DESIGN DATA SHEET
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
1 MARCH 1986
DDS 313-1

SUBMARINE BATTERY ENDURANCE CALCULATIONS

CONTENTS

313-1-a. References.

(a) Naval Ships' Technical Manual NAVSEA S9086-G1-STM-012
Chapter 223 - Submarine Lead-Acid Storage Batteries

(b) Design Data Sheet DDS 310-1 - Design Details of Generating Plants

313-1-b. Definitions.

The following definitions are included for clarity of understanding this DDS. Some of them may have slightly different connotations when used in other documents.

Battery Characteristic Curves - A graph showing battery rate in hours against current, initial volts, average volts and final volts for a particular design of battery cell or number of cells in series. Reference (a) refers to these as the battery service characteristics which are shown in the "Curves and Data Plan."

Battery rate - The time, expressed in hours, required for a new battery to be discharged from a fully charged condition to a defined minimum voltage, at a constant current (the battery rate current).

Initial volts - The voltage existing at the terminals of a battery at the start of a constant current discharge with the battery fully charged.

Final volts - The voltage existing at the terminals of a battery beyond which it is considered unsafe to discharge it further at the particular current.

Average volts - The voltage obtained by dividing the integrated Watt-hours, accumulated during a constant current discharge from fully charged condition until final voltage is reached, by the integrated ampere-hours during the discharge.

Rated capacity (of a battery) - The product of the battery rate and the battery rate current expressed in ampere-hours.

Derated capacity (of a battery) - The rated capacity multiplied by a factor less than 1.0 to define a battery's actual capacity at any point during its service life.

Power analysis - A process by which a definite value of power is assigned to the load of the system to approximate the effect of a total system on a source of power (such as a battery).

Power profile - A graph of time vs. power showing step changes in power and covering a fixed period of time.

313-1-c. Symbols.

The following, other than standard symbols, are used herein:

V_i	Initial volts
V_f	Final volts
V_a	Average volts
D	Accumulated discharge in ampere-hours since battery was in the fully charged condition
DRATED	Rated capacity in ampere-hours (always referred to a particular battery rate)
T	Battery discharge rate in hours

313-1-d. General purpose.

The general purpose of this DDS is to describe a standardized procedure for analyzing the endurance of a given submarine battery when supplying varying power levels over varying lengths of time, and for determining the rating of a battery required to provide a given defined performance.

The following discussion describes the salient characteristics of a submarine battery and the operational requirements of a submarine as they affect selection of a battery.

313-1-e. Scope.

This DDS does not describe all of the internal characteristics of batteries (that information may be found in reference (a)), but only those characteristics which determine the performance of the battery as part of the submarine system. The battery characteristic curves which depict this performance are based on certain service conditions which are specified in the curves and data plan. Since the actual service conditions of a battery (temperature, specific gravity, number of cycles) and the restored charge level vary with battery use, the procedures described in this DDS cannot be used for battery performance simulation purposes. That is, they cannot precisely predict the performance of an existing battery installation unless the service conditions are matched to those specified in the curves and data plan. Therefore, in its present format this DDS is for use as a submarine design tool.

The process of making a power analysis of a submarine under battery operating conditions is not covered herein. For general guidance see reference (b).

There are generally two types of problems which may be approached by the methods given herein. These are:

1. Given a definite power plant and a definite battery installation, determine the time available for submerged operation under battery power. Such an operation could be a propulsion plant restart.

2. Given a definite power plant and a defined margin of safety together with a desired type of battery, determine the rated capacity at the one hour rate of the battery required.

313-1-f. Typical battery characteristics.

1. This discussion applies only to lead-acid types of batteries, although a similar approach could be used to develop methods for analyzing silver-zinc or other types of batteries.

2. A battery, which under discharge, exhibits a voltage at its terminals, which is a complex function of the current being drawn at the moment, the state of discharge, and the previous long term and short term history of the battery. The external characteristics of a new battery are usually described by the manufacturer by a set of curves (Battery Characteristic Curves). These consist of a graph of battery rate plotted against current and initial, average, and final voltage. An abbreviated version of the GUPPY I Mod C type battery characteristic curves is shown in figure 1. Other battery characteristic curves may be found in reference (a).

