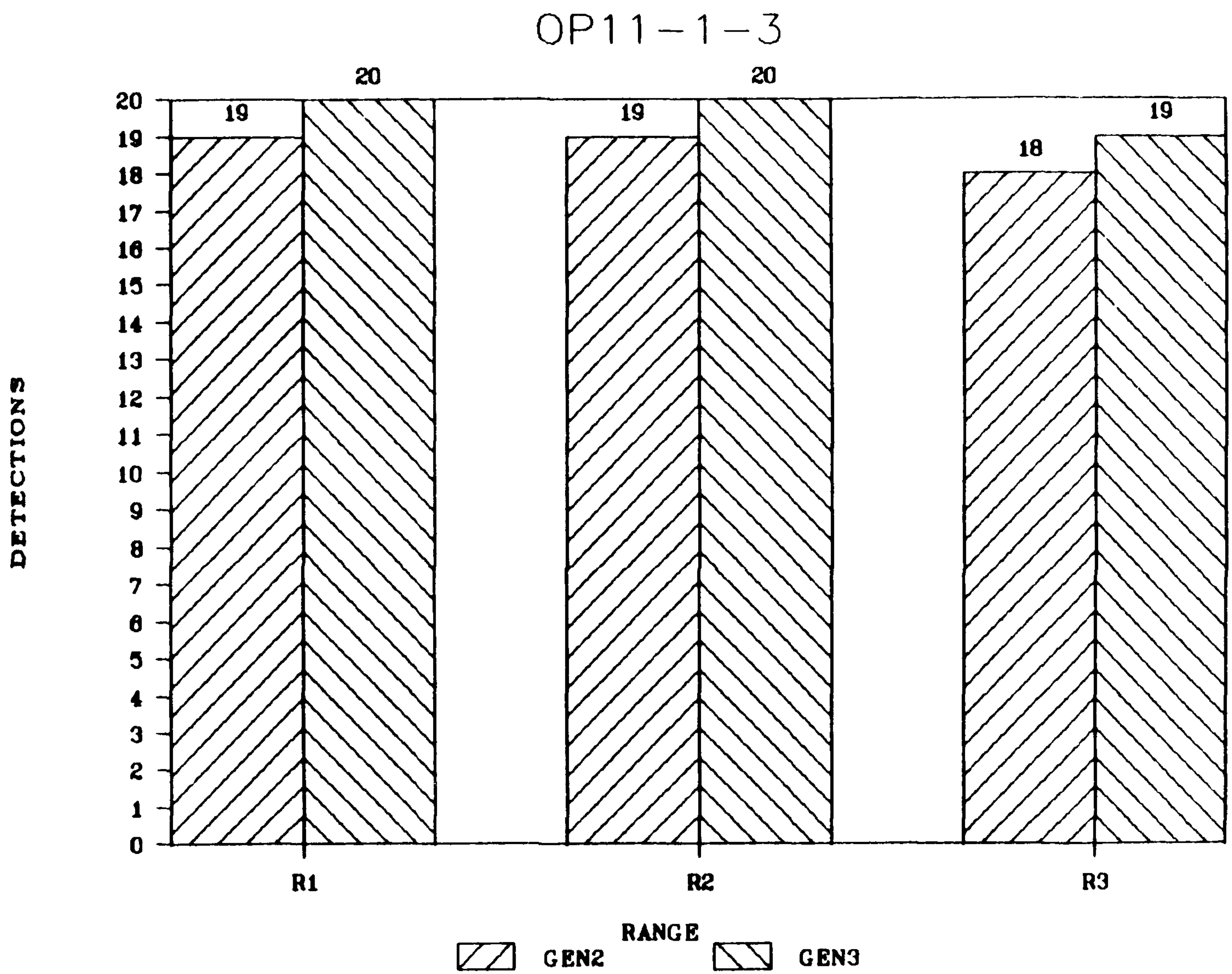
OP11-1-3
DETECTIONS
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RANGE
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