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A SLUDGE DRUM IN THE *APNea* SYSTEM

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ABSTRACT

The assay of sludge drums pushes the *APNea* System to a definite extreme. Even though it seems clear that neutron based assay should be the method of choice for sludge drums, the difficulties posed by this matrix push any NDA technique to its limits. Special emphasis is given here to the differential die-away technique, which appears to approach the desired sensitivity. A parallel analysis of ethafoam drums will be presented, since the ethafoam matrix fits well within the operating range of the *APNea* System, and, having been part of the early PDP trials, has been assayed by many in the NDA community.

DRUM PREPARATION

The sludge drum used in this study was fabricated at the request and expense of the former Lockheed Martin Specialties Components (LMSC) as part of their *APNea* development program. The chemical and physical makeup of the drum was based on information supplied by Greg Becker as to the character of a representative sludge drum. The ethafoam drum was fabricated using standard ethafoam which was shredded and then packed to achieve the desired density. Both drums were modeled after the Performance Demonstration Program (PDP) drums.

SIGNAL ATTENUATION

The first feature of sludge to be addressed is its attenuation of signal neutrons. Fig. 1 shows the response of the total *APNea* detector set to a ^{252}Cf point source positioned at various (r,h) points within a rotating drum. The sludge drum was measured at r=0–12 and h=6–24 inches. The ethafoam drum was measured at r=0–10 and h=3–30 inches. The nominal detected strength of the source without any matrix is 7000cps. Each group of points represents results for r=0,2,4... inches, respectively. The leftmost point of each group indicates the height value. Points measured at r=$\pm$12 inches are just outside the drum. The ethafoam matrix has attenuated this by 32% at the center of the drum and by about 20% by

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the time one reaches the edge of the drum. Sludge, on the other hand, attenuates by nearly 96% at the drum core but ONLY by 58% near the edge of the drum. The sludge results at 24 inches are high because this sludge matrix was not filled up to that level. The official PDP sludge drum was noticeably taller. The results at $r = 12$ are high because this radius is outside the drum.

The response of detector N2 (a vertical detector centered in an *APNea* chamber wall) to a ^{252}Cf point source positioned halfway up in the matrix and at various radial positions from one side of the drum to the other is shown in Fig. 2a. MT and MTD refer to an empty chamber and to an empty drum, respectively. These two null matrices show the geometric dropoff as the source moves away from the vertical N2 detector. Ethafoam and raschig rings (RR) exhibit a moderate attenuation. Until recently soil (SOIL) and concrete (CONC) were the worst cases studied by the *APNea* System. But sludge now claims the title as the ugliest matix. All of the real matrices, other than sludge show an enhancement over the null matrix at r=10 inches due to back scatter off the matix material. But sludge requires that the point source be all the way outside the matrix before this scattering shows up as an enhancement. Approximately 4% of the fission neutrons survive the journey from the center of the sludge and the survival rate continues to drop until r=-6 inches. The turnover at this radius is surely due to neutrons escaping from the back of the drum and then scattering off the chamber walls around to the N2 detector. The attenuation is so extreme in sludge that fission neutrons simply won't make it through the entire diameter of the sludge.

ACTIVE THERMAL FLUX

The thermal flux characteristics in the sludge drum in the *APNea* System are not radically different from those in other matrices. Figs. 2b,c,d show the response of the matrix to active stimulation by a beam of 14MeV neutrons from a $d + t$ neutron generator. The neutron generator is positioned (figuratively) on the right side of these graphs some 22 inches from the center of the drum. Thus, some or much of the dropoff in flux from right to left in Figs. 2c,d is a geometric effect, but it is clear that flux in the sludge drops off more rapidly as one penetrates the matrix than it does in concrete or soil. Presumably, there is so much hydrogen (water) in the sludge that a significant fraction of the beam is moderated and scattered before it reaches the center and nether regions of the drum. The flux projected to be available at $t = 0$ in Fig. 2c is certainly comparable to that found for concrete or soil. The more rapid dropoff across the drum must be a result of the high hydrogen content. The ethafoam apparently benefits hugely from flux generated in the *APNea* cavity. Fig. 2b shows the dieaway time character of the thermal flux. The dieaway time in the sludge is expected to be shorter both because of the high hydrogen content and because of the presence of other thermal neutrons poisons, particularly chlorine. The dieaway time of the empty *APNea* cavity is over 700μs, so the dieaway time of the ethafoam is clearly compatible with its being in equilibrium with the cavity. In particular, the dieaway time in the ethafoam matrix is radius independent, indicating that cavity and matrix flux have fairly uniformly mixed. The three heavy matrices show a minimum decay time near the center of the drum with a rise at the drum surface as cavity flux begins to contribute to the faster decaying internal flux. The result of delaying the sampling of the flux until after 300μs, leads to the actual integrated flux of Fig. 2d. Essentially all of this flux is utilized by the *APNea* System which begins its data acquisition beginning at $t = 300\mu$s. Note that, because of the short dieaway time of sludge, systems which wait until 700μs to begin their data acquisition ignore a significant amount of potentially useful flux.

