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Post-depositional decay: A Simulation

Assumptions and results of computer simulations of natural decay and mechanical destruction of find distributions are presented. The output suggests that small-scale patterning is relatively rapidly lost, but that major patterns can still be recognized when more than 80% of the orignal material has disappeared.

1. Introduction

On the occasion of the research at Hekelingen (Louwe Kooijmans/Van de Velde 1980) my attention was drawn to the post-depositional, pre- and peri-excavational behaviour of archaeological material; at that site many of the archaeologically relevant units showed nice, almost exemplary normally distributed densities of artefacts. In other excavations find distributions are not so well-structured, generally. At Hekelingen instant departure after deposition may possibly explain these patterns so conform to theoretical expectation, the more irregular distributions at other sites are not acountable for that way. In the relevant literature emphasis is directed towards what happens right at or immediately following deposition (e.g., Gorecki 1985, Schiffer 1985, Villa/Courtin 1983) or to the vertical movement of artefacts (e.g., Cahen/Moeyersons 1977), for which ecological macro-causes and effects have been described (Wood/Johnson 1978). Of course, several students have started from the other end, attempting to derive the original pattern from the archaeologically observed one (e.g., Hietala/Stevens 1977). The concern with the vertical movement of artefacts is linked to excavations at stratified sites, where a mixture of deposits is suspected (Cahen/Moeyersons 1977, Villa 1982). Horizontal distributions have been studied for the reconstruction of prehistoric events (Cahen/Moeyersons 1977, Binford 1978); implicitly, stable positions of the artefacts after deposition and subsequent burial are assumed. However, given the truly disquieting results of the work on vertical movement, it is highly likely that artefacts have moved horizontally, too, and the problem therefore arises how well archaeological distributions are representative of prehistoric distributions in the horizontal plane.
As against vertical distribution where gravitation may override all other forces (and so results will tend to be skewed downward) the forces in the horizontal plane will work in all directions; being incidental or discontinuous, their impact will be random on every single artefact in a distribution. Two general factors affecting the appearances of artefact distributions in a soil matrix can be distinguished: a mechanical one with kicking and treading as obvious members, and a chemical one, with decay as main component. As will be explained below, kicking and treading, and natural decay, too, are stochastic processes as far as their impacts on artefact distributions are concerned. It is the randomness of these influences that suggests a simulation of the post-depositional evolution of artefact distributions.
The validity of a simulation depends at least as much upon the assumptions that go into it as on the computational methods employed by it. Hence, I will now first discuss the design of the simulation program, and only after that the results.

2. A first specification

After burial two general factors work upon an artefact distribution: natural decay (which includes bio-chemical weathering, ecoturbation, and the like) and/or mechanical, in many cases human interference (treading and kicking, hoeing and ploughing). Erosion will not be considered because of its large-scale disastrous effects which are generally clearly visible. Ultimately these factors cause the virtual elimination of the distribution – although, of course, some individual artefacts may survive, and thus (by definition) still constitute a distribution.
If this outline of the factors working upon a find distribution is acceptable, then it follows that to simulate their effects these processes have to be modeled. The first one, natural decay, describes the gradual physico-chemico-biological destruction of archaeological matter after deposition, some of it fast, some of it slow: organic material is less likely to survive burial than is anorganic. In a realistic model, allowance has to be made for this difference.
Bioturbation, which is also included in the natural factor, moves objects around in the soil: worms, moles, plant roots extend their influence often quite deep (Wood/Johnson 1978; Gorecki 1985) and push artefacts from their previous location. Apparently this factor is

highly variable (Wood/Johnson 1978), dependent upon the composition of the biological brigade; it would be erroneous to leave it out.
Human interference is the second offending and re-distributing factor, by way of treading, hoeing and ploughing. As long as no deep-ploughing is involved, the effects of plough, ard and hoe will be similar (cp. Gorecki 1985), re-locating part of the archaeological debris with every pass over the distribution. Although hoeing and ploughing are very much directed processes, they are directed *per pass* only. After sufficient time, sod relocation will have been towards all azimuths with - at least in the plains - no single orientation preferred. Similarly, kicking and treading work in all directions. Thus, these processes should be simulated incorporating a random directionality. Probably an important part of the archaeologically interesting distributions of artefacts has never been touched by agricultural implements; I decided therefore to run a separate simulation.

