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TITLE

URANIUM SWELLING IN N-REACTOR
(PT-NR-4, Sup. A, Report No. 1)

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A. E. Guay

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URANIUM SWELLING IN N-REACTOR
(PT-NR-4, Sup. A, Report No. 1)

By

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ABSTRACT

Five monitor columns, containing some pre-irradiation weighed inner and outer fuel elements, were discharged under authorization of PT-NR-4, Sup A at tube average exposures in the range from 1554 to 1631 MWD/T. Uranium swelling values have been calculated from post-irradiation weight measurements and these swelling values have been compared with those swelling values obtained in the KER loop tests. There is acceptable agreement between KER and NPR results for swelling of inner uranium; there is acceptable agreement for outer fuel elements at higher exposures but ends-of-the-column elements(i.e. low-exposure values) are not in agreement.

The current swelling values have been extrapolated to determine the tube-average exposure that will result in outer clad strains of one percent. At this conservative value of clad strain, one can predict entirely adequate performance of outer fuel elements to tube average exposures of 2200 MWD/T and inner fuel elements to 2700 MWD/T tube average exposure. Elements that will soon be discharged at tube average exposures ranging from 1900 to 2100 MWD/T, can be evaluated for swelling during the next outage and a much better prediction can be made on the relation of exposure vs swelling and hence exposure vs fuel element integrity. The continuing objective of this production test remains as the determination of fuel element performance vs exposure. This objective will be attained by irradiating the monitor columns to progressively higher exposures and continuously evaluating performance and predicting failure limits.

CONCLUSIONS

Three conclusions can be drawn from the results and analyses made to date:

1. Fuel element performance will be entirely adequate for tube-average exposures up to 2200 MWD/T for outers and 2700 MWD/T for inners.

2. Exposures at which fuel performance may not be adequate have not been determined and can only be firmly established by swelling data at still higher exposures.

3. The confidence level of the predicted limiting exposures will be greater after data are obtained on twenty-four monitor columns being discharged in the next outage.

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DISCUSSION

Nearly one hundred columns of fuel elements, which were charged in the first fuel loading of N-Reactor, contain some measured and weighed elements. These columns, called monitor columns, are to be discharged at progressively higher exposures of the first load to evaluate fuel element performance indices. One of the most important indices that will be evaluated is swelling of uranium. This index will provide an important base for comparison of both the present uranium alloy of 150 ppm Fe plus 100 ppm Si with newer uranium alloys and the design and manufacturing process changes that have been made and are to be made.

Five monitor columns have been discharged at this time. These five columns had reached tube-average exposures in the range from 1554 to 1631 MWD/T. Uranium swelling values were measured on twenty three (23) outer elements and nineteen (19) inner elements from these columns. These N-Reactor swelling values are compared with values that were obtained on fifty-five (55) outer and inners irradiated as fuel element assemblies in the KER loops in KE Reactor.

In advance of presenting a comparison of fuel element irradiations in two reactors, the following differences in irradiation conditions in each reactor should be kept in mind.

1) The entire irradiation history of N-Reactor fuel elements has been in a closed, pressurized loop with inlet water temperatures above 347°F (175°C). The KER data are from four tests where equivalent inlet coolant temperatures were maintained for 63 to 86 percent of the time of the irradiation cycle; for the remaining time of the irradiation cycle, inlet temperatures were 68°F (20°C) and the loops were not pressurized.

2) KER test columns were shorter columns; they were charged with either thirteen or fourteen assemblies (nominal 24-inch lengths). N-Reactor fuel columns contain the equivalent of eighteen, 24-inch long assemblies (in various combinations of 24, 18, and 12 inch lengths). Ends-of-the-column elements operate at different specific powers in the two reactors.

3) N-Reactor is under moderated in comparison with KE reactor and the resulting differences in flux energies lead to different power distribution within assemblies. In N-reactor, the ratios of power and burnup in the outer and inner elements in an assembly are more similar than these ratios in an assembly in KE reactor. The important result is a faster burnup rate of inner elements in N-reactor.

4) The test irradiations in KE reactor were conducted under full-power operating conditions for the period of the exposure. N-Reactor fuel elements have had a much longer in-reactor residence due to extensive testing of the reactor which was necessary as power was gradually increased to design level.

5) Swelling results that have been reported for KER tests have been subjected to review, correction, and analysis that time has not yet permitted for the N Reactor data in this preliminary report. Some corrections in these

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N-Reactor swelling data can be expected as they are subjected to statistical analysis and interpretation.

Figure 1 shows two nearly parallel curves that define the range of swelling values for outer uranium in KER tests when plotted against an arbitrarily chosen index of the product of exposure and volume mean uranium temperatures (i.e. MWD/T x °K). Superimposed on the KER swelling area are the twenty-three swelling values obtained in N-Reactor. There is good agreement between these data at index values greater than 1.05 MWD/T x °K but noticeably more swelling in N Reactor results at lower index values.

Figures 2,3,4,and 5 show the same twenty-three, outer-uranium swelling values plotted by position in the fuel column. These four figures each show two different plots. The top plot shows measured swelling (% ΔV) and exposure (MWD/T) vs fuel element position. The bottom plot shows measured swelling and calculated swelling vs fuel element position. Calculated swelling values have been computed from an equation developed by Battelle Northwest Laboratory using swelling values measured in KER irradiated outer uranium and expressed as a function of burnup, volume mean uranium temperatures, and system restraint (i.e. the sum of coolant pressure plus clad strength).

The top plots in Figures 2 through 5 show correlation of swelling with exposure when plotted for each element's position in the fuel column because this plot serves to eliminate the effect of variation in volume mean uranium temperature at a fixed falue for system restraint. The bottom plots in Figures 2 through 5 show correlation of calculated vs measured swelling that is to be expected from the variation between the measured swelling in N-Reactor and the measured swelling in K Reactor (Figure 1).

Figure 6 shows two nearly parallel lines which represent the range of inner uranium swelling values from KER tests vs the arbitrary index of exposure times volume mean uranium temperature. Again, values of inner uranium swelling for nineteen elements irradiated in N-Reactor are superimposed upon the KER swelling area. There is much less scatter in these inner swelling values at any given product of exposure times volume mean uranium temperature than was observed with the outer uranium swelling values.

Figures 7, 8, and 9 of inner fuel results again show two different plots. The upper plots show inner uranium swelling and exposure as a function of the position of the element within the column and the lower plots show measured inner uranium swelling and calculated inner uranium swelling as a function of position within the column. Both sets of plots show less variation than was found in those same plots for outer uranium and the lesser variation was expected from Figure 6.

