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Physical Evaluation of Personnel Exposed to Microwave Emanations

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Interest in the biological potentials of microwave radiation date back to 1943, when early studies on United States Naval personnel engaged in the operation and maintenance of relatively low power radar equipment was performed by Daily[1] and several years later by Lidman and Cohn[2]. The development and operation of increasingly high-powered transmitters. following World War II, stimulated additional studies and for the first time reports of tissue damage and animal deaths appeared in the literature. These studies, reporting production of lenticular cataracts and corneal opacities in rabbits, testicular degeneration in white rats, and hemorrhagic phenomena in other test animals were reproduced or summarized in electrical and electronic journals, and all too often found their way into lay publications and newspapers. Unfortunately, the publication of this information within the past several years coincided with the development of our most powerful airborne radar transmitters and considerable apprehension and misunderstanding arose among engineering and radar test personnel.

As a result of the interest engendered among aircraft electronics personnel and the relative paucity of knowledge concerning the effects of extremely high-powered electromagnetic waves on animals or humans, the Lockheed Medical Department in the Spring of 1954 instituted a comprehensive physical examination program encompassing studies recommended by earlier medical investigators and within the operational limitations of an industrial medical department. This paper is a report of our objectives and procedures and outlines some preliminary observations and statistical data.

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The program had three major objectives; first, to determine the cumulative biological effects, if any, of longtime contact and exposure to radar equipment and emanations; second, to detect possible effects upon personnel working with or near high-powered airborne radar with pulsed wave emanations for relatively short periods of time and lastly, to establish correlation between objective findings and units of exposure as measured in terms of time-field power density relationship, with the ultimate objective of delineating safe exposure standards.

In order to achieve our first objective all personnel who had worked with any type of radar equipment in the past and who, it was anticipated, would continue in this field in the future, were identified and included in the program. The possibility of slowly developing pathology due to the cumulative effects of microwave radiation has been speculatively raised in literature, although most effects noted in animals have occurred within minutes or in the case of ocular changes, within several days or months of intensive exposure. The physical examination included detailed studies of those body organs or systems in which repeated minimal stimulation might conceivably have resulted in cumulative effects detectable by objective diagnostic procedures. It was anticipated that in a mass examination program involving extensive diagnostic procedures a high percentage of incidental pathology would be uncovered. In an attempt to validate our statistical data we included in our program, as a representative control group, a fairly large number of employees with no history of any possible industrial radar exposure.

It is not our intention to discuss the detailed technical aspects of radar formulations or transmissions or to present any theories as to the mechanism of biological action. These are outlined in the literature in excellent articles by Boysen[3] and Brody[4]. For purposes of orientation, however, a brief review is indicated. Radar emanations originate as electromagnetic impulses in a high frequency oscillating tube, the magnetron, and are propagated through a wave guide to an antenna or dish. Following illumination of the dish, they are projected into space as continuous or pulsed waves. The impulses, travelling with the speed of light, upon striking an object in space are reflected back and travel a reverse path to the wave guide. The impulses, similar in frequency and wave length, but of considerably reduced power, are directed to a receiver and displayed on a screen where they are visualized as "pips".

The radar bands commonly associated with airborne equipment are the "S" (3,000 megacycles) and the "X" bands (9,000 megacycles). "S" band radiation in current use contains the longer wave lengths (10.4 cm) whereas the "X" bands are of the shorter wave lengths (3 cm). The biological effects of radar are to a great extent associated with their frequency and wave length as well as their field intensity, "S" band radiation producing maximal thermal effects in the subcutaneous tissue and "X" band at the superficial or skin level. There is some disagreement as to whether the biological effects of radar are due entirely to the increased heat generated by the absorption and dissipation of this energy in the body or are secondary to other than thermal phenomena. The concensus among most investigators places the primary mode of action at the thermal level and would appear to eliminate specific ionization as a causative or contributing factor.

The pathology noted in ocular tissue of animals following radiation definitely suggests a thermal rather than ionizing causation. Microwave diathermy is capable, under certain experimental conditions, of producing lens opacities by a direct heating effect. Longer wave lengths have a more penetrating thermal effect as demonstrated by Richardson[5] and his a. ociates (Figure 1). In excised beef eyes, they found that with longer wave lengths (12.25 cm) the highest temperature occurred in the posterior cortex of the lens; with slightly shorter wave lengths (8.5 cm) in the anterior cortex and with wave lengths of 3 centimeters in the cornea. In rabbits, 3 centimeter wave lengths caused opacities to develop in the anterior cortex while 12.25 centimeter wave lengths caused opacities in the posterior cortex. These pathological changes were highly suggestive of a direct thermal effect. Experimentally, three types of heat cataracts have been described, diffuse opacities beneath the anterior capsule, feathery cortical opacities in the anterior cortex and delayed opacities in the posterior cortex.