3. During a constant-current discharge, the battery terminal voltage gradually drops from the initial volts until it reaches the final volts beyond which further discharge could cause an individual cell voltage to suddenly drop to zero and reverse its polarity, with heavy gassing and potential damage. During such a constant-current discharge the terminal voltage drops slowly at first and more and more rapidly toward the end. This characteristic results in the average voltage always being above the median between initial and final voltage.

4. The voltage at any point along the battery terminal voltage curve between initial and final volts is a function of the total ampere-hours which have been withdrawn from the battery since it was last fully charged and the discharge rate (current) at that time. For the following calculations it is assumed that it makes no difference at what rates (current) these ampere-hours were accumulated when the battery was charged.

5. The product of the discharge current and the rate in hours is defined as the ampere-hour capacity of the battery. For higher currents this product is always smaller because the discharge time to final volts is disproportionately less. Thus a battery can be discharged at a certain current to the point where its rated capacity has been depleted and its final volts reached. Then, if the current is reduced, it will be found that the battery voltage will increase to a value above the final voltage for the reduced rate and still further ampere-hours can be removed.

6. Age and other factors such as number of cycles and temperature affect the capacity of the battery. If a battery is stated to have 80% capacity, this means that at a given current its ampere-hour capacity will be 80% of rated capacity. It will therefore reach its final volts in 80% of the time shown by its characteristic curves to correspond to the given current. The derating factor shall be determined by NAVSEA.

313-1-g. Typical Power Profiles.

The primary purpose of the battery on a submarine is to provide stored energy for emergency maintenance of certain vital services until the normal power source can be restored. Beginning with the initial loss of steam power and through a period of reduced emergency power, to a final restoration of steam power, there are usually well defined changes in the required power demand. This is usually defined by a power profile. A rough power profile would show a short period of high demand during which the operators would secure all except vital services, followed by a second time period given to allow correction of the casualty and having a lower level of power demand, and finally a period of higher demand as the steam plant is restored. In a design for which the battery has not been defined, the time duration of the second period would have to be specified. For a design in which the battery is already defined, this period would be left open and the available time would be calculated. A more refined power profile would break down each of the three major time periods into a number of shorter time periods which represent the operation of specific systems or individual machines. See figure 3.

313-1-h. Detail calculations for a defined battery.

Since all calculations are based on an assumption of constant power over a finite time, and all battery characteristics are based on constant current discharge, any calculation is an approximation. The accuracy desired and the time required to make a calculation will determine what process to use. Calculations in which the battery characteristic curves are defined can be made as described below:

1. Kilowatt-hour approximations. If the discharge current at a given battery rate is multiplied by the average voltage for that rate, a value of average power in watts is obtained. If this power is multiplied by the rate in hours, a value of watt-hours is obtained. Plotting this as watts vs. watt-hours gives a battery watt-hour capacity curve. By using this curve, a quick approximation of battery endurance for a given power profile can be made. (See example No. 1).

(a) The curve is used by locating on the curve the kilowatts specified for the final time period and reading the corresponding kilowatt-hours available. If a derated battery is specified this figure is multiplied by the derating factor.

(b) The product of the kilowatts and the time specified for the final time period is obtained and subtracted from the capacity determined in step (a). The remainder is assumed to be the available kilowatt-hours which can be used in the preceding periods.

(c) One of the time periods specified must be of unknown (indeterminate) length. All of the other periods are calculated first, multiplying the specified kW by the time to get kilowatt-hours. These are added together and subtracted from the remainder determined in step (b). The final remainder is the available kilowatt-hours applicable to the indeterminate time period.

(d) The kilowatt-hours remaining after step (c) are divided by the specified kilowatts for the indeterminate period to determine the time available in the period.

2. Ampere-Hour Approximations. Since the battery characteristic curves relate capacity to the ampere-hours used, an accurate estimate must involve conversion of power to amperes. Since the voltage is varying continually, the current is likewise varying. One method for approximating ampere-hours used involves making rough estimates of average voltage during each step of the power profile and determining the average amperes and ampere-hours from this. The accuracy of this method depends on the experience and intuition of the person making the study, but it can give results that are more accurate than the kilowatt-hour method with somewhat greater time and effort. This method is described as follows: (See example No. 2)

(a) Amperes and ampere-hours are determined from the basic battery characteristic curves which show current and initial, average, and final voltage vs. rate (see Figure 1).

