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NAPC

HAZARDS OF A REACTOR ACCIDENT

DEPARTMENT
OF
NUCLEAR SCIENCE AND TECHNOLOGY

RESTRICTED

NUCLEAR ACCIDENT PROCEDURES COURSE

HAZARDS OF A SUBMARINE REACTOR ACCIDENT

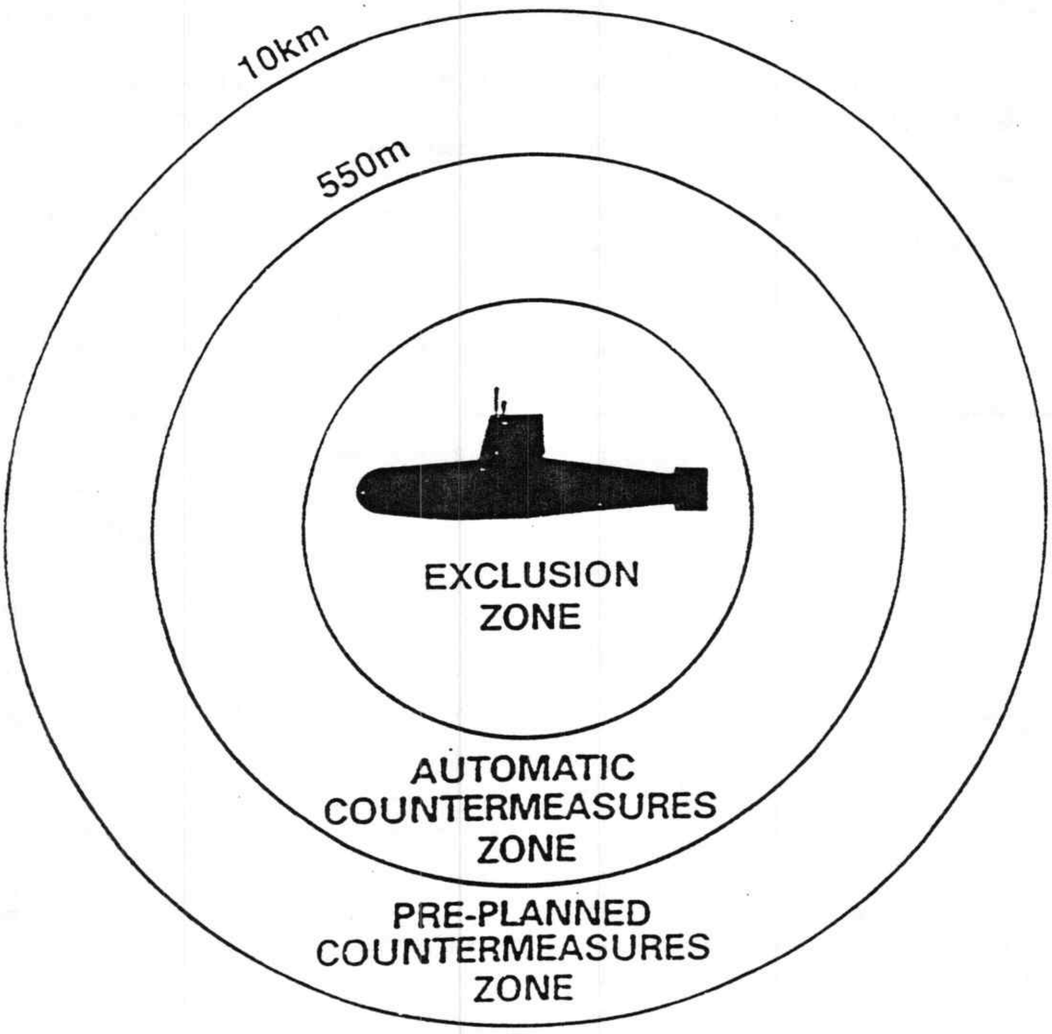
1. INTRODUCTION

The sequence of events leading up to and immediately following a major loss of coolant have already been discussed. Here we examine the nature and extent of the radiological hazard posed to site personnel and members of the public. The discussion will concentrate on the likely requirements for implementing countermeasures and the distances out to which such actions might be required for a range of accidents of varying severity.

2. PLANNING ZONES

Figure 2.1 shows the MOD reactor accident planning zones.

FIGURE 2.1 MOD REACTOR ACCIDENT PLANNING ZONES



The Zones are defined as follows:

a. Exclusion Zone - approximately 50m around the reactor compartment of the submarine. The zone is physically delimited by barriers, access is controlled and personal dosimeters are worn.

b. Automatic Countermeasures Zone - 550m around the submarine. This zone incorporates the base. Individuals within this zone respond immediately to a nuclear warning alarm or message, sheltering or evacuating according to a rehearsed plan. Potassium Iodate tablets (PITs) are issued (i.e distributed and taken) to all personnel.

c. Pre-planned Countermeasures Zone - 550m out to 10 km, 360° around the SM. Countermeasures are not automatic, but monitoring of airborne and deposited activity begins immediately after the accident. Countermeasures, downwind of the SM, are advised on the basis of projected doses from measured levels of radioactivity in the environment. The probability of requiring countermeasures beyond 10 km is so low as negate any requirement for planning beyond this distance.

3. EMERGENCY REFERENCE LEVELS FOR IMPLEMENTATION OF COUNTERMEASURES

The NRPB, recognising the adverse effects of countermeasures as well as the potential benefits provide guidance Emergency Reference Levels (ERLs) for dose averted for each countermeasure. Below the lower ERL, the countermeasure is likely to do more harm than good. Above the upper ERL, there will almost certainly be net benefit. ERLs are used in preparing contingency plans.

TABLE 3.1 EMERGENCY REFERENCE LEVELS (mSv)

	LOWER		UPPER	
	Whole Body	Single Organ	Whole Body	Single Organ
EVACUATION	30*	300	300	3000
SHELTERING	3	30	30*	300
IODATE		30*		300

The MOD specify single values (rather than a range) - these single values are called Emergency Action Guidance Levels (EAGLs) and are indicated by "*" in the Table above.