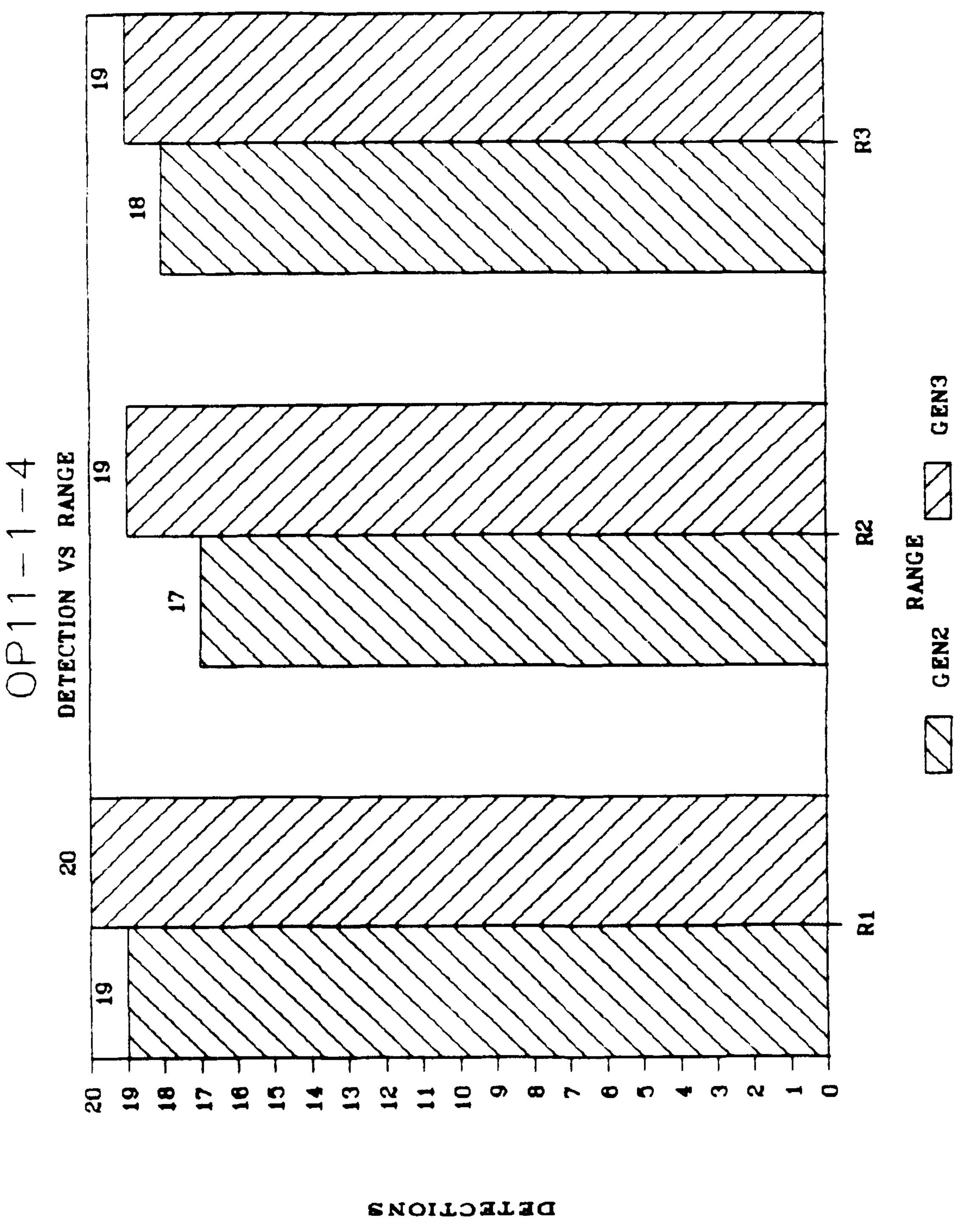
GEN3


OP11 - 1 - 4
DETECTION VS RANGE
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R2