The extrapolation of KER swelling data to high tube average exposures in N-Reactor has been made previously but it is exceedingly dangerous since there is no technical basis on which to base answers on any of the following questions:

(1) Will breakaway of the rate of swelling, as a function of exposure, occur?

(2) Where will breakaway occur?

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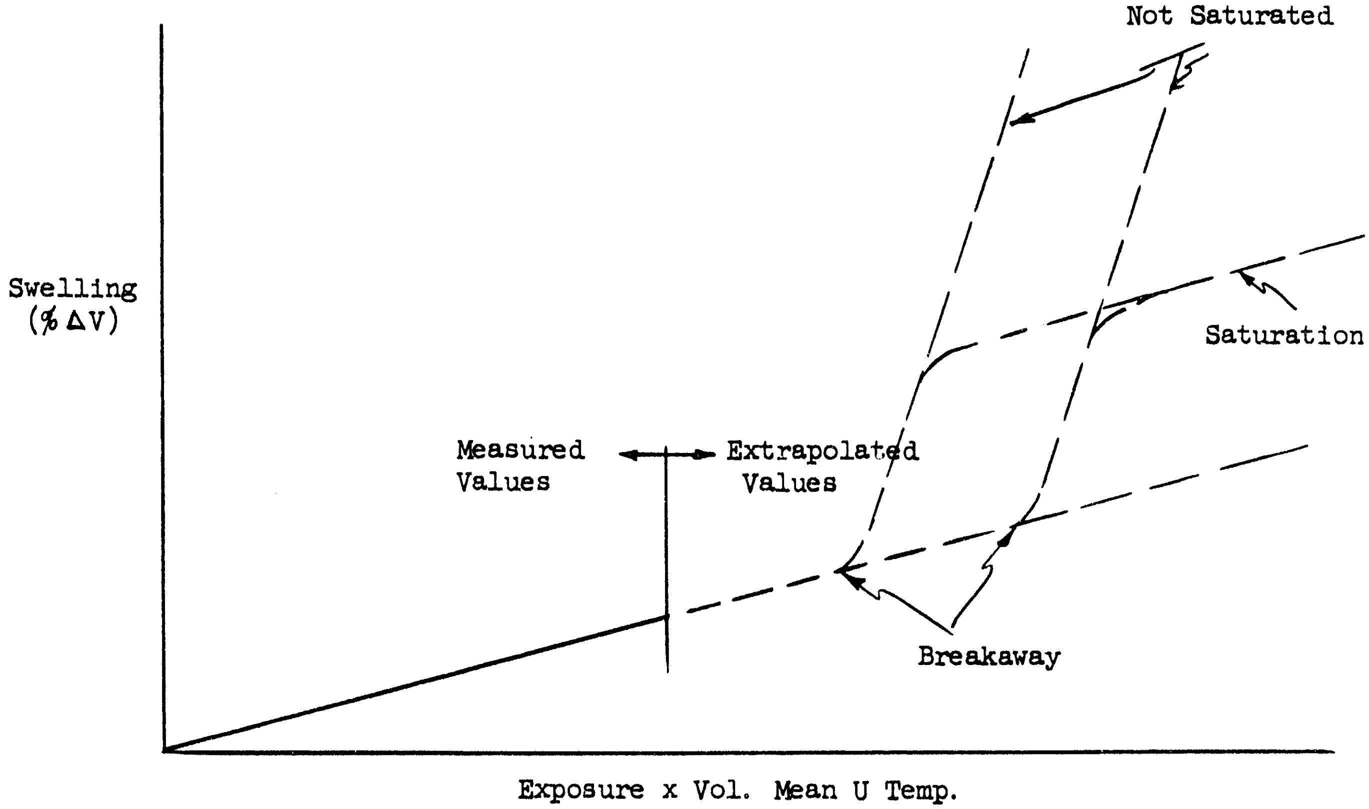
(3) Will breakaway saturate?

(4) Where will breakaway saturate?

In these questions, the word breakaway is defined as "the limiting exposure, beyond which there will be a marked increase in the rate of swelling as a function of burnup" and the word saturate is defined as "swelling after breakaway will be limited (i.e. will saturate) by system pressure." Schematically, the events illustrated by these questions are plotted in Figure 10 below but it is the express purpose of the production test to obtain answers to the four questions.

FIGURE 10

ILLUSTRATION OF BREAKAWAY AND SATURATION OF SWELLING



Notwithstanding the arguments for not extrapolating the present data to higher values of exposure, the following extrapolations are offered to predict when uranium swelling may cause limiting strain in the outer cladding of inner and outer fuel elements. The extrapolations are based on a few of the highest swelling values obtained and predict the swelling in only the hottest inner and outer element per column.

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TABLE 1

PREDICTED SWELLING OF INNER AND OUTER URANIUM AT PROJECTED TUBE AVERAGE EXPOSURES

Tube Average Exposure (MWD/T)	Hottest Inner Element(1) Exposure (MWD/T)	Hottest Inner Element(1) U-Swelling (%)	Hottest Inner Element(1) Outer Clad Strain (%)	Hottest Outer Element(2) Exposure (MWD/T)	Hottest Outer Element(2) U-Swelling (%)	Outer Clad Strain (%)
1600	1882	1.63	<1.0	2460	2.93	<1.0
1700	1998	1.72	"	2608	3.27	"
1800	2135	1.81	"	2761	3.63	"
1900	2235	1.89	"	2915	3.99	"
2000	2350	1.98	"	3069	4.38	"
2100	2470	2.08	"	3221	4.75	"
2200	2589	2.17	"	3376	5.15	≈1.0
2300	2705	2.25	"	3530	5.50	>1.0
2400	2822	2.35	"	3682		
2500	2940	2.44	"	3835		
2600	3059	2.53	"	3990		
2700	3175	2.63	=1.0	4141		

(1) at 387°C = 660 °K, Volume Mean U Temp.

(2) at 367°C = 640 °K, Volume Mean U Temp.

From the data of Table 1, one can conclude that a pessimistic handling of the data shows that the current goal exposure of 2100 MWD/T should not result in excessive swelling and limiting fuel element performance.

A final comment is offered on the plot of N-Reactor outer uranium swelling data vs KER data. The plot in Figure 1, page 7, indicates that zero swelling does not result at zero exposure. This observation suggests a bias error which could be of the following form:

(1) An error in the weight of the standard 24 inch long fuel element used in weighing in the 333 building.