Again, to simplify emergency actions (in the pre-planned zone): it is anticipated that if the issue of PITs is required, sheltering would also be advised.

4. RADIOLOGICAL HAZARDS OF THE REACTOR ACCIDENT

Core melt-down, described in previous lectures, led to a reactor compartment containing large quantities of fission products. Most of the Gamma radiation (from the fission products), devoid of the normal layers of radiation shielding, penetrates the hull. This leads to potentially huge increases in gamma radiation dose ashore and is referred to as HULL GAMMA SHINE. On board, some protection is offered in the fore and after ends due to shielding by bulkheads and machinery.

Fortunately all beta radiation is stopped by a few mm of material so does not contribute to radiation dose at this stage.

However both beta and gamma will become hazards outside the submarine if the radioactive fission products escape from the reactor compartment and the submarine pressure hull forming a plume which drifts downwind. Containment, it is thought, will not fail in 99% of reactor accidents.

Before going on to look at the plume hazards which would arise, therefore, in a only 1% of accidents, the HULL GAMMA SHINE HAZARD will briefly be quantified.

4.1 Hull Gamma Shine

The scenario relates to TRAFALGAR class with complete core melt following standard core history - effectively a **worst case scenario.** Isodose curves, given in BR 3019(1) (Part 7 App 1), indicate the following:

a. **Dose rates (1 m above sea level) around the SM show 1 Sv/h (serious immediate radiation injury) - 10 m or so from the hull. At 200 m, midships, the doserate is 10 mSv/h (no serious immediate injury - but untenable location for any length of time). At 400 m the doserate is 1 mSv/h (tenable for operational tasks).**

b. Extrapolating these doserates beyond 550 m would suggest doserates in excess of 7.5 microSv/h - the normal level for a controlled radiation area. However, local topography and buildings provide significant shielding and it is unlikely that countermeasures (against hull gamma shine) will be required beyond 550m.

c. The dose rates above apply initially, but over a period of time, **the complex mixture of fission products will decay to an extent, gamma levels reducing by a factor of 10 over 4.5 hours, 100 over 18 days and 1000 over 1 year.**

d. **Underwater doses of 1000 Sv/h in contact with the hull fall away by to 1 microSv/h over a distance of 10m or so.**

e. **Aerial approaches** - an approach from midships at a height of 50m would lead to an intolerable dose of 1Sv/h at a distance of 50m. Approaching along the SM axis to the bow or stern at a height of 20m would give rise to a doserate of around 50 mSv/h in the hover.

4.2 The Airborne Hazard

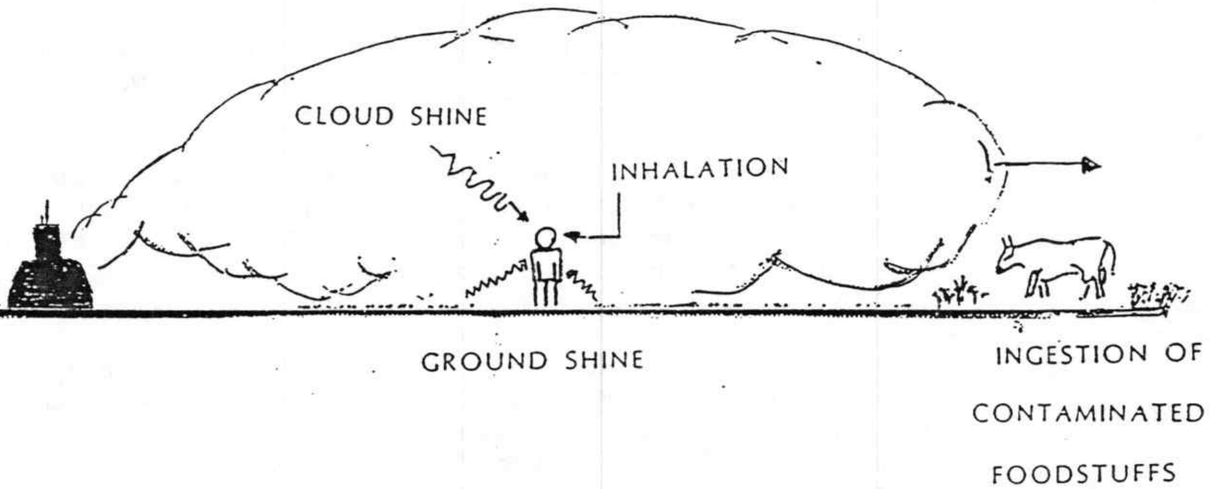
The extent of the hazard depends on a multitude of factors, for example:

a. magnitude and composition of release
b. physical and chemical form of release
c. duration of release
d. wind direction and resultant plume trajectory
e. atmospheric stability and turbulence
f. rainfall
g. location and actions of exposed individuals

There are a number of pathways, shown in Figure 4.1, which contribute towards the doses received in both short and long term:

FIGURE 4.1

EXPOSURE PATHWAYS FOLLOWING REACTOR ACCIDENTS



4.2.1 Fission Product Cloud Shine

If containment is breached or by-passed, the hazard will not be confined to hull gamma shine - downwind, there will also be the hazard of direct γ from the fission product cloud (or plume).

4.2.2 Fission Product Cloud Inhalation

For a large release, inhalation is likely to give the largest dose, the dominant dose is due to inhalation of radioactive iodine which transfers to the thyroid gland. Radioactive material taken in to the body gives an accumulating dose until such time as it has decayed away or been excreted by the body - doses calculated for application of countermeasures take this accumulation of dose (committed dose) into account.

4.2.3 Ground Shine

Direct γ and β from ground deposition of fission products. The dose continues to accumulate after the plume has passed.

4.2.4 Ingestion of Contaminated Foodstuffs

Ingestion from exposed food, vegetables etc.
Cows concentrate radioactive Iodine in milk. I-131 has 8 day half-life and therefore milk may be affected for several months.
Grass in some areas concentrates Cs-137 (30y half-life) and mutton may continue to be contaminated for several years.
Venison and fish from inland lakes are also prone to higher levels of Cs-137.

5. CONTINGENCY PLANNING

Current contingency plans are based on the methodology and dose calculations given at Annex A.