By contrast ionizing radiational cataract whether caused by x-rays, gamma rays or fast neutrons may occur without evidence of injury to other ocular tissues and exhibits a characteristic appearance. The first stage, as described by Duke-Elder, consists of granular capsular dots at the posterior pole with vacuole formation in the posterior cortex. The granular opacities form into a double layer, fuse at the margins and develop into a ring shape. In the second stage a central plaque with dense margins is present at the posterior pole and there is a variable amount of opacification spreading both axially and equatorially; in the final stage the lens is completely opaque.

Boysen, in his studies with rabbits, detected evidence of damage in the central nervous system with degeneration of neurons in the cerebral cortex, the medulla and the basal ganglia; degenerative changes in the tubules of the kidney and moderately severe degenerative changes in the myocardial fibers. In addition, other partially reversible pathology was noted, including hemorrhagic changes in the respiratory tree, degeneration of the hepatic cells and hemorrhage and necrosis of the intestinal mucosa and stomach.

Imig[6] reported testicular degeneration in adult albino rats with histological changes similar to that produced by intensive infra-red irradiation and typical in appearance to the degeneration seen in experimental cryptorchidism. Despite extensive changes in the gonads, the epidermis was not damaged.

Physical examinations were conducted on 226 employees. The procedure included an extensive systemic and organ inventory and a complete physical examination. Emphasis was placed upon the ocular structures, central nervous system, gastrointestinal and urinary tract, hematopoietic system and skin. The presence of embedded metallic foreign bodies was elicited. Evidence of past or current emotional instability was noted. Careful inspection for manifest hemorrhagic phenomena was performed. A modified Rumpel-Leede test was done by placing the blood pressure cuff on the arm and maintaining pressure midway between systolic and diastolic pressure for three minutes. The appearance of petechiae in a circle 4 centimeters in diameter below the antecubital fossa was noted. The test was considered positive when more than 10 petechiae were noted.

The second phase of the examination consisted of ocular and slit lamp studies and routine laboratory procedures including complete blood counts, platelet counts, urinalyses and chest x-rays. In addition each employee was carefully questioned concerning his marital and fertility history and more detailed information obtained concerning duration and type of exposure to radar equipment. The slit lamp examinations were performed under cycloplegia, by a single ophthalmologist with extensive practice in industrial ophthalmology and one who had considerable experience with thermal injuries of the eye.

Table 1 identifies the test subjects and controls by age grouping. The majority of radar personnel were below the age of 50. The control group of 88 subjects was in a somewhat older age grouping. Table 2 reveals the distribution of the total red blood count in terms of years of exposure. Three major groups were identified from 0 to 2 years (106 subjects); 2 to 5 years (83) and from 5 to 13 years (37).

The counts were tabulated as less than 4.5 million, 4.5 to 5 million and over 5 million. In addition, the over-all distribution was noted and compared to that of the control group. The percentage was approximately the same for all groups studied, and revealed no significant changes.

Table 3 reveals a similar study for the white blood count, with a tabulation based upon a total count of less than 5,000, 5-to 10,000 and over 10,000. The table reveals no significant variation in the percentage distribution for any of the groups as compared to each other and the controls.

Table 4 reveals the distribution of white blood cells based upon the over-all findings in the radar group as compared to the control group. There is an apparent significant decrease of polymorphonuclear cells below 55 percent in one quarter of the radar personnel and is disproportionately high when compared to the controls. Of further interest is a rather marked increase in monocytes (over 6%) and eosinophiles (over 4%) in the radar group. The significance of these changes cannot at this time be evaluated.

Table 5 outlines the distribution of blood platelets for the various groups and defines percentage distribution in terms of platelet counts under 200,000, between 200,000 - 300,000 and over 300,000. The table reveals no significant deviation in any group.

Urinalyses revealed abnormal findings in 6 percent of the radar personnel as compared to an equal percentage in the control group. Abnormal findings in both groups were essentially identical and consisted of pyuria, the presence of casts and in several cases albumin and/or red blood cells.