(2) An error in assessing a weight correction for the presence of eight steel shoes on irradiated outer elements.

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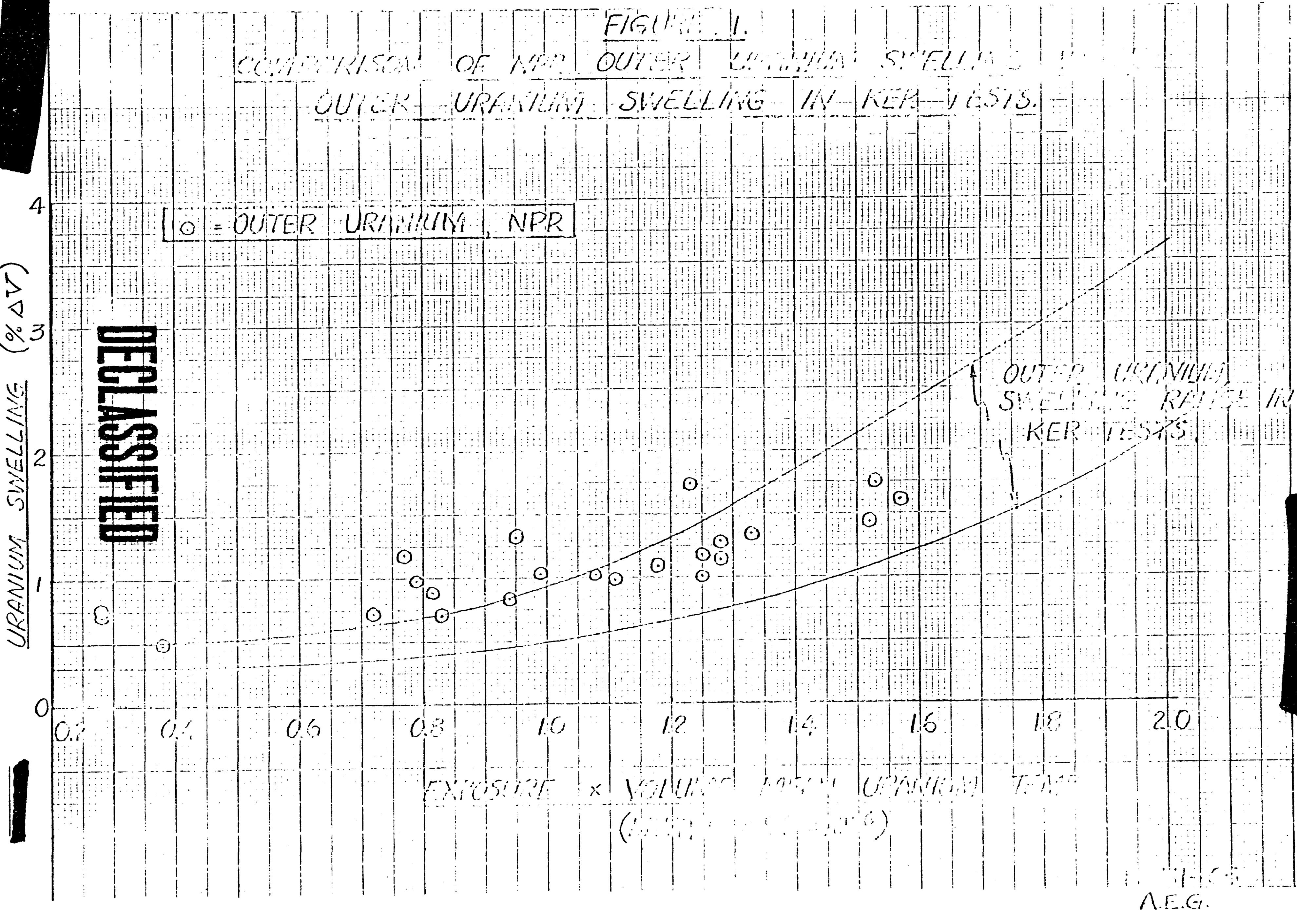