(b) The final time period is considered first as in the kilowatt-hour method. The specified kilowatts is converted to amperes by estimating a value of volts. Knowing that the battery will be discharged at the end of this period, the voltage will be assumed near the final volts value. A quick iteration is made until a reasonable value of voltage and current are determined which give the specified kilowatt value.

(c) The ampere-hour capacity of the battery for the current determined is obtained from the curves. If a derated battery is specified, this capacity is multiplied by the derating factor given. The product of the specified time and the assumed average current for the final period is subtracted from the total available ampere-hour capacity. This gives the number of ampere-hours available for all previous periods.

(d) The currents and voltages for all specified time periods are estimated as before but considering that the battery is not yet discharged, the voltage assumed should be nearer to the initial volts value. Multiplying the specified times by the currents obtained by this approximation gives the ampere-hours discharged during these specified time periods. Subtracting the sum of these ampere-hours from the remainder obtained in step (c), gives the amount available for the indeterminate time period.

(e) The voltage and current are estimated for the kilowatts specified for the indeterminate time period. Again, the discharge condition must be taken into account and a value of voltage intermediate between initial and final volts must be selected. The current determined by this estimate is divided into the remaining available ampere-hours to obtain the time available in the indeterminate period.

3. Iterative Calculations. By taking small intervals of time, calculating the voltage that exists at that time, and the current from this, the

amperehours accumulated in the intervals of time can be added over a period to get a close approximation of the true discharge condition. The accuracy of this process depends on the length of the time intervals used and on the accuracy of the voltage calculation.

(a) Voltage Estimation. During any constant current discharge, the battery voltage drops as the discharge continues. The rate of drop is lower at the beginning than toward the end. This is reflected in the average voltage curve on the battery characteristic curves, where it will be noted that the V_a is always higher than the voltage half way between V_i and V_f. Since the battery characteristic curves do not show how the instantaneous battery voltage varies between V_i and V_f over a constant current discharge, a set of equations having the form:

$$V = V_f + (V_i - V_f)\ (1 - {}^{D}/\text{DRATED})^{E}$$

where E is an exponent developed by curve fitting methods to match the battery voltage characteristics at different constant current discharge rates. For the GUPPY I, Mod C battery, E has the following forms:

$$E = 0.55 \text{ for } 0 \leq T \leq 1$$

$$E = \frac{(T - 0.36)\ 0.76}{T} - \frac{T}{11.683} \quad \text{for } 1 < T \leq 4$$

$$E = 0.43 \text{ for } T > 4$$

Where T is the battery discharge rate in hours.

(b) Procedure (Refer to Example No. 3)

(1) Start from the beginning of the first period and iterate to obtain the voltage and current assuming the voltage is equal to the initial volts corresponding to the current in question. This iteration can be carried out to any specified error tolerance. An error of plus or minus 2.0 volts usually results in a solution in one or two iterations and is considered to be sufficiently accurate for most purposes.

(2) Divide each power profile period into small intervals of time. Calculate the voltage at the end of each interval by assuming the current is constant during the interval and using the equations in paragraph 3(a). The current for the next interval is calculated by dividing the specified power by the new voltage.

(3) When the addition of these time intervals is equal to the specified time for the period, proceed to the next defined time period. Whenever the power level changes reiterate to determine the voltage and current.

(4) At the end of the last defined time period before the indeterminate period, note the total ampere-hours accumulated.

(5) Now proceed to the end of the final period. Iterate to obtain the voltage and current, assuming that the voltage is equal to the final volts at the power level in question.

(6) Proceed backwards in time, starting at the end of the final period and assuming a total ampere-hours equal to the capacity of the battery at the final current. Assume that the current is constant during each interval at the end value for each interval. The voltage at the beginning of each interval is calculated by the equations in paragraph 3(a), the value of D being equal to DRATED at the end of the step and decreasing by an amount equal to the time interval multiplied by the assumed constant current in each interval. If a derated battery is specified, the value of DRATED must be multiplied by the derating factor each time.

(7) When the addition of these time intervals is equal to the specified time for each period, proceed to the next previous period. When the indeterminate period is calculated, make the last interval just long enough to make the accumulated ampere-hours at the beginning of the period equal to the total determined in step (4). The addition of the time intervals used in the indeterminate period will then give the time available in the period.