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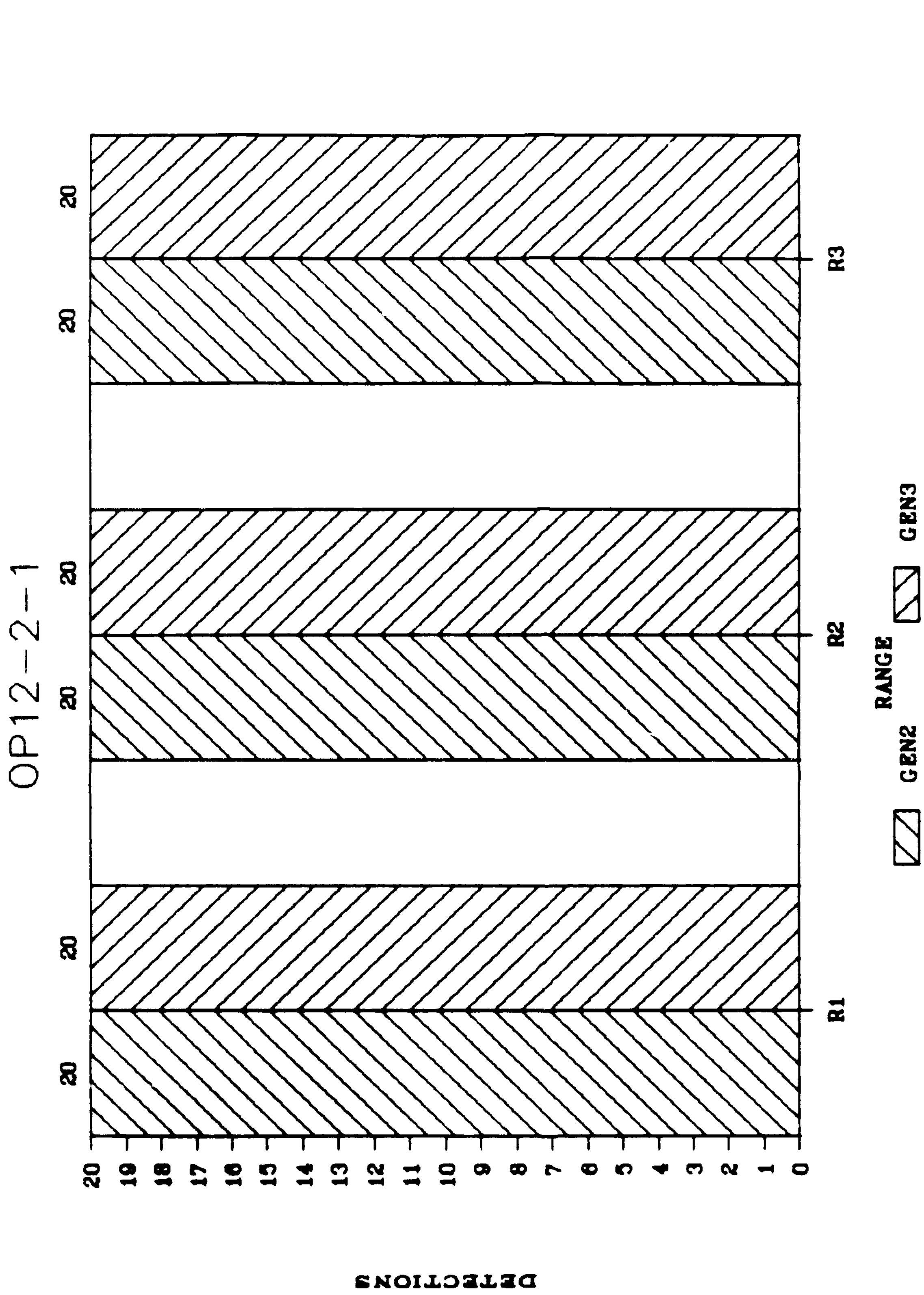
RANGE
GEN2
GEN3



OP12-2-1
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