In reality, all decay processes work simultaneously; on a computer only one thing can be done at a time, however fast that may be done. To compensate for this lack, simulation programs are given a cyclical structure: the subject distribution is treated to all processes in turn (one cycle), repeating the cycles as long as the results continue to be of interest (Kerbosch/Sierenberg 1973). In less general terms, the set of numbers which represents the distribution goes through a number of cycles each consisting of a round of decay and a turn of ecoturbation; in the second simulation a number of ploughing-events 'occurred' one after another. After each cycle stock was taken, and if necessary repeated. The point where a distribution changes into a scatter - the terminal point of a comparison of distributions - depends on many factors, here I will arbitrarily set the limit at a density of about 15 per cent of the original; from the results this remainder will appear to be on the safe side.

A word or two should still be said about the shape and contents of the distributions upon which the disturbances had to work. To get an impression about the variability of the effects one unstructured and two structured parent distributions were implemented. The unstructured one consisted of a matrix of random numbers only. The first structured distribution consisted of a normal distribution, the second of two rectangular blocks. Such deterministically structured distributions are not very realistic, though: as implemented on a computer they are highly deterministic. By setting the initial (deterministic) maximal value to 4.5 points per cell, and subsequent scaling with a random normal number between 0 and 2, the counter-intuitive appearances were corrected. The three distributions were each laid out on a matrix of the same size; between a number of runs, the sizes were varied from 25×25 cells to 75×75 (more could not be fitted into my Apple II's memory). Similar versions of the program were written in both Basic and Pascal, to compare performance.

3. Further specification: natural decay

As different materials wither away with different speed, one of the important decisions in this simulation is to the nature of this decay, followed by the construction of an algorithm to model the reduction. Regarding the nature of decay, it may be assumed that like most natural processes rot is characterised by an exponential equation. That is, in equal time-periods, equal proportions are dissolved (similar to carbon-14 decay). Moreover and by the same analogue, concepts like 'half-time' should not be understood as being deterministic, but rather stochastic; half-time being merely the long time average of an infinite number of events. Additionally it can be observed that larger pieces are seemingly less affected by rot than are smaller ones - weathering works from without, and is therefore proportional to surface area rather than to weight: heavier pieces have less square centimetres per cube.
Decay is also dependent upon context: it is well-known that acid soils are more destructive to bones than are calcareous ones. Similarly, dry climates result in less rapid weathering than wet ones, and below the groundwater table archaeological deposits stand a better chance of survival than higher up in the profile; high temperatures and humidity in combination are very destructive (cf., a.o., Wood/Johnson 1978). Therefore, any estimate of the speed of rot is a local value only; as the initial stimulus for this simulation comes from an excavation in the wet, above groundwater table, non-acidic clay area of the Western Netherlands, my basic figures are more or less relevant for that part of the world. However the *relative* values may be more or less context-independent; in a simulation like the present one it is nearly impossible to construct a model on anything but relative values or rates (also cp. Kerbosch/Sierenburg 1973: 21-22).
To illustrate such an estimate the example of small animal bones will be used: at Hekelingen they have all but disappeared after some four and a half thousand years. Substituting and solving for A_0 as 90% (the startvalue), 1% as A (the end-value), and 4.5 k yrs for the time-lapse t in $A = A_0e^{-kt}$ (where $k = \ln 2/\text{half-life}$) a half-life of approximately 700 years is found for small bones. In a similar way (and again involving a number of estimates indicative of time ranges rather than of real numbers of years) for pottery sherds a half-life of some 1,500 years can be computed. For large or well-prepared and selected pieces of wood a half-life slightly less than that for small bones is derived, and for flint a half-time some orders of