The majority of personnel included in the initial examinations were exposed to radar equipment of the following types: AN/APS-20A; B and C; AN/APS-28, 30, 31, 33 and 45;

AN/APG-40; SG, SX, SR and AN/APS-6,7. It was impossible to obtain precise data concerning exposure time and field strength intensity as in the majority of cases these were unknown to the subjects. Exposure, however, varied from an occasional incidental contact with the beam to as much as four hours daily close exposure for periods of three to four years, with total maximum contact of thirteen years. Five of the subjects had a history or evidence of metallic implants, such as bullets, buckshot, steel fragments and a steel bone pin. In no instance was any unusual complaint subjectively associated with the presence of the implants. In not a single case was any subject aware of unusual heating sensations associated with jewelry, such as wristwatches and rings.

Subjectively, approximately 25 percent of all employees were aware of heating effects when exposed to the beam and in close proximity to the firing antenna. In the majority of cases heat was noted about the face, neck, chest, head and occasionally the hands. Heating effects were more often noted when extremely close to "X" band antenna; however, since most "X" band equipment was of relatively low power this effect disappeared at relatively short distances from the aircraft radome. Complaints of buzzing, vibrations, pulsations and tickling about the head and ears was more prominent in association with "S" band, high powered antenna. These sensations appeared to be associated with the radar pulses. Complaints of fatigue, headache and aching eyeballs were relatively few. On several occasions subjects complained of a sparking effect between dental fillings.

Table 6 reveals that 66 percent of the radar personnel had sired offspring as compared to 77 percent in the control group. Two thirds of the radar group became fathers after working with radar equipment and in the average case their last offspring was born 2½ years following initial radar contact. 34 percent of the radar group were childless, however, in 83 percent of these cases the cause was known and was not necessarily associated with male sterility. In the majority of these cases the subjects were not married or their wives were known to be sterile. This contrasts with 23 percent of childless subjects in the control group in which 85 percent were not necessarily the male's fault.

Physical examinations in both groups revealed significant disorders as illustrated in Table 7. Only those conditions that had their inception following contact with radar are listed for the test group. In the control group the presence of disorders having their inception within the past five years is enumerated. It is evident that the statistical distribution reveals no unusual prevalence of serious disease in the radar group, as contrasted to the controls.

Modified Rumpel-Leede tests revealed positive readings in five of the test subjects for a total of 2 percent as contrasted to 7 positive tests or a total of 8 percent in the control group. There was no apparent correlation between reduced platelet counts and positive Rumpel-Leede tests. In the radar group the positive tests occurred in subjects with a platelet range of 278,000 to 351,000. In addition there were 7 platelet counts within a range of 137,000 to 192,000 in which the Rumpel-Leede tests were negative. In the control group the platelet counts in all but one positive case was in excess of 200,000.

Ophthalmological examinations revealed the presence of eye pathology other than accountable refractive errors in 12 cases among the radar group as noted in Table 8, as contrasted to the single abnormal finding in the control group. With the single exception of a solitary unexplained retinal hemorrhage in the radar group, the etiology of other abnormalities was established and could not be related to the thermal effects of radar.

Re-examination of personnel was accomplished at 6 to 9 month intervals and constitutes the second and currently sustaining phase of our program. In order to confine these studies to personnel actually exposed to the firing beam it was necessary to establish areas or conditions of exposure. This was done by quantative measuring of field power densities of the several types of radar equipment currently operational at Lockheed. Unfortunately, attempts to obtain measurements of the antenna radiation pattern of airborne radar installations close to the airplane and while it is on the ground, are relatively difficult. The true energy profile is not as predictable as had generally been assumed, and is instead a non-descript intensity fluctuating beam over the phase front.

In a plane perpendicular to the axis of propagation, there are areas in which the energy from the main source (antenna) and that from the secondary reflecting sources (the environment) is in phase, producing so-called "hot spots", whereas in other areas the multi-path energy will be "out of phase" and cancel to a great extent, producing nulls or "cold spots".