Since current plans were drawn up, several changes have occurred:

a. ERLs have been changed
b. Submarine Designs have changed
c. Reactor accidents over a broad range are now being assessed probabilistically, rather than by considering reference and worst case accidents.

The lecturer will outline predictions and extent of countermeasures from the contingency plan review work currently being carried out for TRAFALGAR class using the CONDOR computer code.

Early results indicate that changes in the MOD reactor accident planning zones are unlikely to be necessary.

ANNEX A CURRENT CONTINGENCY PLANNING

1. Benchmark Releases

The amount of radioactivity released in a reactor accident depends on the core inventory at the time of the accident and on the particular accident sequence. The core inventory will depend on reactor power rating and the detailed operating history. The benchmark releases are based on a Standard Core History inventory.

The fraction of activity released will depend on the extent of fuel melt, the volatilty of the various radionuclides and the integrity of the containment systems (primary and secondary). The reactor compartment forms the primary containment and is designed to withstand the pressure surges associated with the accident. It is designed to be virtually leak-tight and its hermetic properties are regularly tested. Therefore, provided the containment remains intact, the release of fission products from the RC to the rest of the vessel should be very small indeed. Moreover, if secondary containment is secured, the release to the environment will be further reduced. In the most likely event, the accident will give rise to a slow seepage of mainly inert gases (Kr, Xe) with perhaps a trace of the more volatile radionuclides such as I and Cs. This scenario forms the basis for the benchmark release BR0.

For planning purposes it would be inappropriate to asssume such a small release. The primary containment boundary is penetrated at various locations (eg to allow cabling to reach reactor instrumentation), and these penetrations represent possible leak sites. Thus, for planning purposes, it is assumed that 1% of all fission products in the RC leak out over 24 hours, and that a further 10% of those are released to the atmosphere. This scenario forms the basis of benchmark release BR3.

On the other hand, it is just conceivable that for some reason both primary and secondary containment fail, or are by-passed, (eg pentetration of the hull). In this extremely unlikely event it is possible that the entire contents of the RC could be released in a very short time (minutes). This scenario, the so-called Primary Containment Failure Accident, forms the basis for the "worst case" benchmark release, BR6.

Table 1 summarises the release fractions and release durations assumed for each of the three benchmark releases. Also, in order to put the releases into some perspective, Figure 2 illustrates a "Richter Scale" of nuclear accidents. Note that the scale is logarithmic (ie an accident on scale 4 releases ten times as much activity as a scale 3 accident). The Windscale, Three Mile Island and Chernobyl accidents are represented. The BR0, BR3 and BR6 benchmark releases would be at 0, 3 and 6 on the scale, respectively.

2. Consequences of the Benchmark Releases

Figure 2 shows the whole body dose profile (dose versus distance from the source) for each of the three benchmark releases, in "average" weather. The whole body dose includes cloudshine, inhalation (50 year committed EDE) and groundshine (dose accrued in first 24 hours only). The horizontal lines on the graph are the 1 mSv (annual background) and 100 mSv (evacuation EAGL) doses. From the graph it is clear that the EAGL is NOT exceeded beyond 500 metres in the case of BR0 and BR3. However, in the case of BR6, the EAGL for evacuation IS exceeded, to a distance of some 10 km.

Figure 3 shows the dose to the thyroid as a function of distance from the source. In this case, 95% of the dose is from inhalation of radioiodine. The EAGL for distributing PITs is 50 mSv. Comparison of the dose profiles with this limit shows that for BR0 there is no exceedance beyond 100 metres. In the case of BR3, the EAGL IS exceeded to a distance of approximately 1 km. For the BR6 release the EAGL is exceeded beyond 100 km.

The dose profiles obtained from the BR3 release (the "planning" accident) are shown in figures 4 and 5 with finer resolution. In this case, the profiles are shown for "average" weather (that is, stability category D, wind-speed 4m/s) and for "worst-case" weather (that is, stability category F, wind-speed 1m/s). At any distance, the difference between avarage and worst case weather is about a factor of 6 - 10. In Figure 4 (whole body dose), the 100 mSv EAGL is not exceeded beyond 100 metres in average weather, but IS exceeded out to a distance of some 500 metres in the worst case. The EAGL is NOT exceeded beyond the site boundary at 550 metres. In figure 5, the thyroid dose exceeds the 50 mSv EAGL to a distance of 300 metres in average weather, increasing to 1.5 km in the worst case.

The doses quoted above are subject to large uncertainties and should be treated with some caution. Nevertheless, they provide "ball park" figures for the extent of the hazard posed by each of the specified releases.

3. Importance of Exposure Pathways

The effectiveness of any countermeasures depends crucially on the timing of the countermeasure and on the relative importance of the various exposure pathways. Figure 6 is a set of pie charts showing the contribution of cloudshine, inhalation and groundshine to the total effective dose equivalent at 1 km down-wind. In the case of BR0, cloudshine is the only significant exposure pathway. This is because the BR0 release is dominated by inert gases (Kr, Xe) which do NOT deposit and which are NOT absorbed in the lung. In the case of BR3, about 90% of the exposure is from cloudshine and inhalation (ie during plume passage) and only 10% is from groundshine. In the case of BR6, inhalation is the dominant pathway (60%), followed by groundshine (34%) with only a small contribution from cloudshine (4%).

It is clear that exposure to the passing plume gives rise to most of the accrued dose. It would appear then, that evacuation during plume passage might exacerbate the situation, causing a net increase in the accrued dose. On the other hand, advising people to shelter during plume passage could have substantial benefit; sheltering is a fairly simple countermeasure to adopt and is effective in shielding individuals from cloudshine, as well as reducing the inhalation dose because of the filtering effect of the building. Decisions on evacuation (or even relocation) can then be taken on the basis of the projected doses from groundshine; these can be computed with some accuracy from monitoring information.

Considerable benefit can derive from a delayed evacuation. Figure 7 shows how the dose from deposited activity accrues as a function of time after the accident. Relative to the dose accrued over 50 years, about 5% is received in the first day, and about 20% in the first week. These estimates take account of removal by natural processes such as radioactive decay and weathering, but do not assume decontamination.