(c) Battery Endurance Calculation Computer Program - The iterative nature of the previous procedure makes it a good candidate for a digital computer program which would greatly decrease computation time. The Fortran program, which may be obtained from NAVSEA determines the amount of time available in the indeterminate period of a power profile and/or calculates the total ampere-hours used in each time period of the power profile. The Fortran program flow chart is included herewith. This program contains sets of subroutines which represent the mathematical models for three batteries, the GUPPY I Mod C (Gould TLX-39-B), the C&D SCC-57 and the GUPPY I MOD. E. The program can be modified to include other battery types. The accuracy of the program is ± 5 percent.

The program will automatically read a new set of input data so that a number of battery endurance calculations for any of the three battery types (power profiles) may be run in sequence. Each power profile may have a maximum of nine (9) time periods with a limit of nine hundred (900) intervals. Up to five (5) power profiles may be run in sequence.

The procedure for preparing the input data and the form of the output data is given in Example 4.

4. Comparison of methods. The following general conclusions can be drawn of the three methods described for estimating the margin or deficiency of a given battery:

(a) The kilowatt-hour method is reasonably accurate if the power profile does not have great differences of power between the different time periods. It can be used for making quick estimates where a large number of different power profiles are to be compared.

WARNING--For power profiles in which the last period is a lower power than the preceding period, a check must be made using the preceding period as though it were the last. Otherwise a false indication of total battery capacity may result.

(b) The ampere-hour method is highly subjective and may give questionable results if estimates by different people are being compared. It takes possibly 25 percent as much time to make one estimate as for the iterative method.

(c) The accuracy of the iterative method is dependent upon the accuracy of the power profile and the battery characteristic curves being used, as well as the length of the time intervals. If intervals of time in the order of 5 percent of the battery rate are taken, the accuracy of this method will be much superior to that of the previous two. A study using 5 percent intervals might take approximately 4 hours for an experienced operator to manually calculate or approximately 30 seconds using the Battery Endurance Calculation Computer Program.

313-1-i. Estimation of battery rating required.

When a power profile is specified and it is desired to determine the rating of battery required, the method described below can be used to obtain approximate ratings from which the physical size and weight of the battery can be estimated.

1. Principle. Two lead-acid batteries of similar general characteristics will have approximately the same ratio between a particular pair of rates. For instance, the ratio between the current at the one-hour rate and the two-hour rate will be the same. The same holds for the average power at particular rates. Figure 4 shows the relation between the one-hour rate average kW of a Guppy I Mod C battery and the kW at other rates.

2. Procedure.

(a) If the total kilowatt-hours required by the power profile are divided by the final period kilowatt rate, the battery rate at which the capacity must be developed can be determined. Using this rate and Figure 4 the required one-hour rate kilowatts is determined.

(b) Using a known battery as a model, the ratio of its one-hour rate average kilowatts to the one-hour rate average kilowatts of the required battery is determined.

(c) Since this method uses the average kilowatt rating obtained from the constant-current discharge characteristics, rather than true constant kilowatt characteristics, the results will be in error in some degree. The battery determined by this method will usually be found to be too small when checked by the iterative method. The size of the battery should usually be increased by about 10%. When justified by circumstances, an iteration by time intervals as described in paragraph 313-1-h.3 should be made. When doing this the power specified should be divided by the KW ratio of Figure 4 before using the curves applicable to the model battery. Example 5 illustrates the process described.

EXAMPLE NO. 1

Problem: Calculate by kilowatt-hour method the time available in the indeterminate period for a system using a single 126 cell GUPPY I, Mod. C battery derated to 80% and having a power profile as follows:

Period	I	II	III
KW	585	400	600
Time(hrs)	.325	Indeterm.	.333

Step No. 1. From manufacturer's battery characteristic curves for GUPPY I, Mod C, which are abbreviated as Figure 1, plot a curve of kW vs. kWh

kW = I x Va
kWh = kW x T (Rate in hours)

Such a plot is shown on Figure 2.

Step No. 2. Determine rated capacity from Figure 2 for the last period kW. This is found to be 945 kWh.

Step No. 3. Multiply rated capacity by the derating factor 0.8 to obtain the derated capacity. This gives a value of 756 kWh.