Three dimensionally, this phenomena takes the form of multi-finger lobes in the direction of propagation of a power density greater than expected as predicted by the inverse square of distance (far field measurements) interspersed with deep nulls of low energy levels. These lobes of high energy concentration change in power level and relative location in respect to the axis of propagation, both as the antenna is rotated in azimuth and as the very environment of the area changes from day to day. Tilting the antenna during operational tests will also change the instantaneous power density profile to the extent of nulling out previous hot spots; thus, most of the detrimental beam shaping is caused by the unnatural state of confining a supposedly free space beam of energy between the airplane and the ground, a condition that automatically exists along with the problem of exposure of maintenance personnel. Figure 2 is a sketch of the probable deviation of the theoretical beam radiated from the antenna of an airplane on the ground. It is apparent then, that since field intensity measurements of airborne radar transmitters undergoing ground level tests do not follow the inverse square law of measurements in the near radar field, studies of power densities in the far field cannot be accurately extrapolated for near field exposures. It must, therefore, be assumed that field power densities rise abruptly as one approaches the near vicinity of a firing antenna and that this near field of high magnitude extends considerably further geographically for the higher powered, larger antenna radar. Since biological effects depend upon exposure to average field power densities the difficulties of measuring and unitizing exposure dosage becomes immediately apparent.

Field power densities upon which zones were eventually delineated were based upon measurements of intensities in the "hot spots" at various distances from the antenna. Three zones were delineated and all personnel in Zone A were automatically included in the program. The minimal field strength in this zone was .0131 watts/cm^2. The maximum power density in this zone was not determined but presumably, if measured at the radome, was many times greater than the minimum. This is not to be construed as indicating the selection of the lesser figure as a potentially biological hazard. To the contrary, all zones were basically defined in geographical distances from the radomes, and in consideration of the information outlined above.

All personnel working in Zone B, except those who were exposed to the beam by occasional transit through the area, were included in our re-examination program. This zone geographically encompassed field intensities of .0131 watts/cm^2 to .0039 watts/cm^2. Zone C extended beyond this area, but, due to the relatively low field power densities personnel working in "C" were eliminated from the study.

As a result of the establishment of these zones, steps were immediately taken by supervision to prohibit all but a very few test personnel from entering Zone A. This in effect limited field exposure so that the subjects re-examined had mainly incidental exposure to stray radiation of relatively low intensity for various intervals during the day. The majority of these personnel work with or around the AN/APS-20 B and E and the APS-45 radar. The operational testing of this equipment involves scanning of a 30° sector, with the antenna pointed toward an open field. The antenna rotates at two or six revolutions per minute and usually at reduced power.

Approximately 100 subjects have been re-examined to date. Re-examinations are limited to ophthalmological studies, complete blood counts, platelet counts and urinalyses. In select cases additional studies and/or physical examinations are performed. Table 9 reveals blood findings in terms of a ten percent variation above or below the original findings. It is evident that a decrease in the red blood count has occurred in a significantly large percentage of subjects with increases in the white blood count and polymorphonuclear cells. The platelet counts reveals changes in both directions of approximately equal extent.

These are somewhat paradoxical findings as contrasted to those observed in the original long exposure studies. Additional data is needed prior to final evaluation. Urinalyses reveal the majority of previously noted abnormalities to have subsided. There were a small number of abnormalities noted in specimens which had previously been negative.

Ophthalmological examinations revealed no new or progressive changes in the eyes. Pathology noted previously remained stationary with the exception of the single retinal hemorrhage which showed evidence of absorption. There was no indication whatsoever of new damage to or around the ocular tissue. Subjectively, there were no new complaints. Diseases that occurred during the re-check period were all of known etiology and were unrelated to radar. The wives of seven subjects successfully conceived during this period.

Summary and Conclusions

A comprehensive physical examination program of radar personnel at a large airframe manufacturer was instituted in an effort to determine whether prolonged (years) and short (months) duration exposure to microwave emanations had resulted in transient or permanent biological damage. It was further hoped to correlate any significant findings with time-field power relationship and postulate standards for safe exposure.

Included in the program was 226 personnel with histories of radar contact varying from occasional beam exposure to 4 hours a day and up to 13 years over-all. 88 control subjects were given examinations similar in scope for baseline comparison. The examinations were designed to detect pathology experimentally induced in small animals apparently by the thermal effects of absorbed electromagnetic energy. Special emphasis was placed on those structures with poor heat regulatory mechanics, such as, the cornea of the eye and the gastro-intestinal and genito -urinary tracts and those organs and systems adversely affected by excessive heat, such as the gonads and hematopoietic systems.