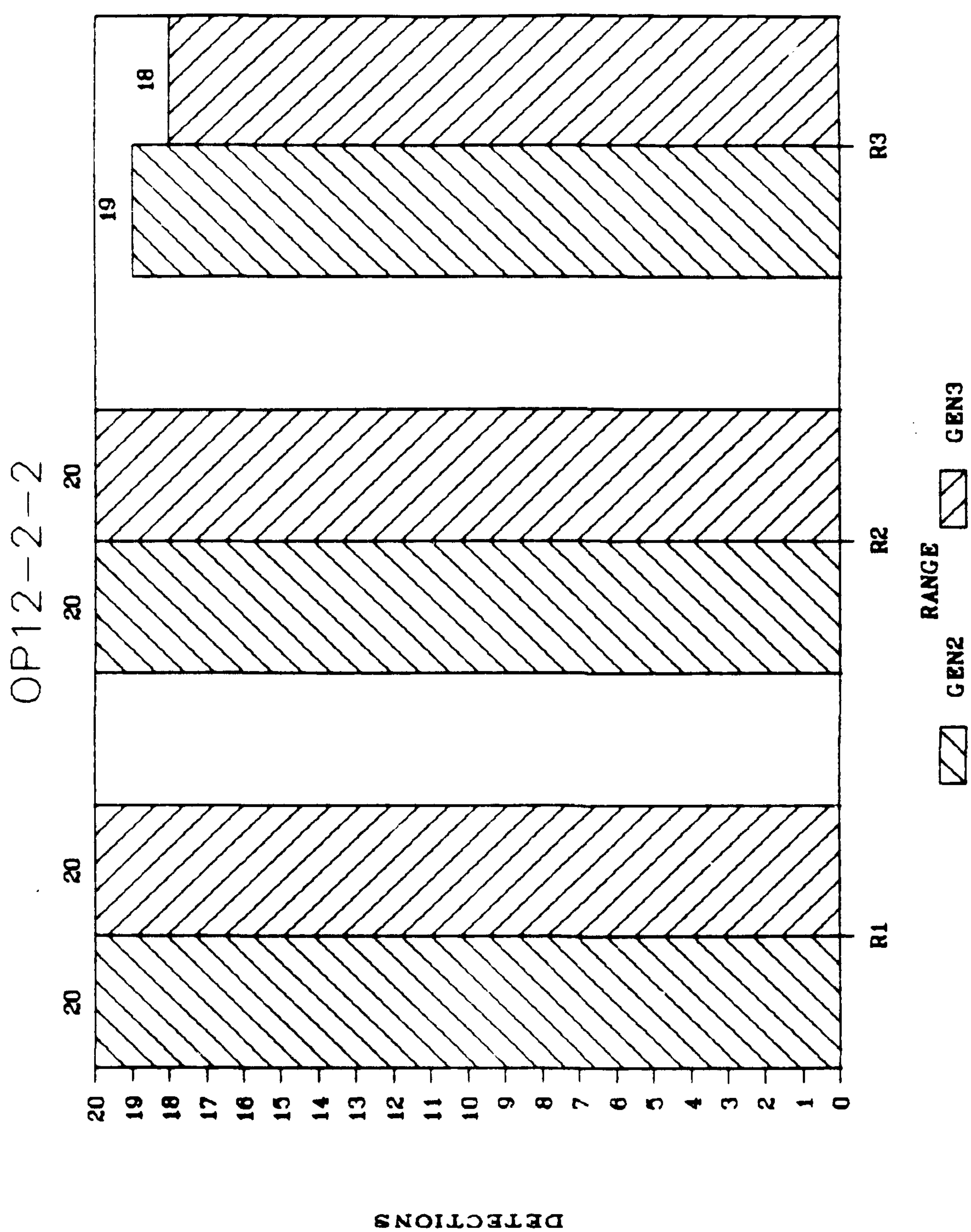
R3
RANGE
GEN2
GEN3


OP12-2-2
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20
19
18
R1
R2
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RANGE