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FIGURE 2

OUTER URANIUM SWELLING IN TUBE 1666

TOP - VS EXPOSURE

BOTTOM - VS CALCULATED SWELLING

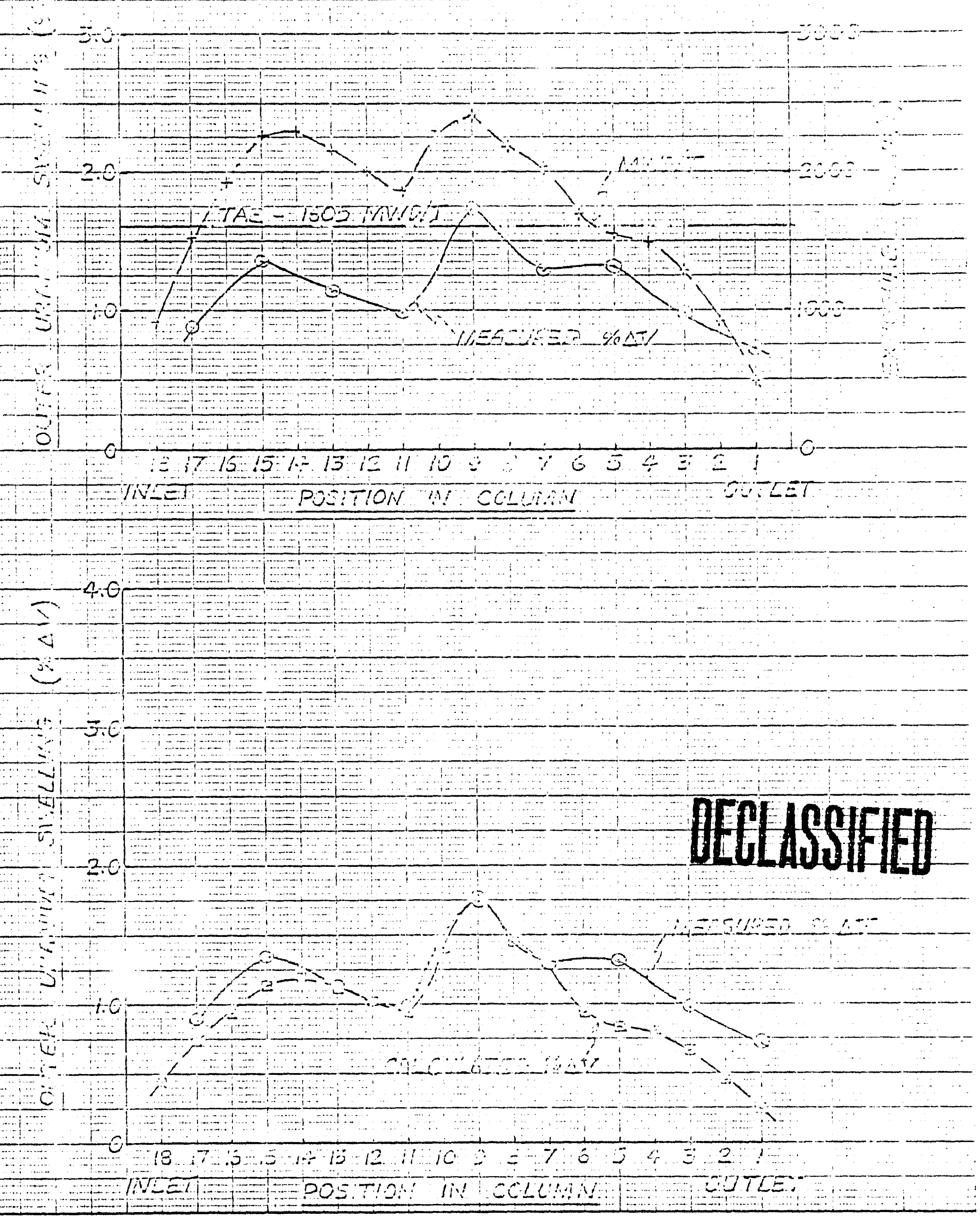

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FIGURE 3.

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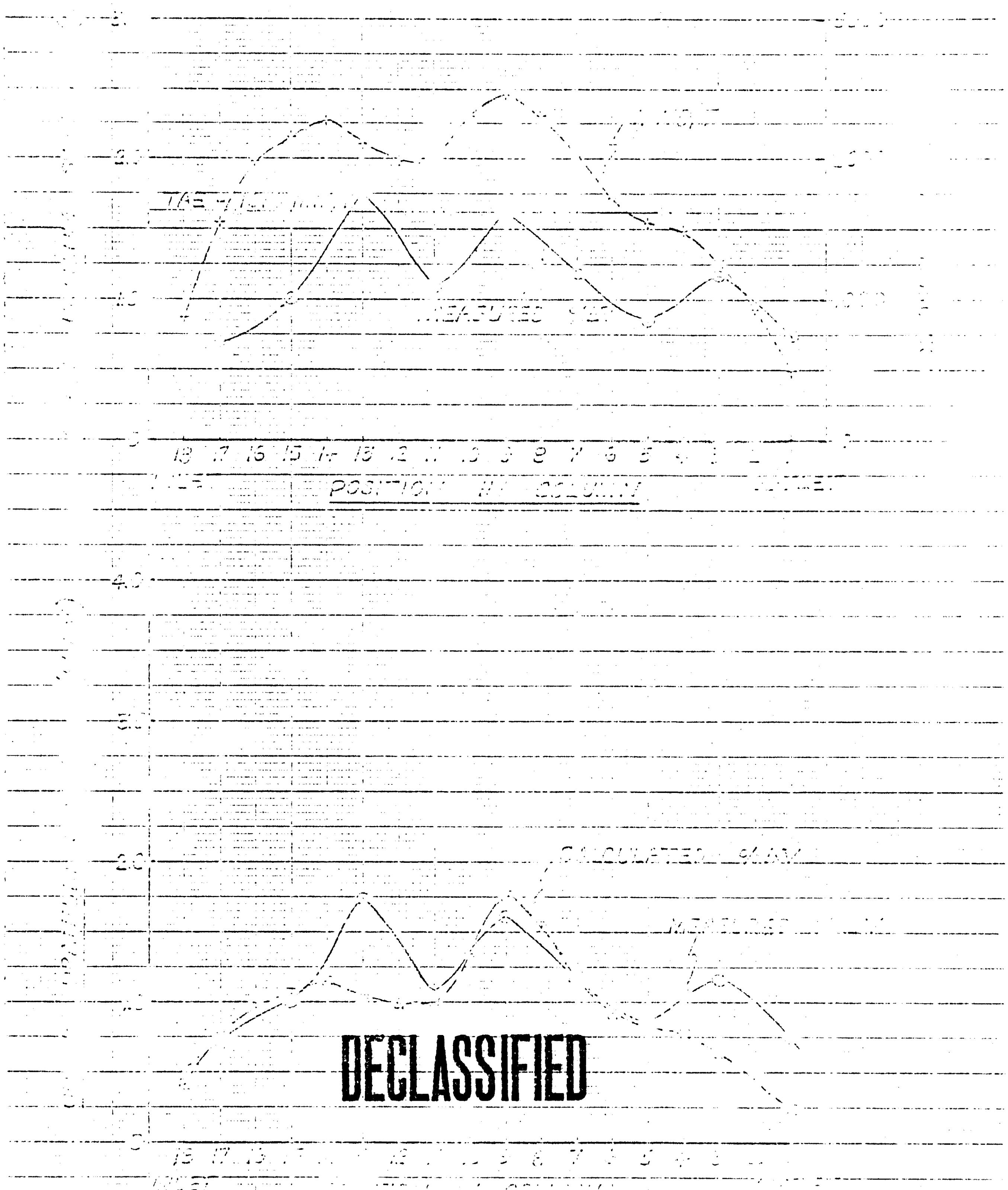