Radar personnel were grouped as to years of exposure, 0 to 2 years, 2 to 5 years and 5 to 13 years. The distribution of the red blood counts, white blood counts and blood platelets was essentially identical among the sub-groups and comparable to the control group. There was a significant decrease in the polymorphonuclear cells in 25 percent of the radar personnel as compared to 12 percent in the control group. An interesting and disproportionate increase in monocytes above 6 percent and eosinophiles over 4 percent was also noted for the radar group. The significance of these changes is not immediately apparent and warrants further study.

Urinalyses revealed no significant difference for the two groups. Fertility statistics were essentially comparable. There was no indication of increased significant pathology among the radar personnel. Ocular examinations revealed a high incidence of pathology for the radar group, however, in all but a single case of retinal hemorrhage, the etiology was known and determined to be entirely unrelated to radar exposure.

Modified Rumpel-Leede tests for capillary fragility were disproportionately high for the control group. There was no apparent correlation between reduced platelet counts and positive tests.

Subjective complaints were present in a minority of cases and consisted essentially of a heating sensation when in close proximity to "X" band antenna and buzzings or vibrations near "S" band antenna. Occasional complaints of fatigue, headaches and aching eyeballs were elicited. The presence of embedded metallic foreign bodies was not associated with any localized heating or tissue destructive effects.

Re-examination was accomplished on 100 subjects following 6 to 9 months of incidental contact with both "S" band and "X" band, pulsed radar transmitters. Examinations were essentially limited to the ocular structures, blood cellular studies and urinalyses. Preliminary observations revealed a decrease of red blood cells in excess of 10 percent from original in 42 percent of subjects; an increase of white blood cells in 58 percent and an increase in polymorphonuclears in 35 percent. The blood platelets showed no significant unidirectional change.

The hematological findings are paradoxical and difficult to interpret. Final evaluation requires additional statistical data and multiple periodic rechecks.

The difficulty in measuring field power densities upon which the biological effects of microwave energy is predicated is stressed. Routine field measurements are generally made in the far radar field, the acceptable boundary of which is defined by $\frac{2d^2}{\lambda}$, where d is the diameter of the round dish propagating energy and lambda the physical wave length of the frequency. Within the far field, accurate field power densities may be formulated by application of the inverse square law of free field air absorption.

Since radar test and maintenance personnel may be exposed to the firing beam at distances not encompassed by the far field boundary, it becomes increasingly difficult to evaluate biological effects and hazards in relation to absolute exposure dosage. The need for more precise measurements is obvious and can be achieved through the development of exposure level meters reflecting absorption in quantum units of radar energy.

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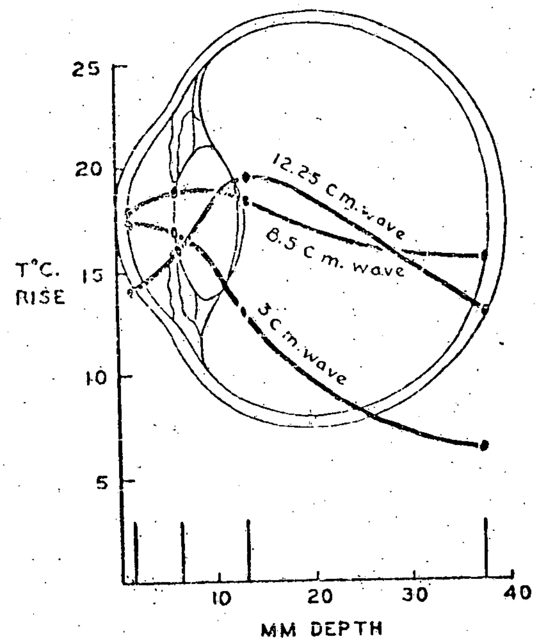

Fig. 1. Temperature gradients in beef eyes induced by microwaves of 12.25, 8.5 and 3 cm. wavelengths. (After Richardson)