Step No. 4. For periods I and III determine the combined kilowatt-hours by multiplying the power by the time for each period and adding the results. This gives:

585 x .325 = 190 kWh
600 x .333 = 200 kWh
Total 390 kWh

Step No. 5. Subtract value of kilowatt-hours used in first and third periods from the derated capacity found in Step No. 3. This gives a value of available kilowatt-hours in period II of:

756 - 390 = 366 kWh

Step No. 6. Divide the available kilowatt-hours for period II by the specified power.

366 ÷ 400 = .915 hours

The estimate is therefore that a time of .915 hours (55 min.) is available in the second period.

EXAMPLE NO. 2

Problem. Calculate by the ampere-hour method the time available in the indeterminate period for a system using a single 126 cell GUPPY I, Mod C battery derated to 80% and having a power profile as follows:

Period	I	II	III
KW	585	400	600
Time(hrs)	.325	Indeterm.	.333

Step No. 1. From Figure 2 determine the rated capacity at the final period rate. This is found to be 945 kWh.

Step No. 2. Multiply this capacity by the derating factor to obtain the derated capacity. This gives a value of 756 kWh.

Step No. 3. Multipy the final period power by the time to obtain the energy used in the final period. This gives:

$$600 \times .333 = 200 \text{ kWh}$$

Step No. 4. It is seen that 200 ÷ 756 = .264 or approximately 25 percent of the total discharge occurs in the final period. Knowing that the voltage drops more rapidly toward the end of a discharge, it is reasonable to assume that the average voltage during this period is more than one-eighth of the total voltage range above the final volts, and probably nearer one-quarter. A quick evaluation of $IV = kW$ using Figure 1 shows that a voltage of 200 gives a current of 3000 for which the initial and final volts are 238 and 191. This is a range of 47 volts. One-fourth of this, added to the final volts gives a voltage of:

$$\frac{47}{4} + 191 = 203$$

Therefore the assumed value of 200 is probably not too far off.

Step No. 5. From Figure 1 determine rated capacity (I x T) at 3000 amperes. This is found to be 4590 ampere-hours.

Step No. 6. Multiply rated capacity by the derating factor. This gives a capacity of 0.8 x 4590 = 3672 ampere-hours.

Step No. 7. Multiply the final period current by the specified time.

3000 x .333 = 1000 ampere-hours used in the final period.

Step No. 8. Subtract the ampere-hours used in the final period from the derated capacity. This gives the number of ampere-hours available for use in the first and second periods.

3672 - 1000 = 2672 ampere-hours

Step No. 9. Now consider the first period. Knowing that the average voltage in this period will be close to the initial volts, and making a quick evaluation of I x V = kW using Figure 1, a value of voltage of 230 and a current of:

585 ÷ 230 x 1000 = 2550 amperes

appears reasonable. A check with Figure 1 shows an initial and final voltage of 242 and 195. This is a range of 47 volts. The energy used in the first period is

585 x .325 = 190 kWh which is: 190 ÷ 752 = .252 or again about 25 percent of the total discharge. (See Step No. 3).

The average voltage during the first 25 percent of a discharge is about 10 percent of the total range below the initial voltage.

242 - .10 x 47 = 237.3

Therefore a better value of voltage would probably be about 237. Using this value gives an average current of

585 x 1000 ÷ 237 = 2468 amperes

Step No. 10. Multiply the first period current by the specified time:

2468 x .325 = 802 ampere-hours

Step No. 11. From step No. 8 it was determined that 2672 ampere-hours were available for periods I and II. Subtracting the first period ampere-hours,

2672 - 802 = 1870 ampere-hours

are available for the second period.

Step No. 12. Observing that the ampere-hours available for the second period amount to approximately 50 percent of the derated capacity, the average voltage for this period can be estimated at about 1/3 of the voltage range ($V_i - V_f$). So assuming a voltage of 220 V, an initial current value of 1818 is determined.

For this current the voltage range from Figure 1 is 241 to 194. The 1/3 point of this range is 225. This gives a current of:

400 ÷ 225 x 1000 = 1780

Step No. 13. Divide the available ampere-hours for the second period as found in step No. 11 by the estimated current:

1870 ÷ 1780 = 1.05 hours

The determination is therefore that the available time for period II is 1.05 hours (63 minutes).