4. Effect of Rainfall

The estimates discussed above assume dry conditions at the time of the release. In fact, rainfall can have a marked effect on the amount of deposited activity; moderate rainfall at the time of the release can increase deposited activity by up to a factor of five, so that groundshine (rather than cloudshine or inhalation) becomes the dominant exposure pathway. Figure 8 shows the effect of widespread rainfall on deposited activity for a range of rainfall rates. At large distances the deposition is reduced because of wash-out closer to the source. In fact this situation is unlikely to arise as rainfall tends to be patchy; this in turn will lead to localised areas of high deposition or "hot-spots".

Rainfall after the passage of the plume can have a significant effect in washing away much of the surface contamination. This could have an important beneficial effect in an urban area where the "run-off" is removed by the drainage/sewerage system. Recent research has suggested that moderate rainfall immediately after plume passage could remove as much as 90% of the activity deposited onto urban surfaces (roads, buildings, roofs, etc).

DOSE TO WHOLE BODY Vs DISTANCE

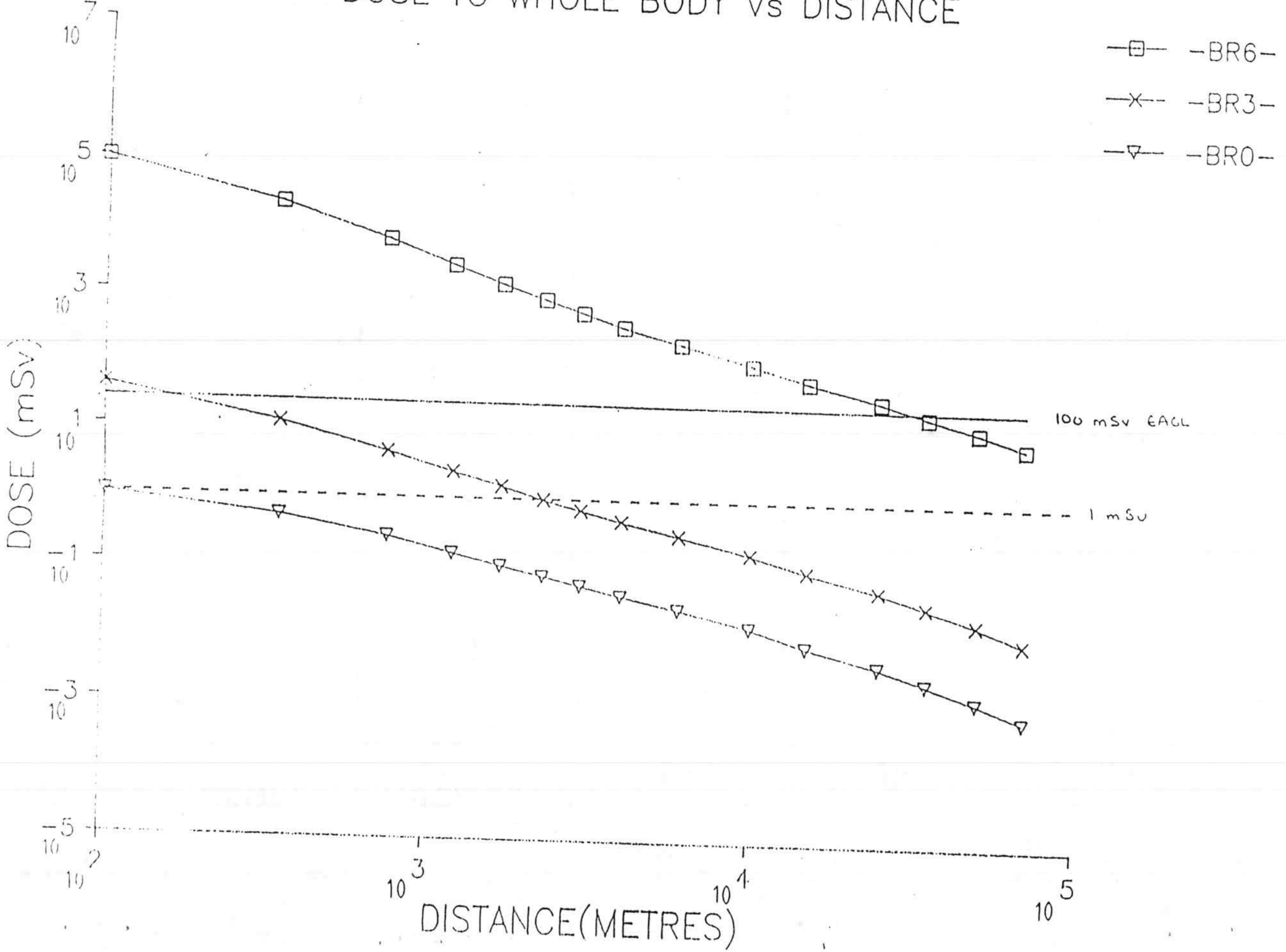


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FIG 2

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GROUP	NUCLIDES	BENCHMARK RELEASE FRACTIONS		
		BR0	BR3	BR6
1	Xe,Kr	0.1	1.0	1.0
2	I,Cs	10^{-6}	10^{-3}	1.0
3	Ba,Sr	$2.5x10^{-7}$	$2.5x10^{-4}$	0.25
4	Te,Sb	10^{-7}	10^{-4}	0.1
5	Ru,others	10^{-8}	10^{-5}	0.01
Release Duration		24 hrs	24 hrs	10 mins