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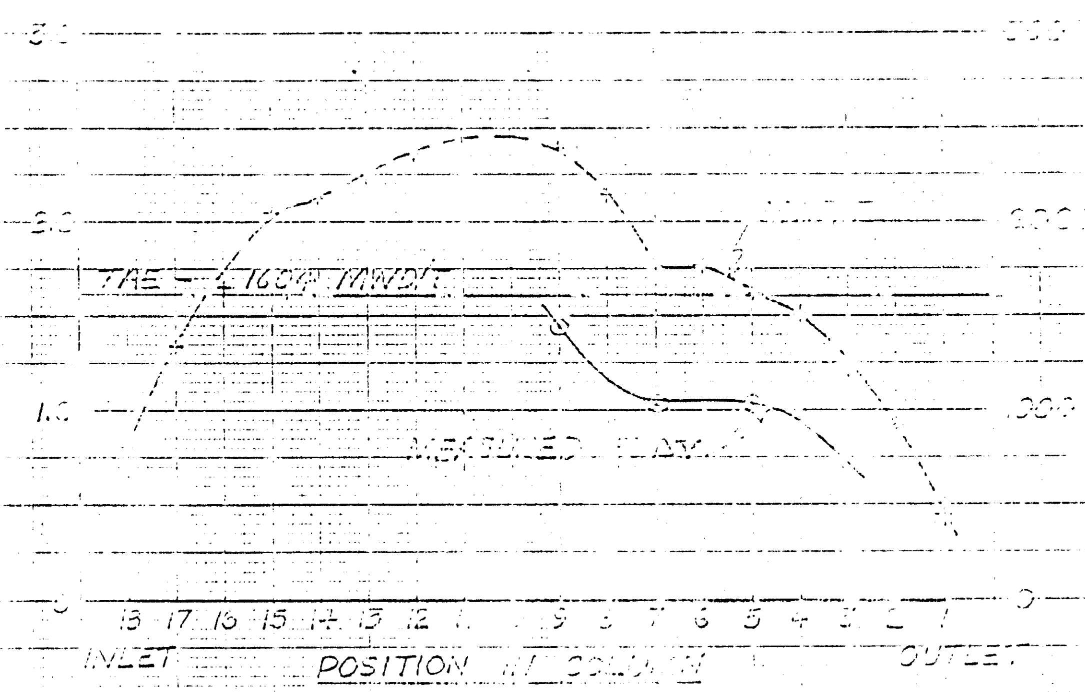
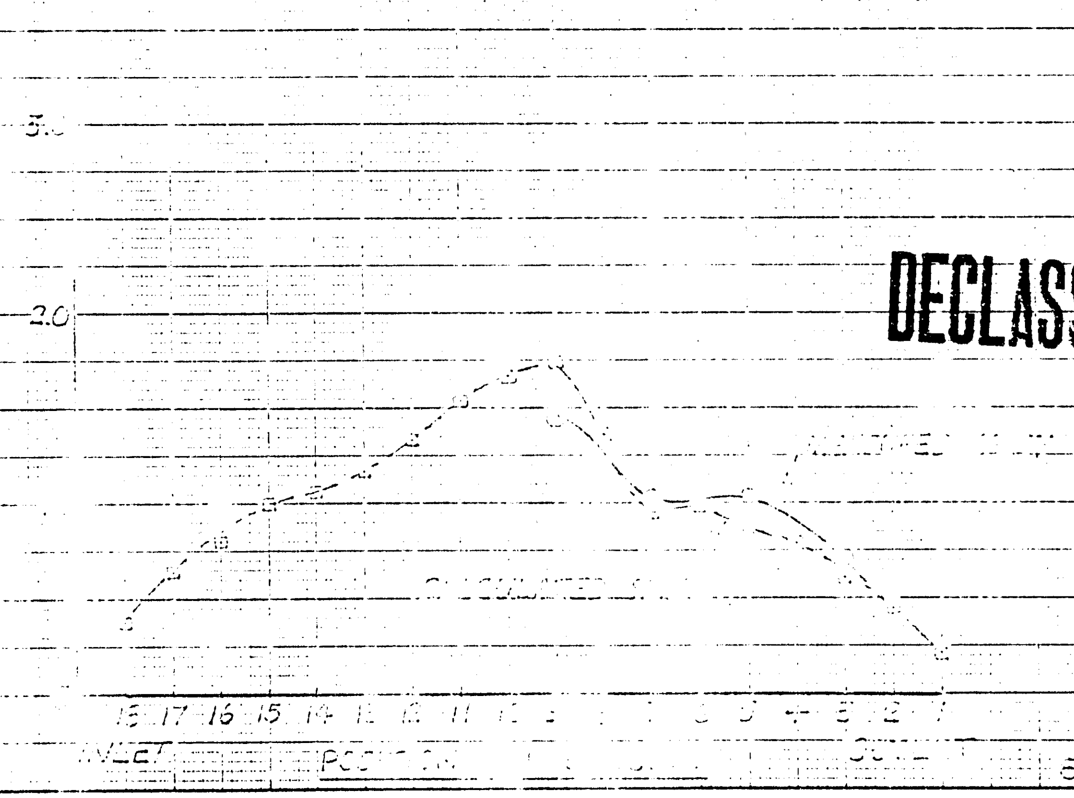
FIGURE 4





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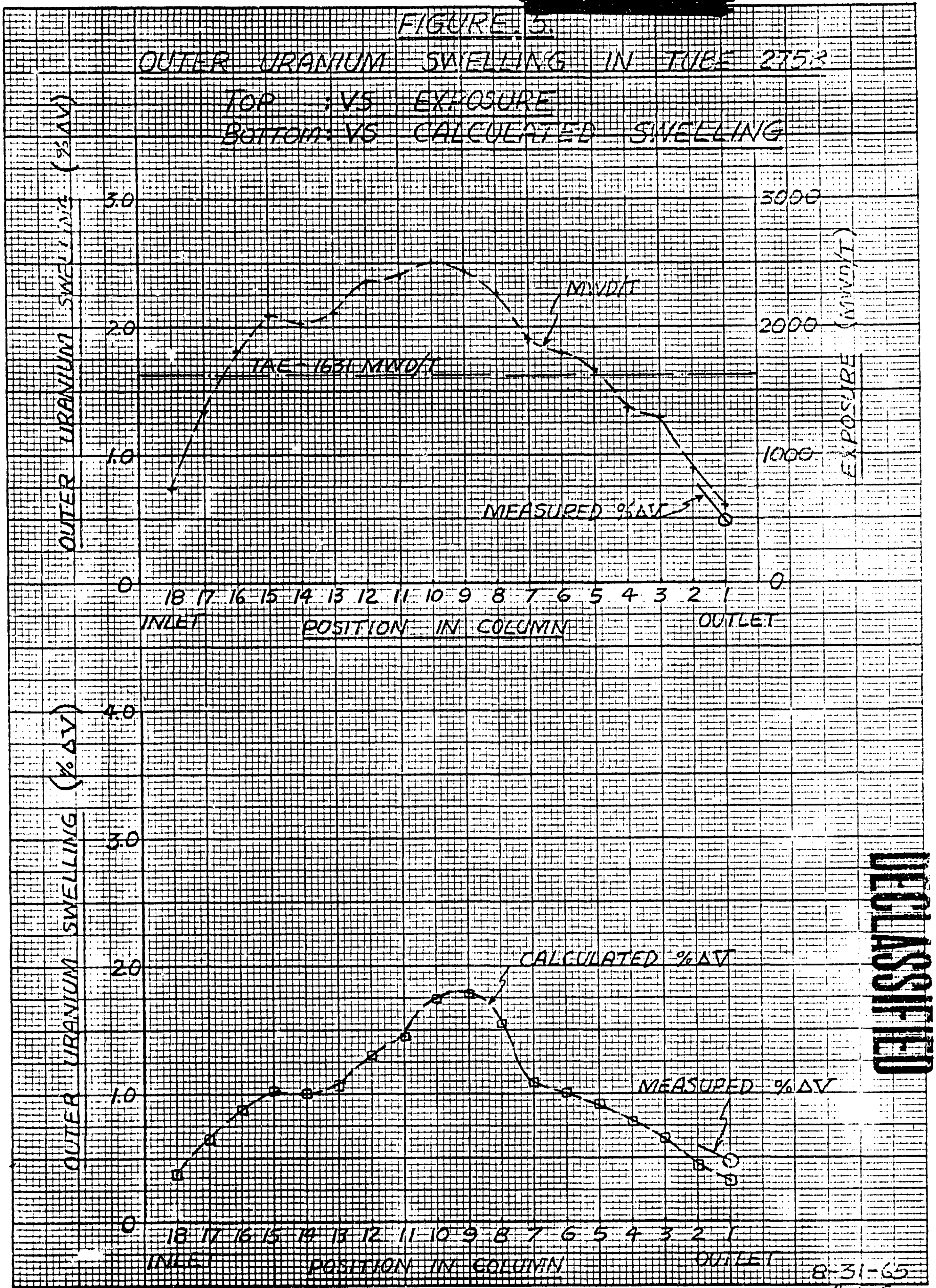