magnitude larger (for present purposes flint may even be considered indestructible).
From this point of view an initial distribution consists of several subsets, each subject to a different rate of decay; thus, the mix or composition of the parent distribution in terms of these subsets is to be determined. Put this way, the arbitrary character of the simulation stands clearly out: I know of no way to eliminate the subjectivity of this choice (unless a *qualitative* simulation were to be performed, for then the resultant distribution should be somehow similar to an excavated one; here, however, only a quantitative approximation is attempted). On the other hand, if someone were to object to the proposed parameters, a simple change of the constants in the program heading would produce the desired result. In the present case, three subsets are hypothesised: 10% indestructible, 30% moderately and 60% fairly liable to decay with the latter subset disappearing at twice the rate of the middle one.
As noted above, half-life estimates are but averages of stochastic processes and allowance for this random incidence will provide a more realistic hue to the simulation. That is, not only is the cell at which decay is effected randomly selected, also the proportion of decay is randomly (and normally) distributed around the average half-life, taking size into account. Some cells are affected several times per cycle, some remain untouched for several cycles: it is the average effect which is modeled.
In a similar way ecoturbation of horizontal movement can be implemented. As everywhere, all values have to be arbitrary as only vertical relocation has been studied with empirical data. *A priori*, heavier pieces are thought to be less amenable to horizontal transport than lighter ones, and this can be taken account of by constructing a table of relative impact, with some normally distributed randomisation around the table values. Then (and this is again an arbitrary decision) in every cycle ca. 65% of the cells is left unaffected, of 30% at least a part is added to one of the neighbouring cells, and from the remaining 5% part or all is dumped on one of the cells at two units away.

4. Further specification: mechanical decay

From field experience I would say that ploughing (and, supposedly hoeing, too) results in shattering of the larger pieces, and a smearing out of distributions. According to the literature trampling of a surface on or below which artefacts are laying – as would occur on a settlement site, for instance – has the same effects (Schiffer 1983; Villa/Courtin 1983). I.e., larger pieces diminish in size, while smaller pieces are only occasionally affected this way but easier moved into the next furrow. The decision to limit shattering to a weight of 3 (or, no pieces larger than 3 can be broken off and removed into the next line of cells) is arbitrary; when graphically displayed this smashing and turnover into the next line has a highly realistic appearance, though. It goes without saying that both the amount broken off and the tossing over are governed by random numbers.
Whereas with natural decay the disappearance of substance is from the outset built into the simulation, this is more difficult to accomplish with ploughing. For, in this latter case, the artefacts are ploughed and reploughed, thus tending to fill in the whole 'field' or matrix with a potentially undifferentiated and even spread; the problem is that the edges of the matrix pose a boundary to the distribution, and within these limits everything has to occur (cf. Justeson/Hampson 1985). As a remedy both ploughing-off and ploughing-onto the matrix will be allowed, independent of one another – in other words, the distributions and processes are modeled as without boundaries.

5. Parent distributions

Three different parent distributions have been employed in this simulation, two structured ones (a block-pattern, and a normal distribution) and one entirely unstructured. In order to keep the results comparable for the unaided eye, the average densities of the initial distributions have been set to approximately equal figures. Thus, in the deterministic preparation of the block-pattern, the sizes of the two blocks implemented were set to 15 to 20% and 10 to 5% of the matrix; as explained already, the subsequent stochastic upscaling of the elements was to bring the theoretical maximum to 9 (via multiplication wit a random normal factor between 0 and 2), and therefore the initial weight of the cells within the blocks was defined as 4.5. The blocks were homogeneously filled to this figure, giving a density of 1.125 point per cell averaged over the whole matrix.
Similarly, the top or maximum of the normal distribution was set to 4.5 points. The condition that sufficient space for smearing out was to be left along the border of the distribution provided an additional parameter: 99% of the contents was to be contained within an area with a diameter of ca. 80% of the matrix's sides. Again, this distribution had to yield an average density of approximately 1.125 points per cell. Afterwards, the normal distribution was also reworked by multiplying each individual element with a random normal figure between 0 and 2. The resulting reworked distributions (blocks; and normal) are here labeled the parent distributions for the simulation.
The average of the sums of these latter two distributions was set as total for the random distribution; again, by stochastically established multiplication with a figure between 0 and 2, values from 0 to 9 were obtained for all

the positions within the matrix: the third parent distribution.

6. Implementation: natural decay

At the start of the simulation the sum-total of the parent distribution was divided into three parts: 10% should be left out of the decay process, 30% was to be subjected to the slower and the remainder to the more (twice) rapid deterioration; each of these subsets was defined by its own total and passed through the simulations on its own. In every cycle, the distributions went through one half-life for the weak portion (leaving 30% of the total), a half cycle of decay for the more robust matter (leaving 22.5% for this part), and a complete cycle of ecoturbation for all elements. That is, after the first cycle, 10% (for the non-destructible material) was left, plus 22.5% (for the denser material) plus 30% (for the weak stuff) equals 62.5% of the parent distributions, of which 65% was still in its original place. In the next cycle, these processes were repeated, leaving altogether 55% (10 + 15 + 30%) of the 'material', with possibly only 42% (65 × 65%) in its place. Etcetera. At the end of each cycle the matrix was sampled to establish the remaining density; when the density of the distribution had dropped below 15% of the average at the beginning, the simulation was terminated. Afterwards, correlations were computed between the parent distribution and the remnant distributions.