FIG 1

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DOSE TO THYROID Vs DISTANCE

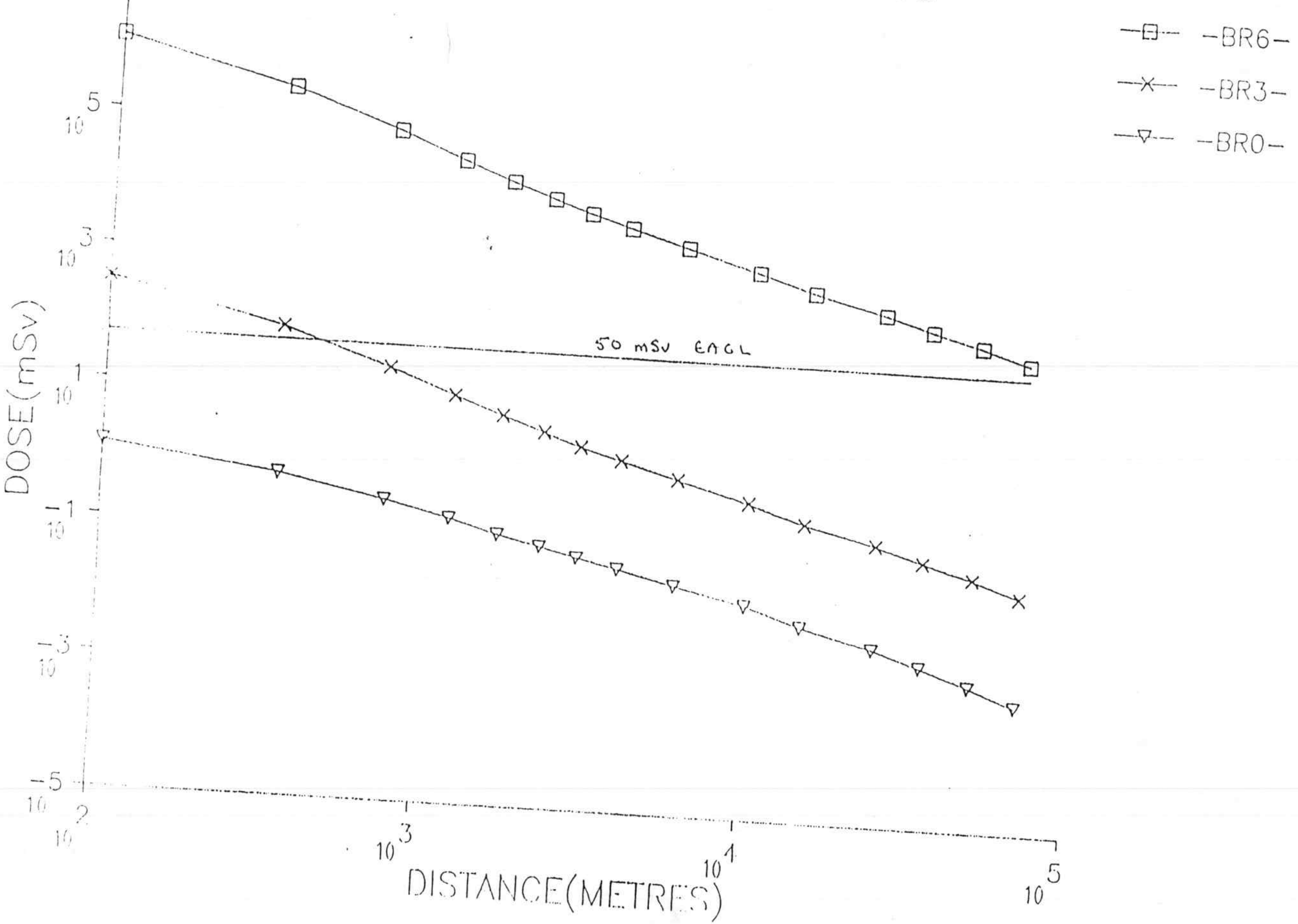

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Fig 3

DOSE TO THYROID Vs DISTANCE

RELEASE BR 3

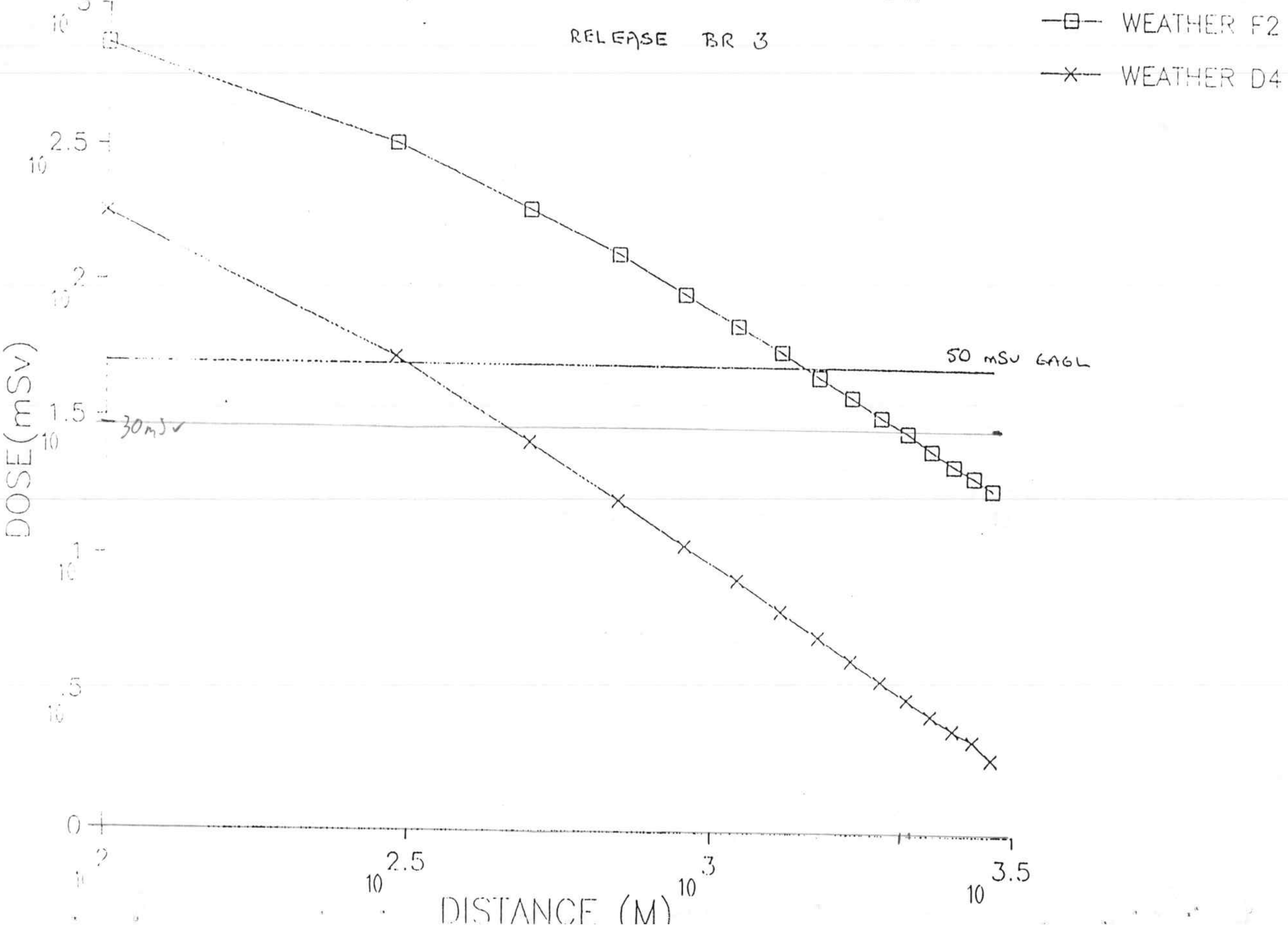

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FIG 4