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FIGURE 6

COMPARISON OF NPR INNER URANIUM SWELLING WITH INNER URANIUM SWELLING IN KER TESTS

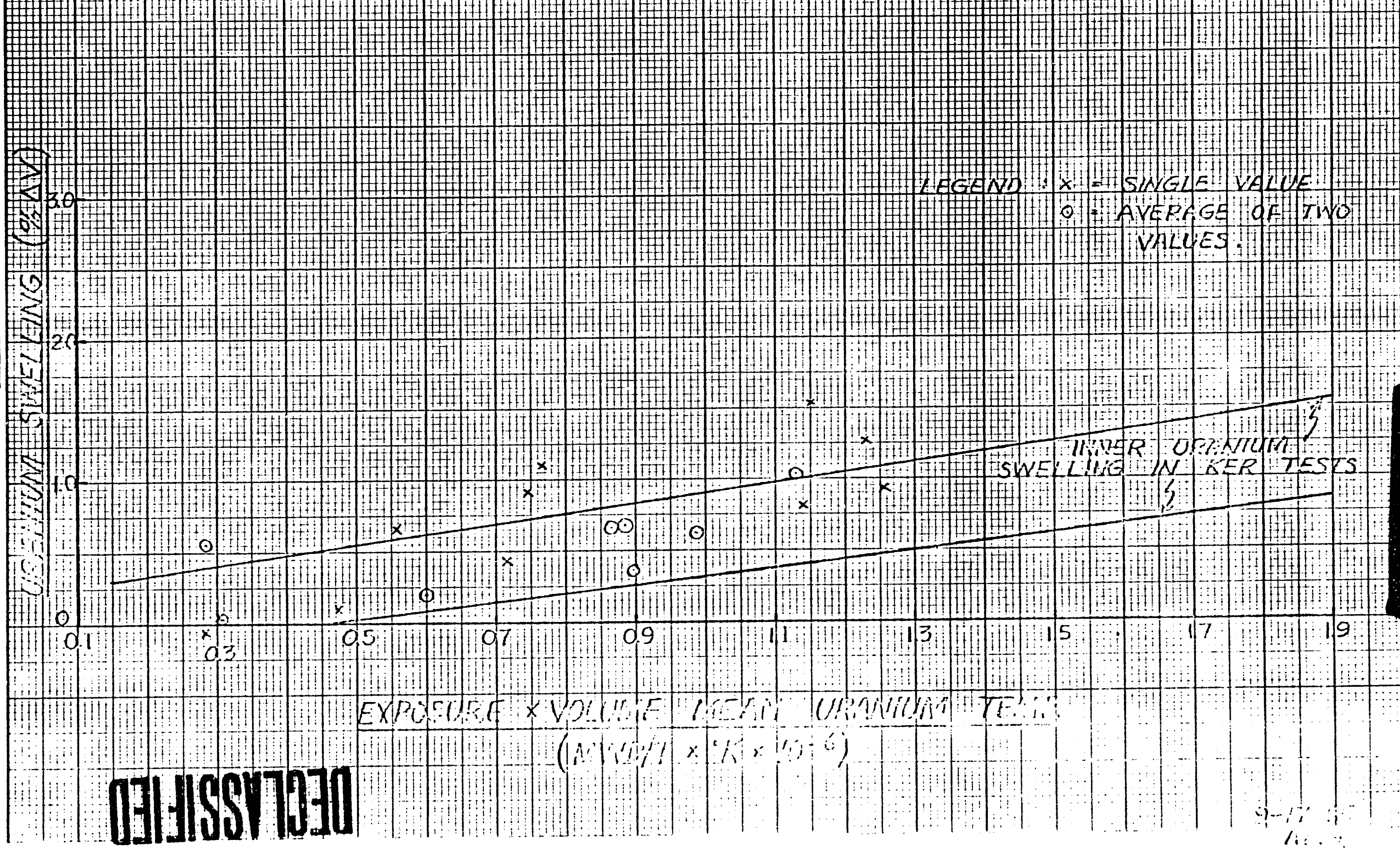

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