7. Implementation: mechanical decay

Ploughing, hoeing and trampling will have worked in all directions, given sufficient time. Normally, the effect of ploughing is to turn the sod into the next furrow, taking with it whatever archeological material is in it. This can be modelled quite easily; however, bigger artefacts are less easily turned over, and are sometimes crushed. The hoe has similar effects, albeit that the displaced sods are less massive than with a plough. Trampling on a superficially covered distribution does not turn sods, but dislocates the artefacts on a considerable scale (Villa/Courtin 1983). Apart from the specifications in previous sections, this 'ploughing' is implemented by randomly selecting East/West or North/South movement along the rows, respectively columns of the matrix models of the distributions. A cycle is set to 10 such rounds of complete overploughing; after each cycle, the remaining density is sampled. The simulation is turned off when the density is lower than 15% of the original average; then, the correlations with the parent distributions are computed.

8. Discussion of the simulation of natural decay processes

As simulated, natural decay worked very gradual changes in the different distributions. The processes were simultaneously observable on the video monitor, and an impression was gained of condensed time: while looking on, the distributions were seen to 'weather' away. This weathering away is also visible in the results as presented in the figures 1-3: the decrease in the total weights with every cycle, and the diminishing correlations. As is to be expected (given the algorithm) totals fall steeply off at first, and later more slowly - this is the effect of dividing the distribution into three classes: a rapidly decaying set of ca. 60% of the 'material', 30% subject to slower weathering, and 10% not amenable to rot at all. After 3 to 5 cycles (equal to as many half-times of the 'organic' part of the distribution) the remainder is around 30% of the original weight.

Regarding the correlations, an important result is that the best-structured distribution (the normal one) remains best recognizable, according to the figures. However, it should immediately be asked what not-so-nice correlations for the random parent distributions entail: no likeness at all to the original random distribution implies either that a 'different' random pattern has originated (and who would care about that), or that a better-structured pattern has resulted from the working over. Randomness is difficult to establish, as all kinds of small-grained or local patterns are visible in a truly random distribution; however, from the fact that very similar, very low correlations are found with the graphs of cells grouped into larger units, I conclude that the underlying pattern (as summed in the single cell distributions) is indeed random, i.e. without (macro-) pattern. Paradoxically, the conclusion can be drawn that the low correlations for the random distribution are indicative of the stability of the random character.

In the figures graphs are presented describing the same distribution and the same process, although summed in different manners. Correlations have been computed for cell-cell likeness (and zero-zero pairs have been omitted in order not to inflate the correspondence), and for grouped matrix cells: 2 × 2, 3 × 3 to 5 × 5 (results of 2 × 2 and 4 × 4 are not shown; they are almost exactly in the middle between their neighbours). It is not really surprising that with increasing cell size - which would mean increasing quadrat sizes in an excavation - the correlations are much improved: the effects of small-scale variations are dampened. This should of course be interpreted as pointing to a general or overall likeness between the 'original' or parent distribution and the distribution potentially 'recoverable' in archaeological fieldwork, with details getting progressively lost through the workings of time.

9. Discussion of the simulation of mechanical decay processes

As simulated, mechanical decay worked considerable changes in the different distributions. The processes were modeled with ploughing in the mind and accordingly an impression was gained of rapid turnover of the 'field': while looking at them, the distributions were seen to be evened out. This leveling is only obliquely visible in the results as presented in the figures 4-6: as with natural decay, in the decreases in the weights left after every cycle, and in the diminishing correlations. The weights decrease more gradually than in the natural decay simulations, which conforms to expectations since here the only way out is over the sides of the matrix.

The correlations for this group of simulations are lower than for the previous one; however, the same general observation as above can be made, viz., that the best-structured distributions remain best recognizable, even under quite generalizing influences as 'ploughing'.