EXAMPLE NO. 3

Problem. Calculate by the iterative method the time available in the indeterminate period for a system using a single GUPPY I, Mod. C battery of 126 cells, derated to 80 percent and having the following power profile (see figure 3):

Power Profile

Period	I	II	III
KW	585	400	600
Time(hrs)	.325	Indeterminate	.333

See procedure on table next page.

NOTES FOR EXAMPLE 3:

1. The desired number of iterations is arbitrary but limited by the reading accuracy of the battery curves.

2. D is the used capacity at the end of interval for forward iterations, or beginning of interval for backward iterations.

3. Period I is the last defined period prior to the indeterminant period. Now iterate for current and voltage for the last interval of the last period using the final voltage curve to satisfy kW x 1000 = V_f x I.

4. At this point, the change in kW would result in a change in current. However, the voltage would have a value of between initial and final voltage. Therefore, the average voltage equation is used (lines 17 through 19) in conjunction with the battery curves to satisfy kW x 1000 = VI. The value of D/DRATE (line 16) is used in the equation.

5. Δt_6 of Period II was estimated by subtracting 782 (line 15 Period I) from 1074 (line 12 Period II) and dividing by 262 (line 14, Δt_5 Period II). Purpose is to insure that line 12 for Δt_6 Period II is equal to line 15, Δt_4 Period I. See the values shown in boxes.

PROCEDURE FOR EXAMPLE NO. 3

	ITEM	DERIVATION Iterating Fwd	Iterating Backward						
1.	Time Period	Given		I	I	I	I	I	I
2.	Iteration or Interval	I = Iteration; t = Interval		I-1	I-2	Δt_1	Δt_2	Δt_3	Δt_4
3.	Power KW	Given		585	585	585	585	585	585
4.	Volts V	Assumed or prev. column line(19)		235.0	243.0	244.0	242.9	241.6	240.1
5.	Current I	(3) ÷ (4) x 1000		2489	2430	2400	2408	2420	2435
6.	Battery Rate	From Figure 1		1.94	2.03	2.04	2.04	2.02	2.00
7.	Initial Volts V_i	From Figure 1		243.0	244.0	244.1	244.1	243.9	243.5
8.	Final Volts V_f	From Figure 1				196.8	196.8	196.6	196.5
9.	Rated Capacity D (Rated)	(5) x (6)				4896	4896	4890	4871
10.	Derated Capacity (DRATE)	0.8 x (9)				3917	3917	3912	3897
11.	Voltage Range (V_i - V_f)	(7) - (8)				47.3	47.3	47.3	47.0
12.	D At Begin of Interval	Assumed or prev. column line (15)	(15) - (14)	0	0	0	218	436	653
13.	Δt	Assumed		-	-	.091	.091	.090	.053
14.	ΔD	(5) x (13)		-	-	218	218	218	129
15.	D At End of Interval	(12) + (14)	Prev. column line (12)	-	-	218	436	653	$\boxed{782}$
16.	Proportion of Capacity Used	(15) ÷ (10)	(12) ÷ (10)	0	0	.055	.111	.167	.200
17.		(1 - line 16)^E (See Exp. Eval. Below)		0	0	.975	.948	.920	.904
18.		(11) x (17)		0	0	46.1	44.8	43.5	42.4
19.	New Voltage	(8) + (18)				242.9	241.6	240.1	238.9
20.	New Current	(3) ÷ (19) x 1000		2430	2400	2408	2420	2435	2447
21.	Accum. Time In Period	Prev. column line (21) + (13)		-	-	.091	.182	.272	.325
22.	Voltage Error	(19) - (4) (Abs. Value)		8.0	1.0	-	-	-	-