ACTIVE FLUX UTILIZATION

It is interesting to see what the raw data for active measurements in the sludge and ethafoam look like, particularly in the center of the drum. Fig. 3 compares the active assay of 500mg ^{235}U in both ethafoam and sludge. The data are broken into two time pieces. The fast region data cover the time from 300μs to 700μs; the other time region is from 700μs to 3ms. The data in Fig. 3b cover the time region similar to that utilized by the PAN[1] system. The top figures compare ethafoam to sludge and the bottom figures expand the sludge results to allow a clearer understanding of the results. Ethafoam is a clear winner in both time regimes, both because of its higher flux and its mild signal attenuation. The average background for both time regimes lies comfortably below the signal. The lefthand most point of each curve is at r=0 inches, the righthand most point is at r=10 inches for the sludge and at r=12 inches for the ethafoam. The sludge results have been blown up in Fig. 3c,d revealing that one does get an active response in sludge, but it is meager.

The average background for the ethafoam data lies well above that for the sludge data. This is understandable since the major component of the backgound arises from neutron generator flux deposited in the detector packs at the time of the zetatron pulse — the background is the remnant of that pulse which has persisted into the analysis region. The sludge background is lower than that for the ethafoam because the sludge has very kindly shielded many of the detector packs from the zetatron pulse, so there is less remant flux to be concerned with. Notice that a few of the sludge points lie below the background. The background is an average background, and the data points are quite low for the inner radii.

The *fast* region is what the *APNea* System adds to the differential dieaway data. The *APNea* data acquistion has moved the time region of interest into 300μs after the pulse. The ethafoam is a clear example of why this wasn't very important in the early applications of this technique. The ethafoam signal above background is of the order of 5000 to 6000 counts in both time regimes. The *APNea* approach has essentially doubled the number of counts by moving into 300μs, but it has blown the background up from 500 to 48,000. Not a pretty achievement, and surely not worth it.

For better motivation, compare the sludge data in the *fast* range with those in the *slow* range. The slow regime data range from 0 to 300 counts, whereas the fast regime data range from 0 to 2000 counts, a gain of possibly a factor of 5 or more. Clearly the difference in dieaway time in sludge has become a major player. Benign matrix materials have a characteristic dieaway time above 500μs, as they often admit large quantities of cavity flux with an over 700μs dieaway. Consequently, little of the useful flux has been lost by waiting until 700μs to begin the measurement. But the internal dieaway time of sludge is down near

200μs, so transient that a mere 22% of the original flux is left at 300μs and a sparse 3% is left at 700μs. But nothing is free, and the increase in useful flux is accompanied by a huge increase in background. In order to move the analysis region into earlier times, it is necessary to change the method by which the background is treated. The *APNea* System does this by binning the active data in a series of time gates so that the time response of the system can be treated in detail. (See Ref. 2 for a detailed discussion of the approach.)

Figs 4a,b show a prediction of what 10g of ^{235}U would look like in the active *APNea*. In this case, since the characterization data are being used to project the data, the background can be kept separate from the signal. The data are shown as a function of time for the fissile source being at various radii and at a height of 12 inches. The detector, S1, presented in Fig. 4a, is a *hot* detector because it is on the same side of the drum as is the zetatron. Thus it is closest to the regions of maximum internal flux and should record the largest signal. On the other hand, it is also closest to the zetatron, so its background response (labeled *FAST* in the figure) is also the largest. The fast background dies away with a characteristic time of 45μs in this detector, so even though it is comparable in size to the various signals at the earliest times, it quickly decays and falls below most of the signal curves which are following the 200μs dieaway time of the internal flux. Most of the change in size of the signal curves from r=10 into r=0 is a result of the signal attenuation and not the dropoff in flux.