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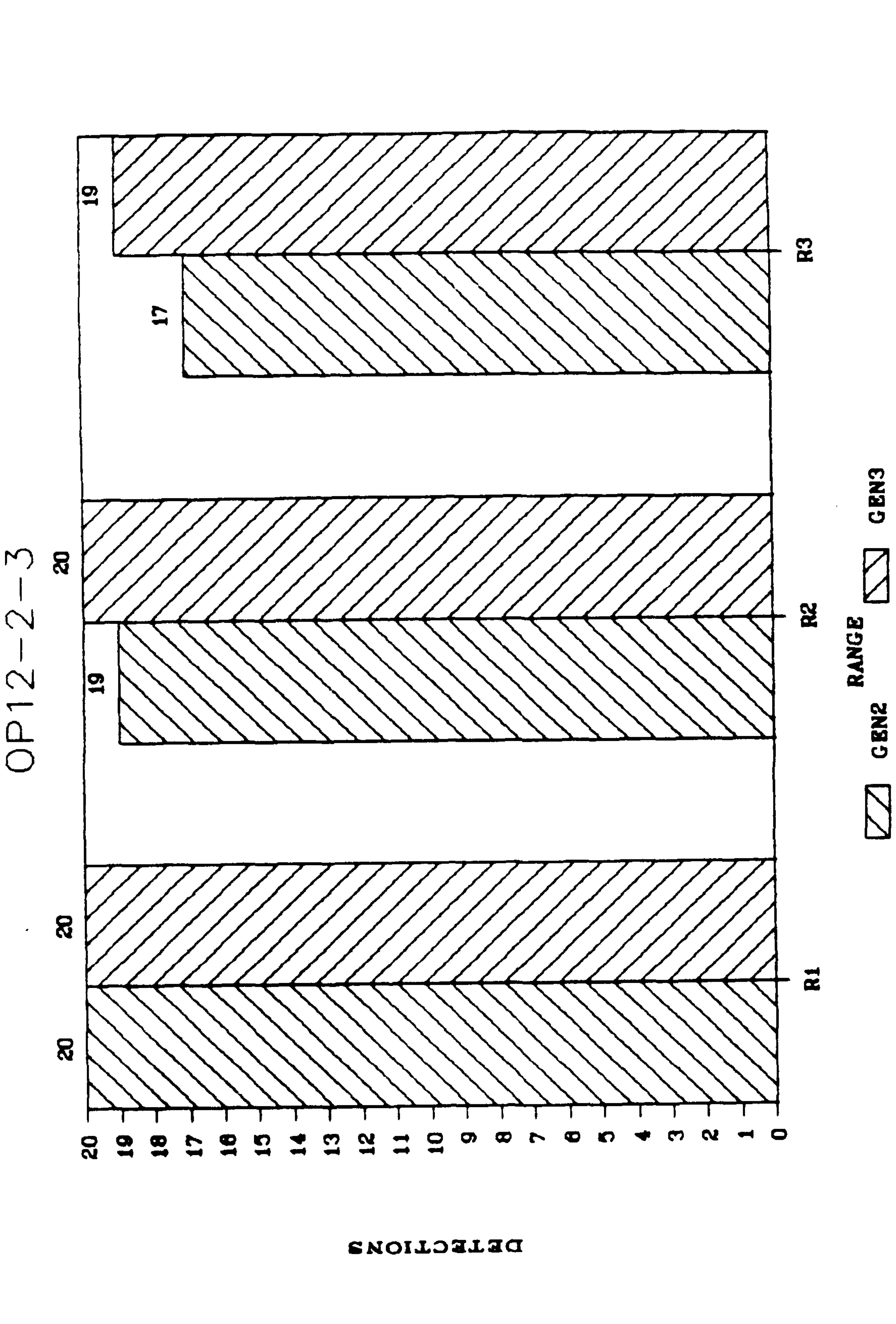
GEN3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