NOW PROCEED TO THE END OF THE LAST PERIOD. SEE NOTE 3

	ITEM								
1.	Time Period	III	III	III	III	III	III	III	III
2.	Iteration or Interval	I-1	I-2	I-3	Δt_1	Δt_2	Δt_3	Δt_4	Δt_5
3.	Power KW	600	600	600	600	600	600	600	600
4.	Volts V	250	196.8	191.5	191.0	191.6	208.6	214.9	218.5
5.	Current I	2400	3048	3133	3141	3130	2875	2791	2745
6.	Battery Rate	2.04	1.51	1.45	1.44	1.45	1.63	1.70	1.71
7.	Initial Volts V_i	244.1	238.1	237.5	237.4	237.5	239.5	240.3	241.0
8.	Final Volts V_f	196.8	191.5	191.0	191.0	191.5	193.0	193.7	194.0
9.	Rated Capacity D (Rated)	-	-	-	4523	4538	4686	4744	4701
10.	Derated Capacity (DRATE)	-	-	-	3618	3630	3749	3795	3760
11.	Voltage Range (V_i - V_f)	-	-	-	46.4	46.0	46.5	46.6	47.0
12.	D At Begin of Interval	-	-	-	3426	3228	3038	2845	2641
13.	Δt	-	-	-	.061	.063	.066	.069	.074
14.	ΔD	-	-	-	191.6	197.1	189.7	192.5	203.1
15.	D At End of Interval				3618	3426	3228	3038	2845
16.	Proportion of Capacity Used	-	-	1.0	.947	.889	.810	.749	.702
17.		-	-	-	.014	.373	.471	.533	.577
18.		-	-	-	0.67	17.1	21.9	24.8	27.1
19.	New Voltage	196.8	191.5	191.0	191.6	208.6	214.9	218.5	221.1
20.	New Current	3048	3133	3141	3130	2875	2791	2745	2713
21.	Accum. Time In Period	-	-	-	.061	.124	.190	.259	.333
22.	Voltage Error	53.2	5.3	0.5	-	-	-	-	-

NOW CONTINUE ITERATING BACKWARD INTO THE SECOND PERIOD. SEE NOTE 4

	ITEM										
1.	Time Period	II	II	II	II	II	II	II	II	II	II
2.	Iteration or Interval	I-1	I-2	I-3	Δt_1	Δt_2	Δt_3	Δt_4	Δt_5	Δt_5	Δt_6
3.	Power KW	400	400	400	400	400	400	400	400	400	400
4.	Volts V	220	230.9	234.3	234.7	236.6	238.9	239.9	242.7	244.3	245.9
5.	Current I	1818	1731	1706	1703	1690	1674	1667	1647	1637	1626
6.	Battery Rate	2.71	3.01	3.07	3.07	3.11	3.15	3.18	3.22	3.26	3.31
7.	Initial Volts V_i	248.5	250.0	250.1	250.1	250.4	250.4	250.8	250.8	251.0	251.0
8.	Final Volts V_f	202.0	203.7	204.0	204.0	204.3	204.3	204.4	204.4	204.6	204.6
9.	Rated Capacity D (Rated)	4926	5210	5240	5230	5255	5273	5314	5314	5340	5387
10.	Derated Capacity (DRATE)	3941	4168	4192	4184	4204	4218	4251	4251	4272	4309
11.	Voltage Range (V_i - V_f)	46.5	46.3	46.1	46.1	46.1	46.1	46.4	46.4	46.4	46.4
12.	D At Begin of Interval	-	-	-	2385	2126	1864	1600	1336	1074	$\boxed{782}$
13.	Δt	-	-	-	.150	.153	.156	.158	.160	.160	.179
14.	ΔD	-	-	-	255	258.5	261	263	263	262	292
15.	D At End of Interval	2641	2641	2641	2641	2385	2126	1864	1600	1336	1074
16.	Proportion of Capacity Used	.670	.633	.629	.570	.505	.442	.376	.314	.251	.181
17.		.622	.661	.667	.708	.751	.772	.827	.860	.891	.924
18.		28.9	30.6	30.7	32.6	34.6	35.6	38.3	39.9	41.3	42.8
19.	New Voltage	230.9	234.3	234.7	236.6	238.9	239.9	242.7	244.3	245.9	247.4
20.	New Current	1731	1706	1703	1690	1674	1667	1647	1637	1626	1616
21.	Accum. Time In Period	-	-	-	.150	.303	.459	.617	.788	.948	1.127
22.	Voltage Error	10.9	3.4	0.4	-	-	-	-	-		

SEE NOTE 5

EXPONENT EVALUATION

$E = 0.55$ for $0 < (6) \leq 1$

$E = \frac{((6) - 0.36)\, 0.76}{(6)} - \frac{(6)}{11.683}$ for $1 < (6) \leq 4$

$E = 0.43$ for $(6) > 4$

Total time available
in the indeterminate
period: 1.127 hours
(67.62 minutes)

EXAMPLE NO. 4

Problem. Using the Battery Endurance Program determine the time available in the indeterminate period for a system using a single GUPPY I, Mod C battery of 126 cells, derated to 80% and having a power profile as shown. Use one minute time increments for the iteration.