Fig. 4b shows a somewhat different picture. N2 is a vertical detector on the side of the drum opposite the zetatron, so it is furthest from the region of maximum internal flux. On the other hand, its response to the source at r=0,2,4 is roughly independent of radius and is much bigger than the fast background. This detector should be more useful in imaging the core than would be the S1 detector, and it is certainly less sensitive to the backgound.

100nCi/g CONSIDERATIONS

The passive results show that the measurment of ^{240}Pu can not be used to establish the 100nCi/g limit for sludge drums. The signal attenuation associated with the core of the drum is much too severe.

The active results are quite promising as the 500mg ^{235}U results (350mg ^{239}Pu) show that the assay can be performed into at least r=4 inches, though the uncertainty in this determination is currently unknown. And when improvements to the *APNea* System focusing on doing sludge measurements are incorporated, it seems reasonable to conclude that the 100nCi/g barrier[3] can be broken. The major assay difficulty is not with the flux which does not vary that much or differ that much from that for concrete. The problem has to do with signal attenuation and the fast response remnant.

It should be noted that less than 15% of the drum volume lies within $r = 4$ inches, so the active measurement is already giving an extremely good total volume measurement. In the event that the Pu is relatively evenly distributed, the active measurement should clearly meet the 100nCi/g limit.

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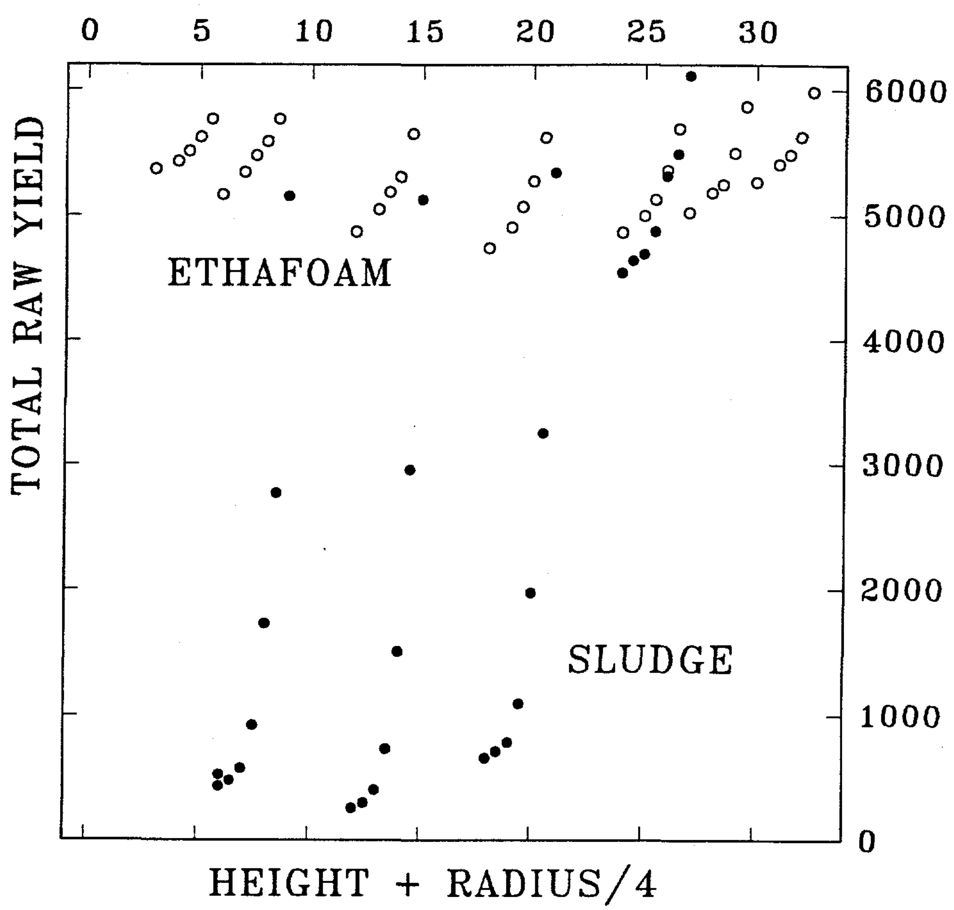
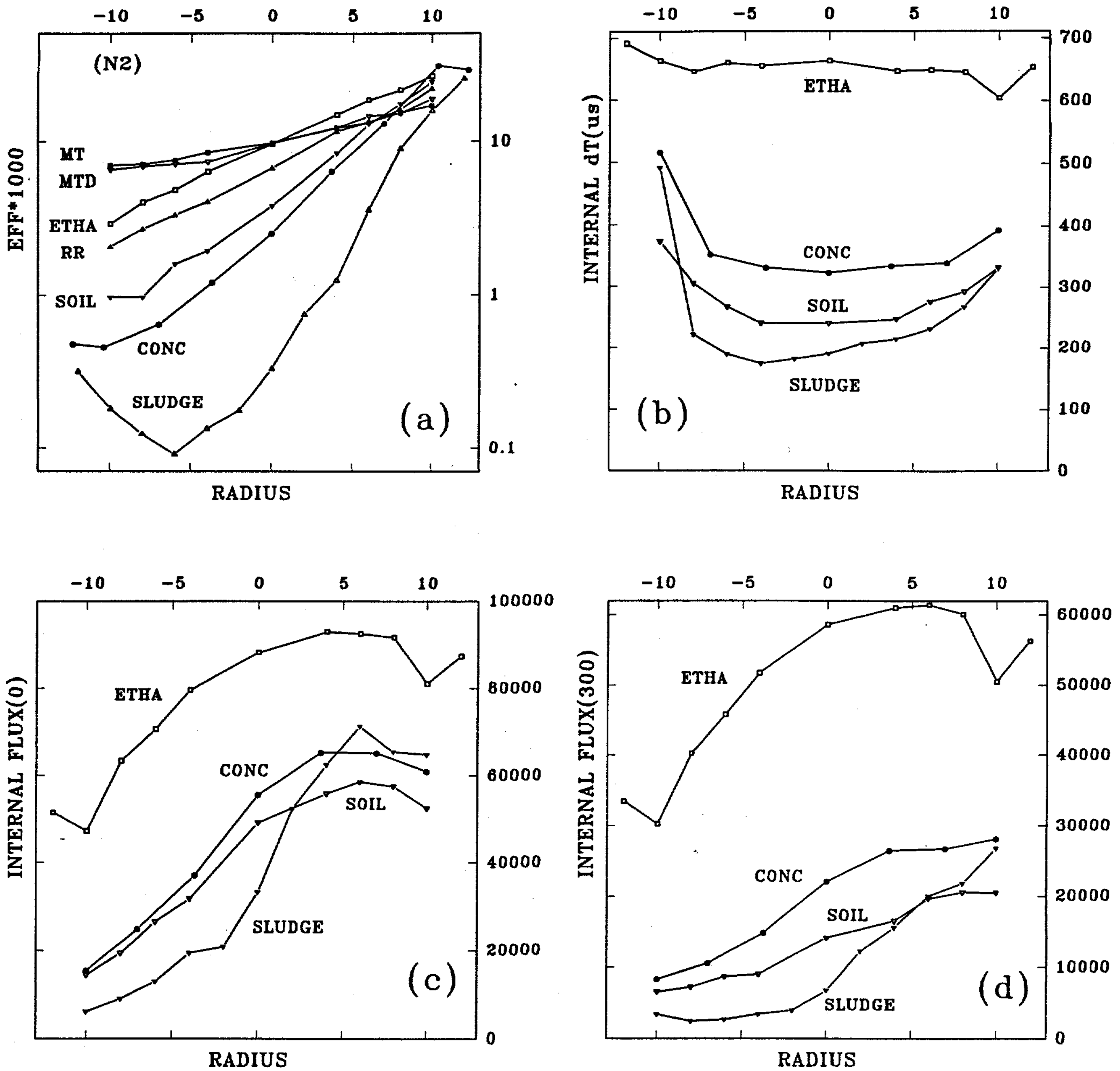
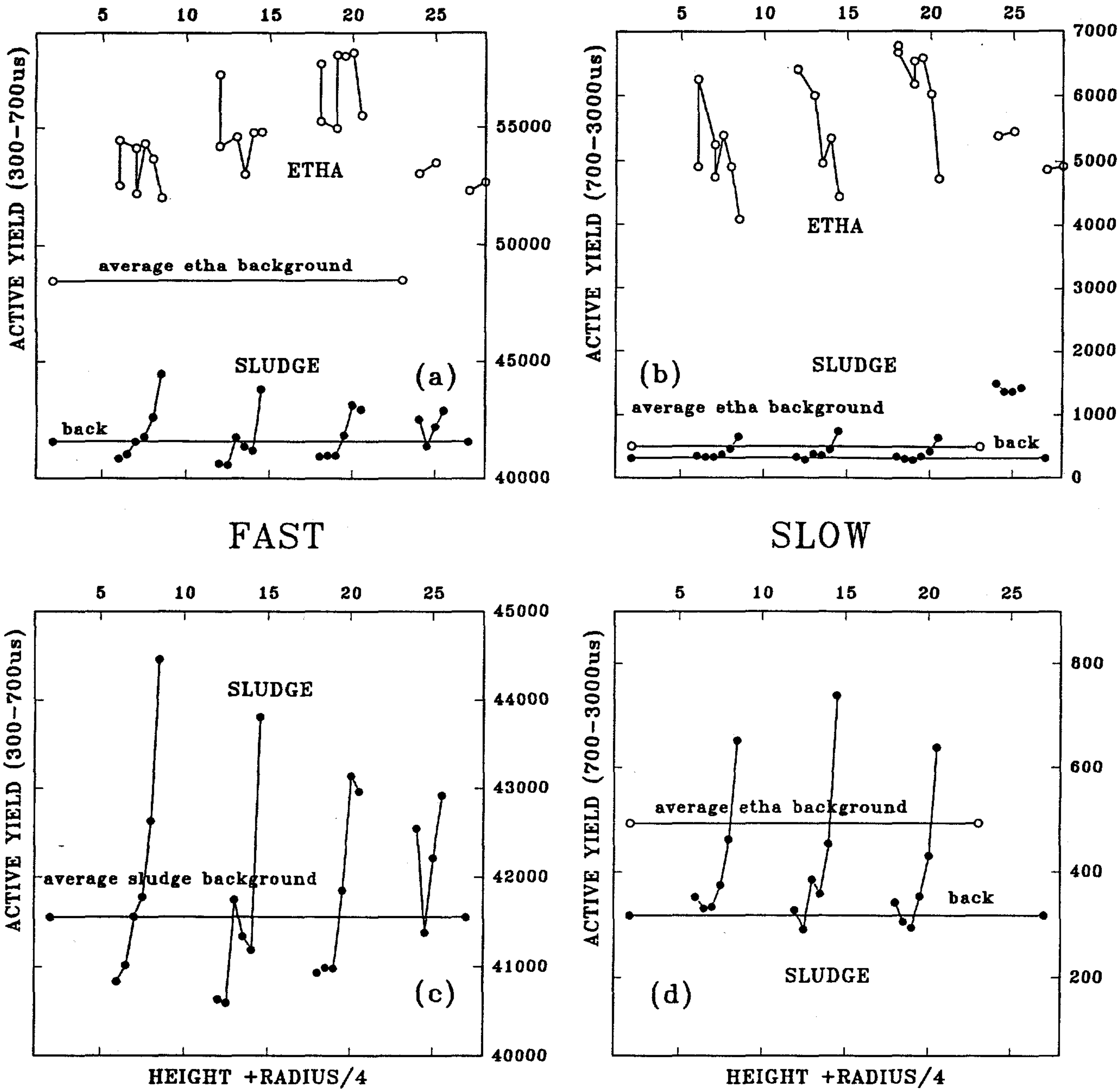