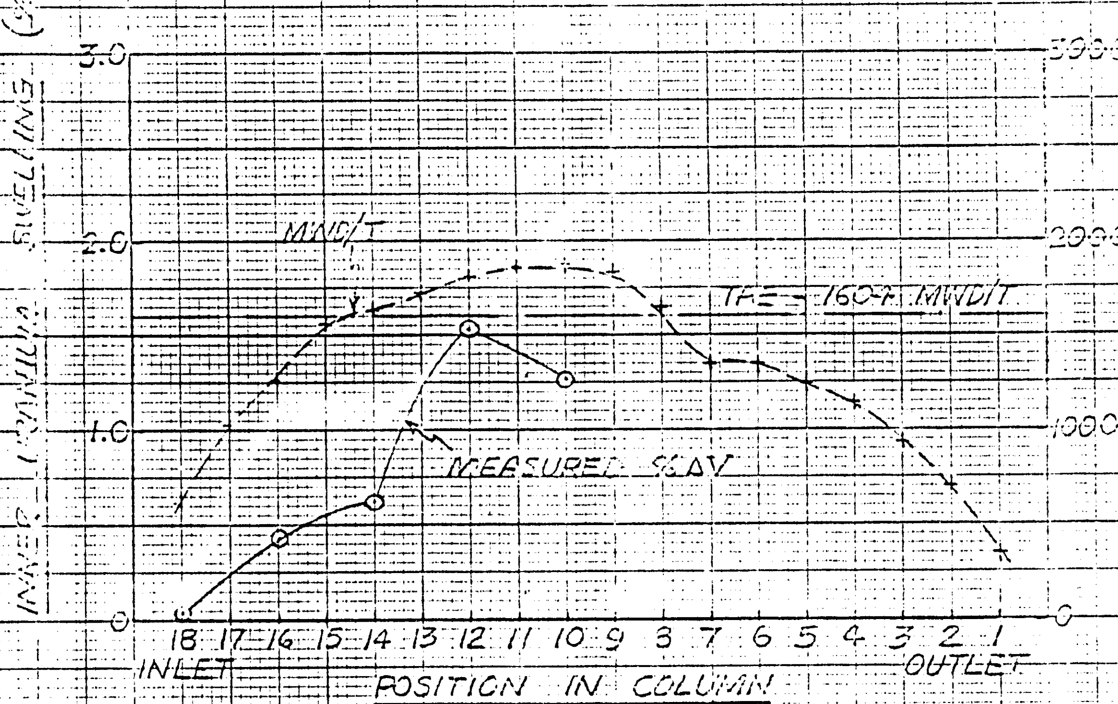
FIGURE

INNER URANIUM SWELLING IN TUBE 27

TOP: VS EXPOSURE

BOTTOM: VS CALCULATED SWELLING



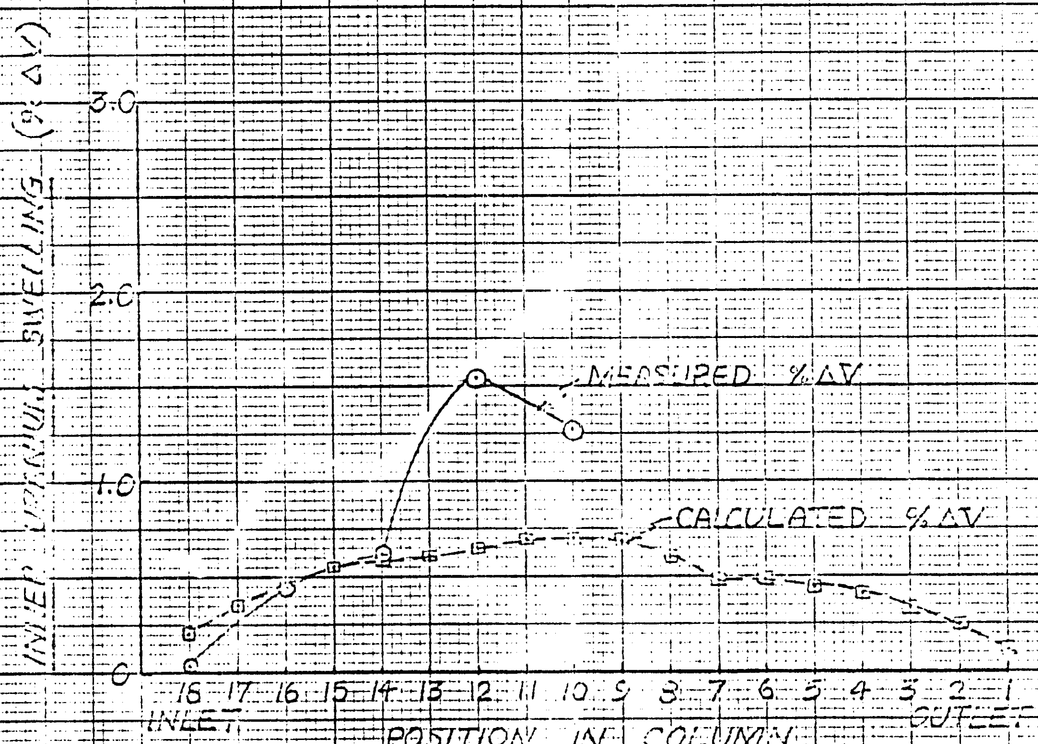


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FIG. ...