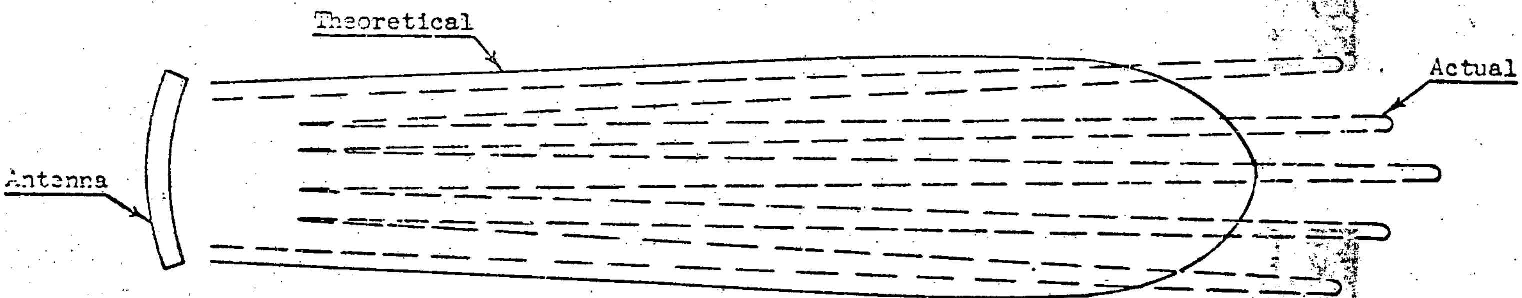

FIGURE 2: DEVIATION OF RADAR BEAM FROM AIRCRAFT ON GROUND

TABLE I AGE GROUPS

	RADAR	CONTROL
AGE	% of 226	% of 88
20 - 29	34	14
30 - 39	49	40
40 - 49	13	27
50 plus	4	19

TABLE II RED BLOOD COUNT

R. B. C.	Years of Exposure			OVER-ALL	CONTROL
	0 - 2	2 - 5	5 - 13		
(Millions)	% of 106	% of 83	% of 37	% of 226	% of 88
Less than 4.5	2	1	3	2	4
4.5 - 5.0	19	25	22	22	23
5.1 plus	79	74	75	76	73

TABLE III WHITE BLOOD COUNT

	Years of Exposure			OVER-ALL	CONTROL
	0 - 2	2 - 5	5 - 13		
W. B. C.	% of 106	% of 83	% of 37	% of 226	% of 88
Less than 5,000	1	1	0	1	0
5,000 - 10,000	84	78	87	82	84
Over 10,000	15	21	13	17	16

TABLE IV DISTRIBUTION OF W.B.C.

	POLYMORPHONUCLEARS		MONOCYTES	EOSINOPHILES
	Over 70%	Under 55%	Over 6%	Over 4%
RADAR (% of 226)	9	25	17	20
CONTROL (% of 88)	8	12	6	8

TABLE V BLOOD PLATELETS

PLATELETS	Years of Exposure 0 - 2	2 - 5	5 - 13	OVER-ALL	CONTROL
	% of 106	% of 83	% of 37	% of 226	% of 88
Less than 200,000	3	3	5	3	1
200,000 - 300,000	51	49	50	50	57
Over 300,000	46	48	45	47	42

TABLE VI FERTILITY DATA

RADAR	% of 226	
One or more siblings	66	
After radar		66
Before radar		34
No siblings	34	
Accountable - other than Male		83
Male sterility or unknown		17
CONTROL	% of 88	
One or more siblings	77	
No siblings	23	
Accountable - other than Male		85
Male sterility or unknown		15

TABLE VII GENERAL PATHOLOGY (5 years)

	RADAR (226)	CONTROL (88)
Nervous System	1	1
Circulatory	2	5
Anemia	2	0
Gastrointestinal (Ulcer:Gall Bladder)	5	7
Arthritis	1	2
Psychiatric	2	1
Bleeding Phenomena	2	4
Migraine	0	2
Jaundice	1	3

TABLE VIII OCULAR PATHOLOGY

RADAR

1. Iridectomy. Esotropia with nystagmus.
2. Diabetic retinopathy.
3. Congenital sutural cataracts.
4. Alternating exotropia, intermittent. Congenital sutural cataracts.
5. Solitary retinal hemorrhage, cause unknown. Left hypertropia.
6. Partial traumatic cataract.
7. Corneal scar.
8. Drusen, macular area.
9. Right surgical anophthalmas following trauma. Left healed chorio-retinitis.
10. Traumatic cataract.
11. Vitreous floater.
12. Exophthalmos, cause unknown.

CONTROL

1. Congenital polar cataract and coronary opacities.

TABLE IX HEMATOLOGY RECHECKS (6 - 9 months)

CHANGE OVER 10%	RED BLOOD COUNT	WHITE BLOOD COUNT	POLYMORPHONUCLEAR	PLATELET
	Percentage of 100			
INCREASE	14	58	35	27
DECREASE	42	23	14	20