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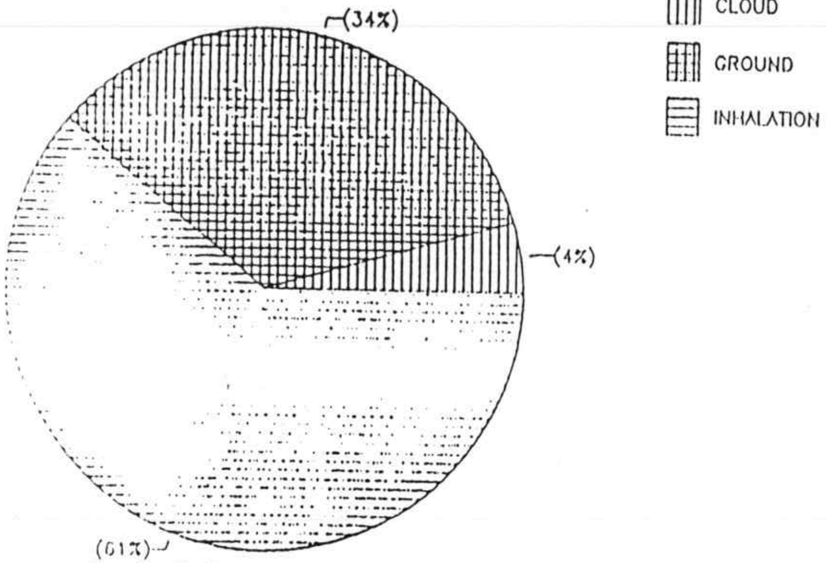
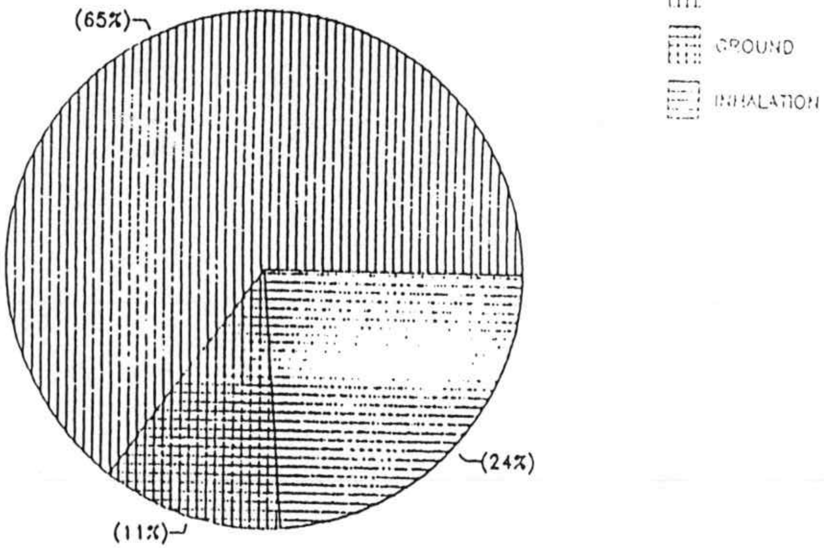
WHOLE BODY DOSE COMPONENTS
FOR BR6 (1Km)



WHOLE BODY DOSE COMPONENTS
FOR BR3(1Km)



WHOLE BODY DOSE COMPONENTS
FOR BR0(1Km)

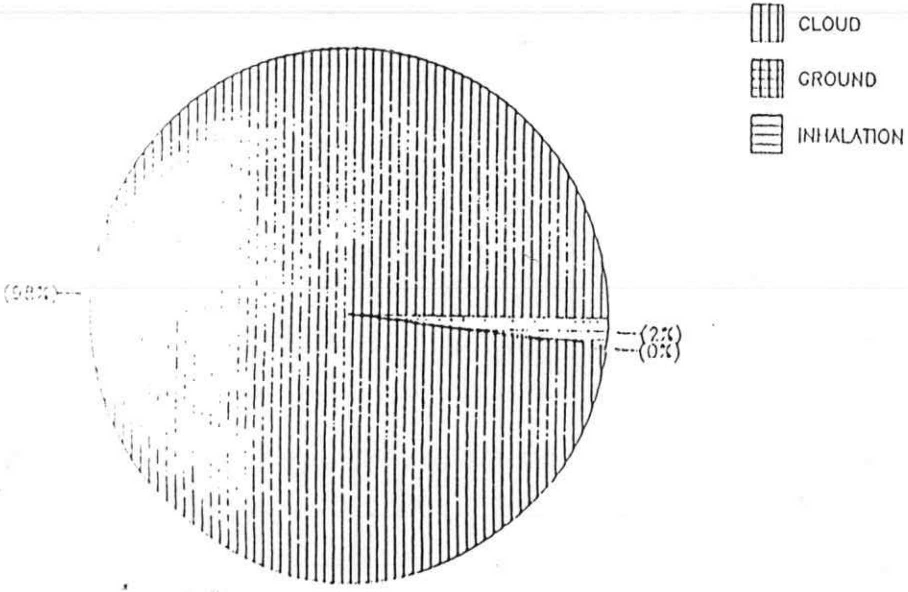


Fig 6

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DOSE TO WHOLE BODY Vs DISTANCE