And again, grouping the values into larger units results in appreciably higher figures. Here, too, as the patterns become more generalized through this grouping, the similarities relate to more general patterns, less likely to be obscured than are individual variations or localized patterns.

10. Results: correlations

One of the conclusions is that the sampling method employed to establish the end of the simulations (putting a threshold density at 15% of the original one) is not very precise: the stops occur at denisties of up to 24% of the original. The sampling algorithm was to sum the elements on the diagonal of the matrix; the cause of the imprecision will be in the non-random, and therefore non-representative character of the sample. The reason for using this method was the speed of execution; it is not the first time that speed is obtained at the cost of reliability. This, however, is more a critique on the programs than on the simulations.

The figures 1-6 represent the outcomes of a specific simulation run; however, very similar outcomes derive from all runs. Thus, the ranges of the values of the correlations are ever within 5%, except for the block-like distributions, where ranges have been observed of nearly 10%. As a consequence, the forms of the graphs are quite stable; the 'shoulders' or rapid fall-off in the right parts of the graphs for 'mechanically decaying' distributions are related to a remainder of 30% of the weight, and occur in every simulation no matter the size of the matrix.

Perhaps most important is the result that even with considerable thinning out of the distributions, a pattern once present remains observable. Yet minor or local variations have effects on small scale observations: when comparisons at the scale of the individual cells of the matrix are considered, the correlations decrease relatively rapidly with time. Therefore, one should ask whether exact 3-d measurements of the positions of individual artefacts serve any purpose. The answer to this question hinges upon the weight accorded to ecoturbation, bearing in mind that the way this latter process has been modeled here has only very mild effects (above).

It is clear from these simulations that natural and mechanical processes of decay (that is, if they have been modeled realistically here) result in a gradual decrease of patterning, considering individual artefacts and local patterns. It is equally clear that archaeological processes as instanced by the choice of larger quadrats when comparing original and resultant distributions have considerable effects: the larger the quadrats, the higher the correlations. This latter point indicates that general patterns in distributions are quite resistant to decay whether natural or mechanical.

11. Summary

Of course, simulation is all make-believe; however, the realistic appearance of the present one on the VDU was quite suggestive, not only to the present author, but to the people who have witnessed demonstrations of the program as well (some of the results have been presented on various occasions; a.o. at the 1986 Reuvensdagen Congress in Amsterdam, and at Discard Day at the Leiden Institute of Prehistory in 1986). Of course, this is no guarantee of the validity of the simulations; such a guarantee can only be obtained from an independent modeling of the same problem by somebody else. Meanwhile, by spelling out the assumptions that have gone into the modeling at least some evaluation is possible.

It was found in the simulations that small scale patterning is rapidly lost with time. On the other hand, general patterns remain visible even after considerable loss of contents, and the better structured an initial distribution of artefacts has been, the clearer the original general pattern can still be recognized even after so many rounds of natural and mechanical decay.

From the rapid loss of local or micro-scale patterning, the question should be derived whether (or not) much value should be accorded to the exact registration of individual artefacts' positions. The modeling of ecoturbation as attempted here (based on the literature, and probably relatively mildly implemented) strongly suggests a sceptical attitude.

note

Listings of the programs are available upon request from the author.

Fig. 1 Correlation coefficients and relative weights for a simulation of natural decay; Normal parent distribution. Horizontally: cycles of decay; vertically: correlations and weight percentages retained.

Fig. 2 Correlation coefficients and relative weights for a simulation of natural decay; Block-like parent distribution. Horizontally: cycles of decay; vertically: correlations and weight percentages retained.

Fig. 3 Correlation coefficients and relative weights for a simulation of natural decay; Random parent distribution. Horizontally: cycles of decay; vertically: correlations and weight percentages retained.

Fig. 4 Correlation coefficients and relative weights for a simulation of mechanical decay. Normal parent distribution. Horizontally: cycles of decay; vertically: correlations and weight percentages retained.

Fig. 5 Correlation coefficients and relative weights for a simulation of mechanical decay; Block-like parent distribution. Horizontally: cycles of decay; vertically: correlations and weight percentages retained.