0
5
10
15
20
25
30
6000
5000
4000
3000
2000
1000
0
TOTAL RAW YIELD
ETHAFOAM
SLUDGE
HEIGHT + RADIUS/4

Figure 1



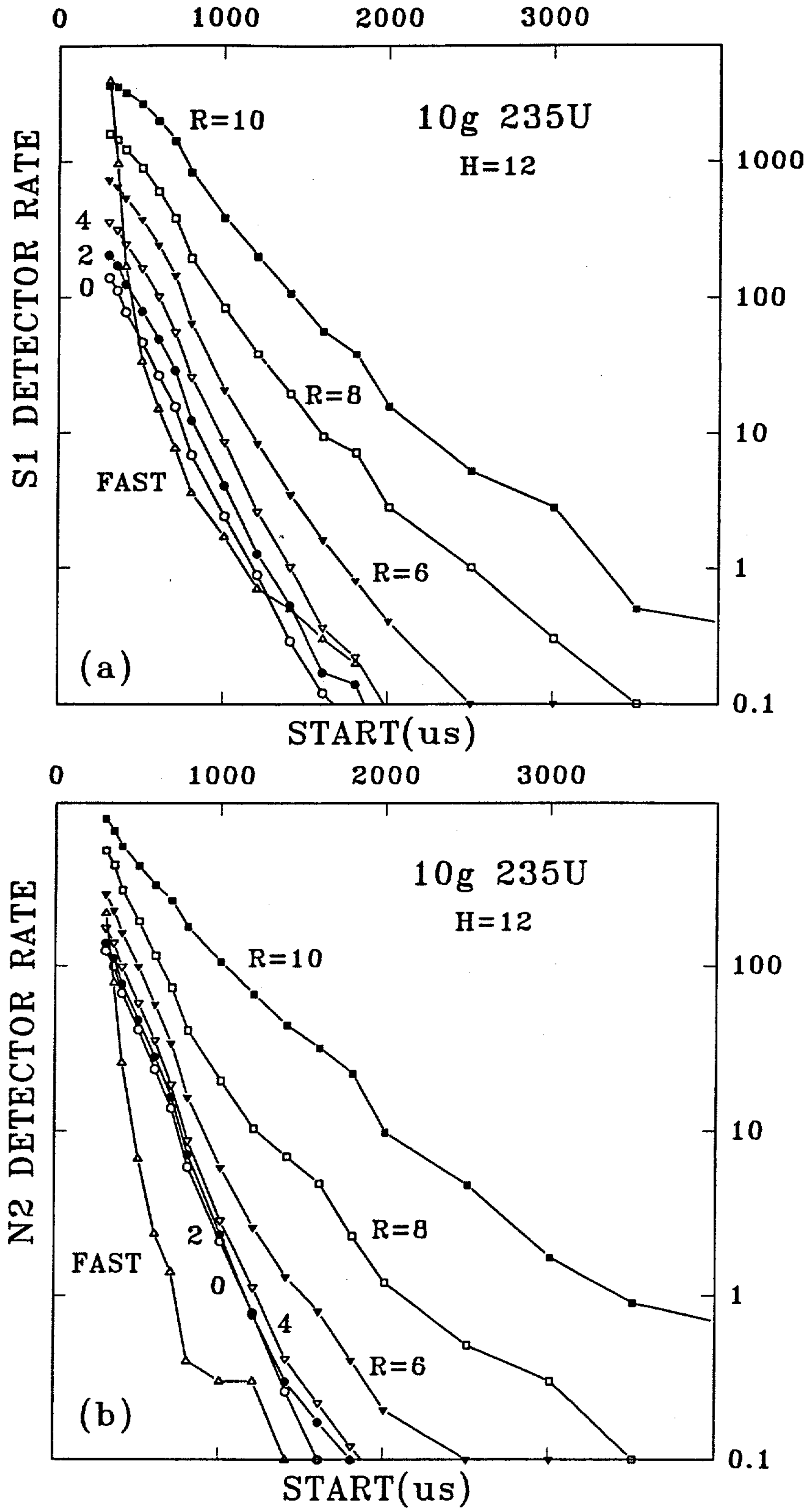
The GOOD, the BAD, and the UGLY

Figure 2



RAW ACTIVE YIELD COMPARISONS

Figure 3



SIMULATED ACTIVE RESPONSES

Figure 4