INNER URANIUM SWELLING IN TUBE 2753

TOP: VS. EXPOSURE

BOTTOM: VS. CALCULATED SWELLING

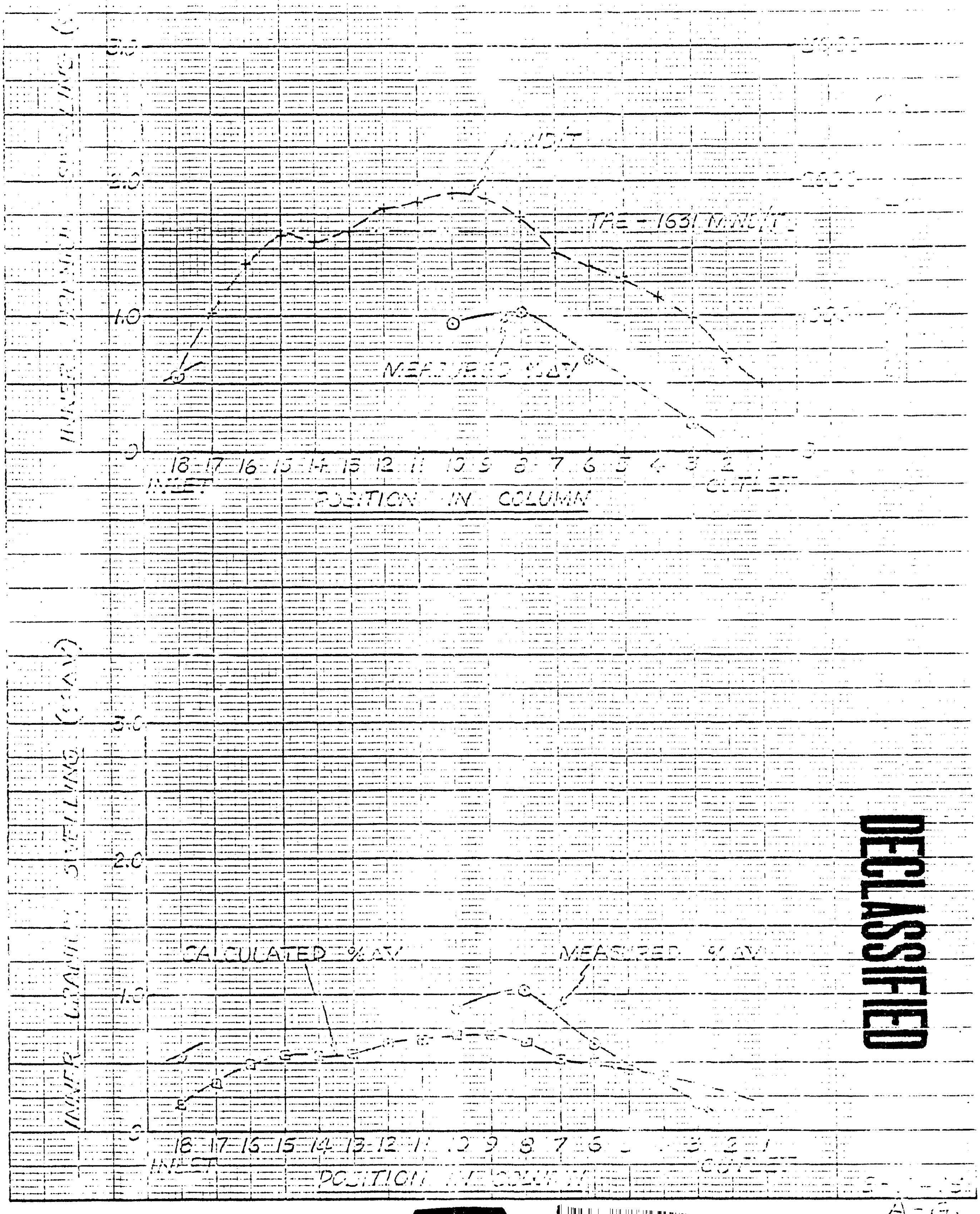

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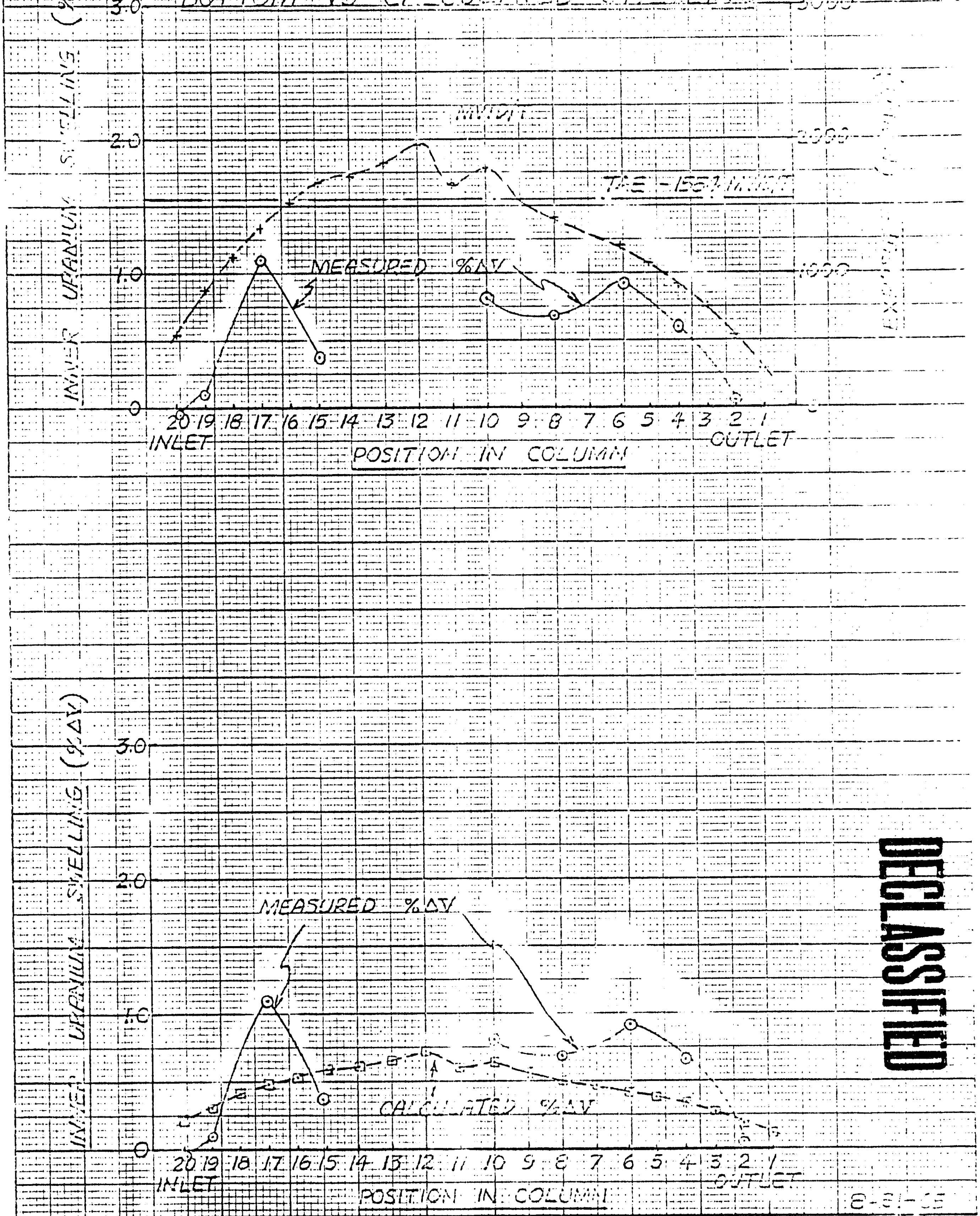
FIGURE 9

INNER URANIUM SWELLING IN TUBE 285[illegible]

TOP: VS EXPOSURE

BOTTOM: VS CALCULATED SWELLING



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