Fig. 6 Correlation coefficients and relative weights for a simulation of mechanical decay; Random parent distribution. Horizontally: cycles of decay; vertically: correlations and weight percentages retained.

dotted line: weight in percents of parent distribution
continuous 1: correlations with parent distribution, cell-by-cell
continuous line 3: correlations with parent distribution, cells grouped 3 × 3
continuous line 5: correlations with parent distribution, cells grouped 5 × 5

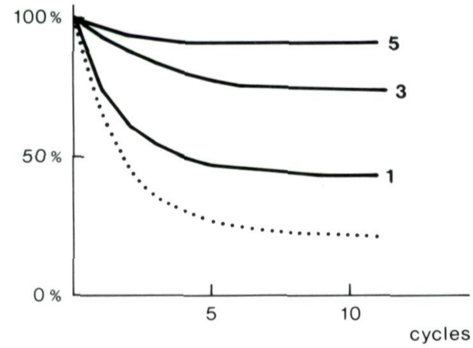

Fig. 1

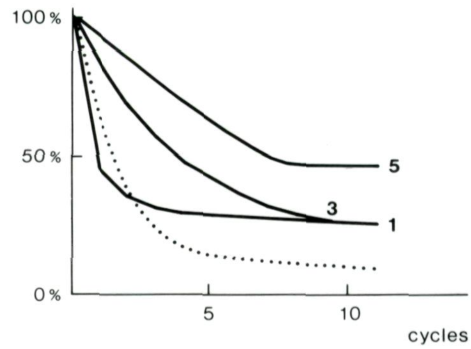

Fig. 2

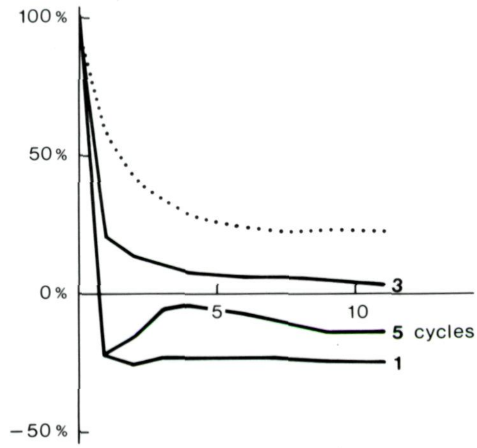

Fig. 3

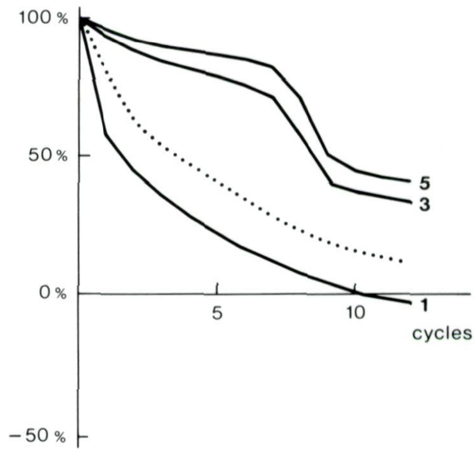

Fig. 4

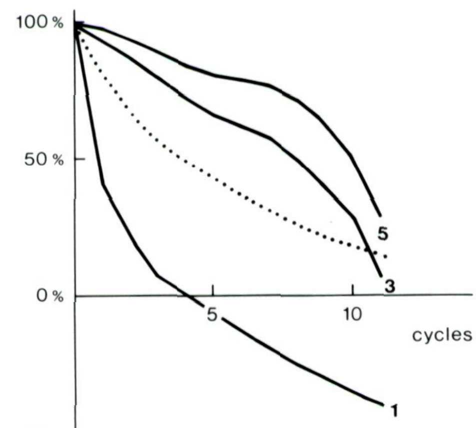

Fig. 5

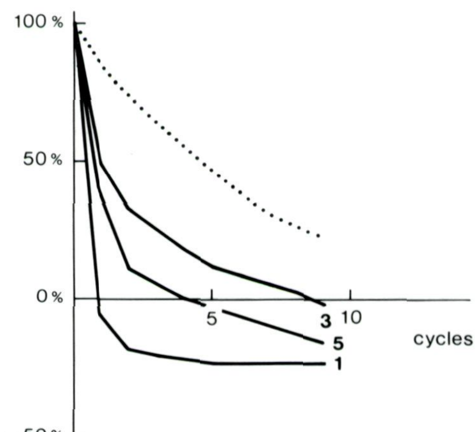

Fig. 6

literature

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