RELEASE BR 3

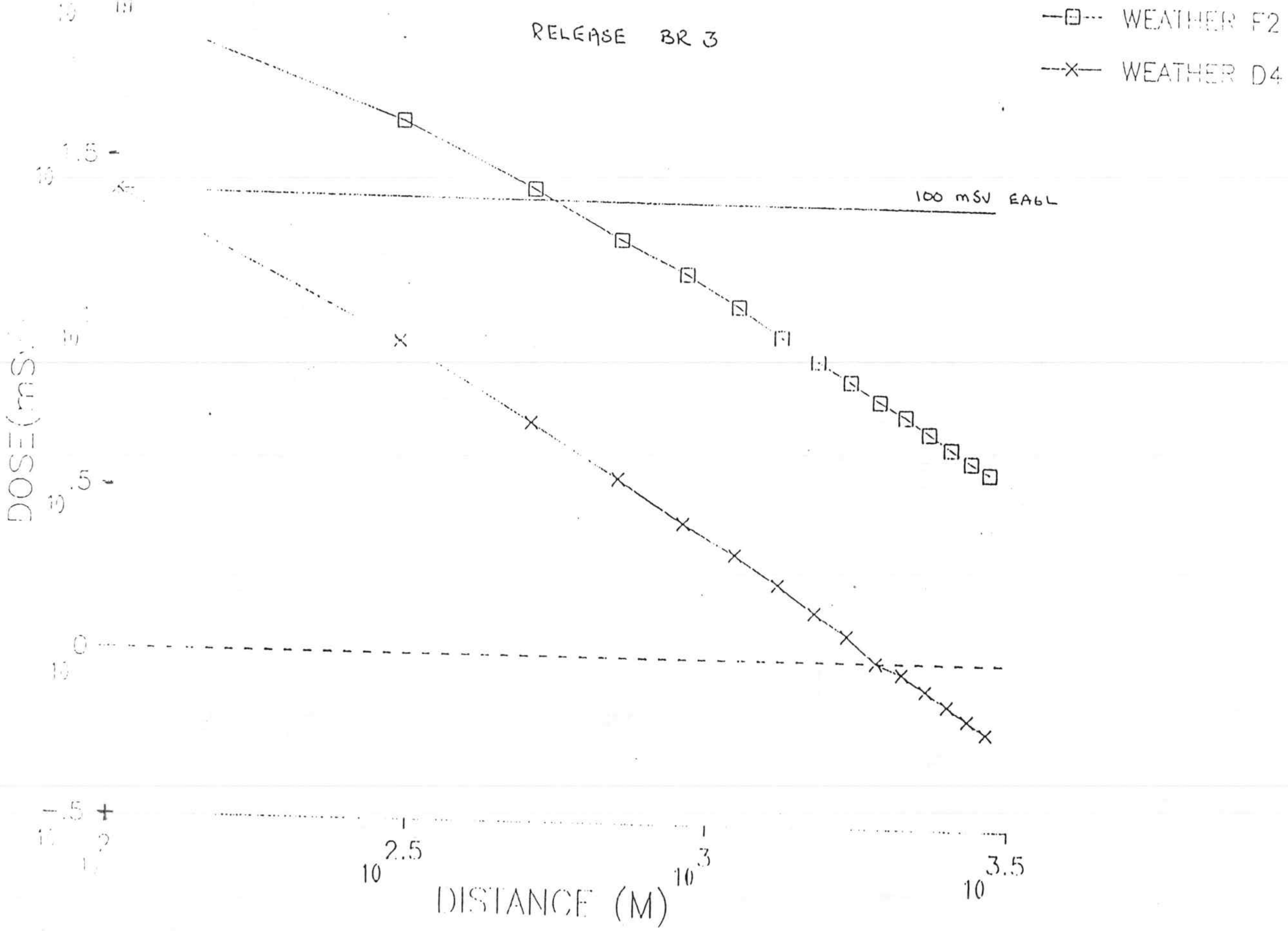

FIG 5

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