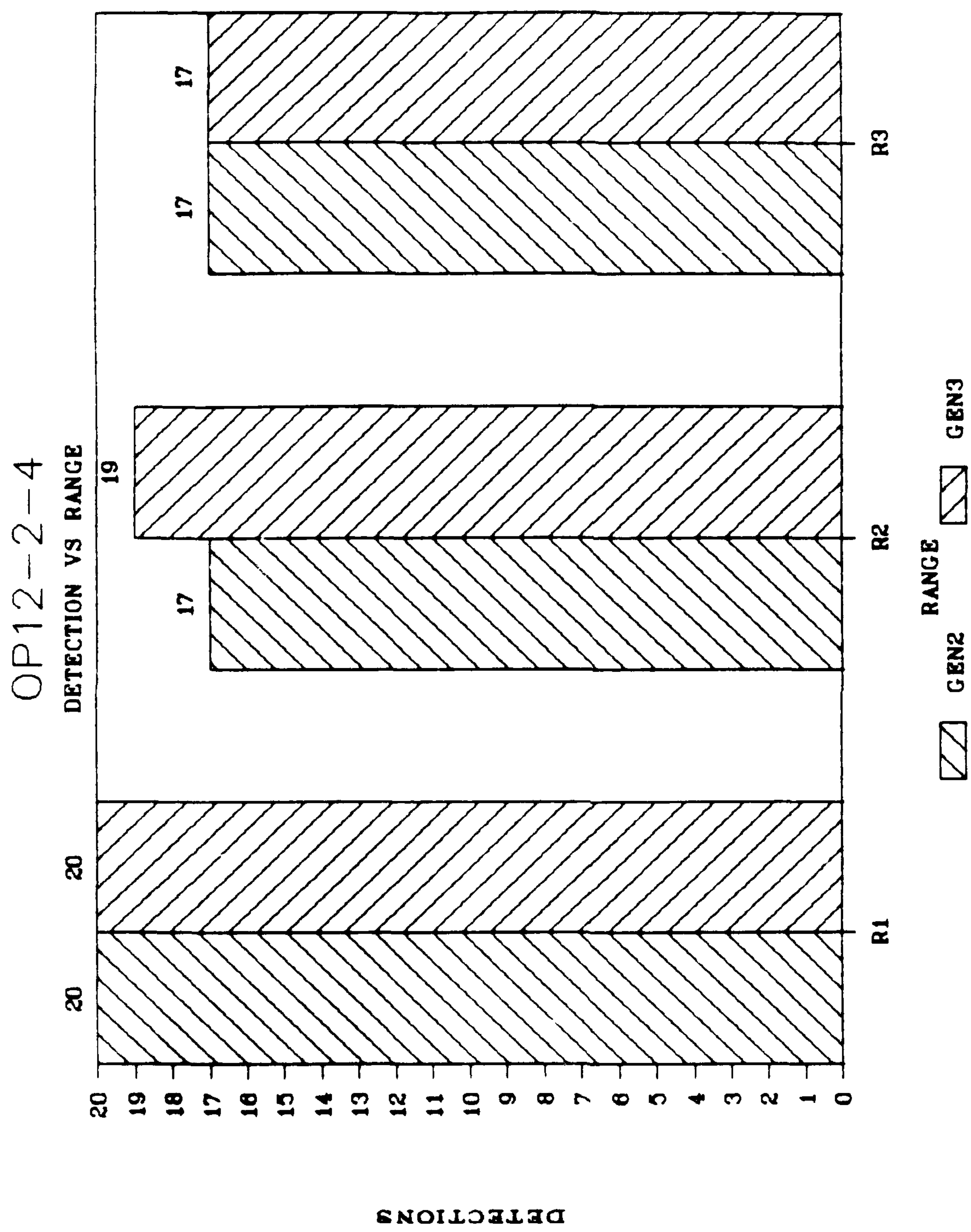
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DETECTION VS RANGE
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