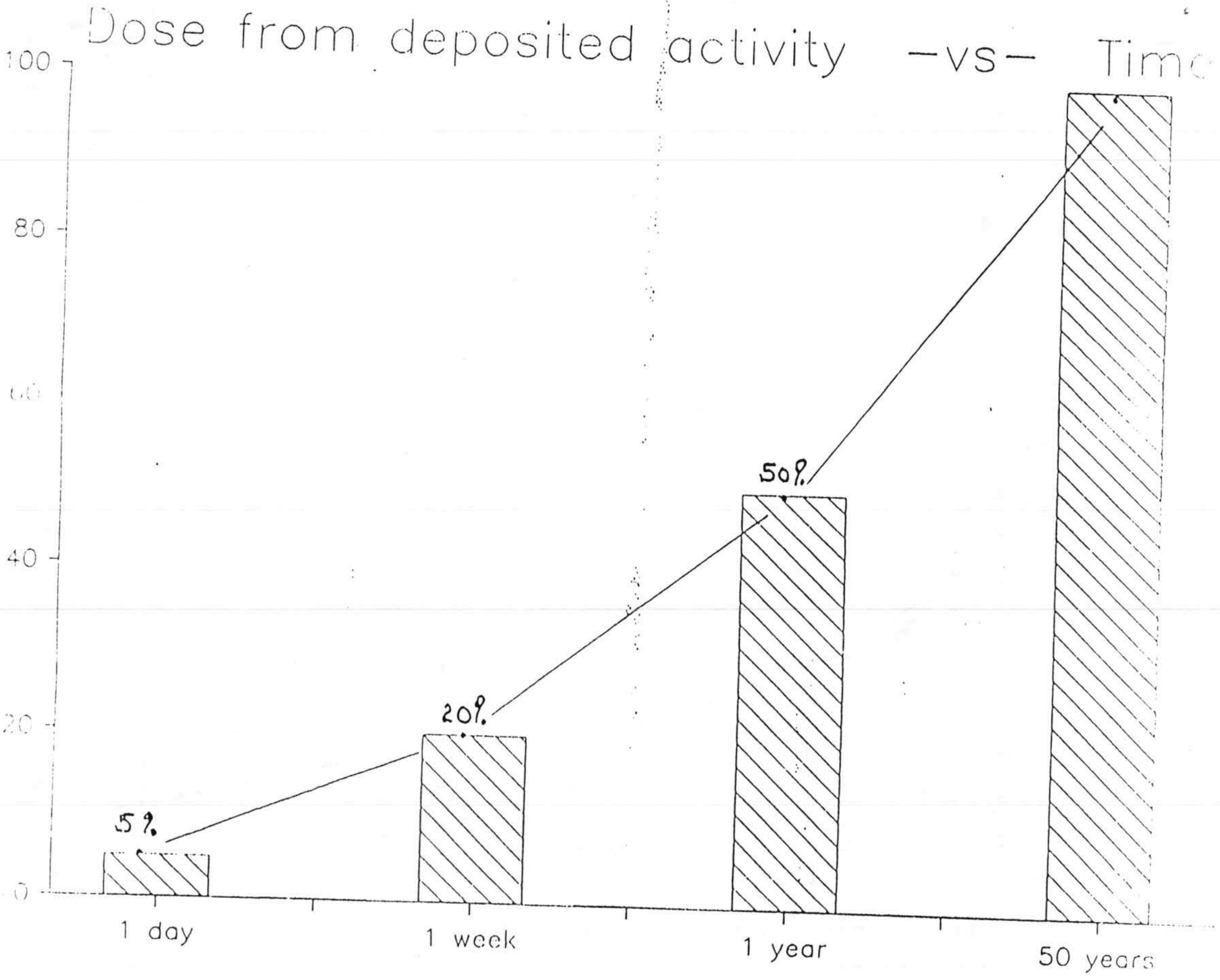
Fig 7



EFFECT OF RAINFALL ON DEPOSITION

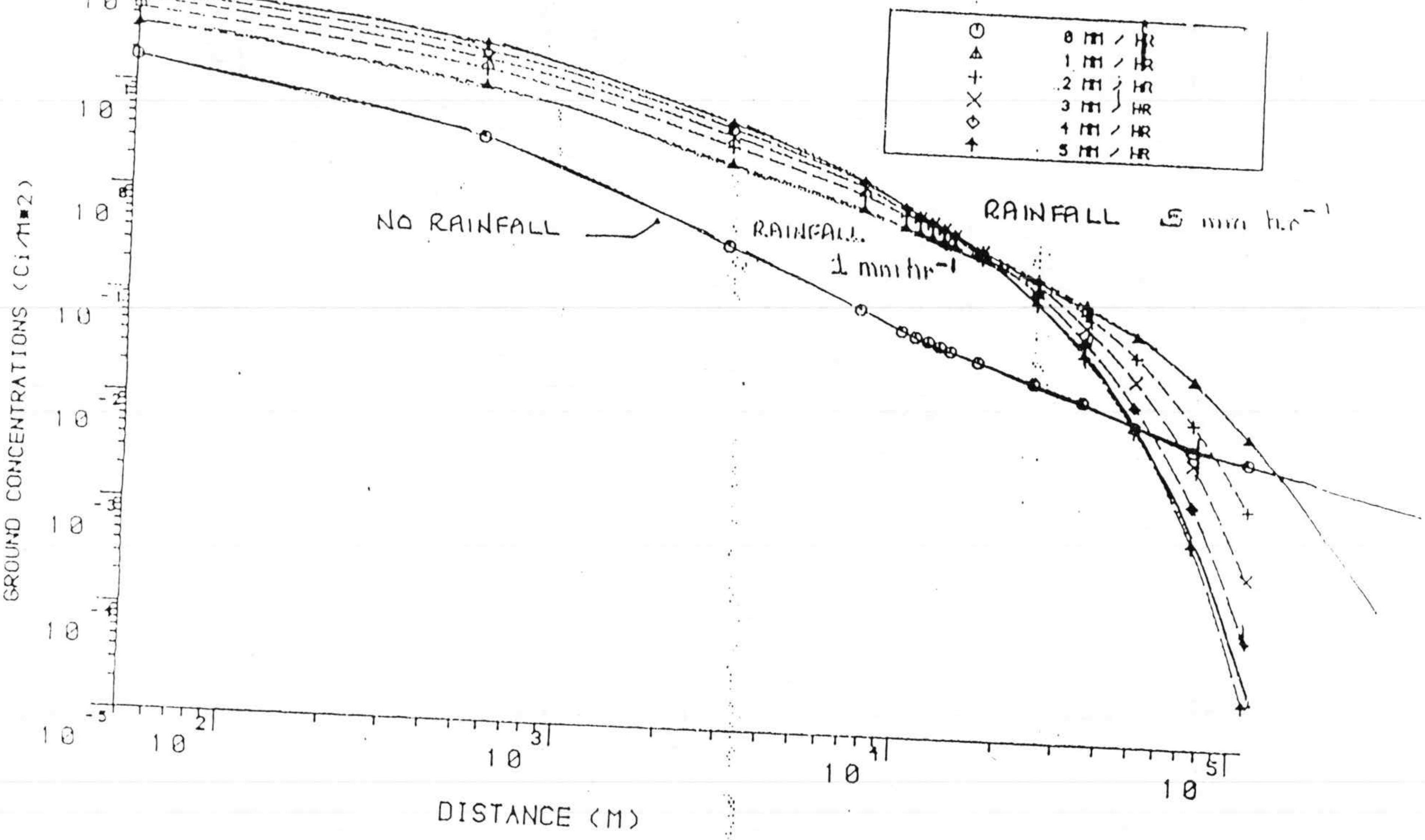


Fig 8