Period	I	II	III
KW	585	400	600
Time(hrs)	.325	Indeterm.	.333

Step No. 1. Prepare input data as indicated below. Input format must be exactly as indicated to preclude format error warnings.

Line number 1 - Ship and Date information:

Column	Field	Variable Name	Description
1-24	6A4	SHIP	Name of the Ship for which the program is being run.
25-48	6A4	DATE	Date of the run.

Line number 2 - Battery and Power Profile information:

Column	Field	Variable Name	Description
1-20	5A5	BTYPE	Battery models used in the program include the TLX-39-B (GUPPY I Mod C) the C&D-SCC-57, and the Guppy I Mod. E.
21-27	F7.4	DEFAC	Derating Factor specified for battery. (Is equal to .8 for this example).
28-32	F5.2	TIMEI	Length of time increment in minutes to be used in the iteration; not to exceed a total of 100 time increments per time period. (Time increment is one minute in this example).
33-34	I2	NPER	Number of time periods per power profile; not to exceed 10. (Is equal to 3 in this example).
35-36	I2	INPER	Indeterminate period specified in the power profile. If all period times are specified, INPER is one (1) greater than NPER. (Period number 2 is indeterminate in this example).

*Line number 3 - Power Profile Period information:

Column	Field	Variable Name	Description
1-10	F10.2	PTIME	Period Time Span in min. Set equal to zero (0) for the indeterminate period.
11-20	F10.2	PLOAD	Period kW load.
21-22	I2	IND	Period Number.

*Note: Repeat line no. 3 for each period of the power profile.

Step No. 2. Execute the program using the previously prepared data. Following is the printout for this example.

```
                    BATTERY ENDURANCE CALCULATIONS

                 SHIP PROOF SHIP                DATE  13 OCTOBER 1983

           BATTERY TYPE TLX-39-B            DERATING FACTOR   0.8000  INTERVAL TIME SPAN   1.00 MINS

            PERIOD NUMBER  1  POWER PROFILE      LOAD    585.00 KW      TIME       19.50 MINS

INTERVAL     VOLTS     CURRENT      RATE     INITIAL     FINAL     AMP-HR     AMP-HR     AMP-HR      NEW-CAL   BATTERY
 (MINS)                 (AMPS)                VOLTS      VOLTS     BEGIN       END        USED        VOLTS     RATING
            241.14     2433.59     1.987     241.18     196.36      0.00                             241.18   3868.45
  1.00      241.18     2425.54     1.995     241.28     196.47      0.00      60.64      60.64       240.96   3871.76
  2.00      240.96     2427.75     1.993     241.26     196.44     60.64     101.10      40.46       240.72   3870.85
  3.00      240.72     2430.19     1.991     241.23     196.41    101.10     141.60      40.50       240.48   3869.85
  4.00      240.48     2432.67     1.988     241.19     196.38    141.60     182.15      40.54       240.23   3868.83
  5.00      240.23     2435.19     1.985     241.16     196.34    182.15     222.73      40.59       239.98   3867.79
  6.00      239.98     2437.72     1.983     241.13     196.31    222.73     263.36      40.63       239.73   3866.74
  7.00      239.73     2440.29     1.980     241.10     196.28    263.36     304.04      40.67       239.47   3865.66
  8.00      239.47     2442.88     1.977     241.07     196.24    304.04     344.75      40.71       239.21   3864.57
  9.00      239.21     2445.50     1.975     241.04     196.21    344.75     385.51      40.76       238.96   3863.47
 10.00      238.96     2448.14     1.972     241.01     196.18    385.51     426.31      40.80       238.70   3362.35
 11.00      238.70     2450.82     1.969     240.97     196.14    426.31     467.16      40.85       238.43   3361.21
 12.00      238.43     2453.52     1.967     240.94     196.11    467.16     508.05      40.89       238.17   3360.04
 13.00      238.17     2456.26     1.964     240.91     196.07    508.05     548.99      40.94       237.90   3858.87
 14.00      237.90     2459.02     1.961     240.87     196.04    548.99     589.97      40.98       237.63   3857.67
 15.00      237.63     2461.82     1.958     240.84     196.00    589.97     631.00      41.03       237.36   3856.45
 16.00      237.36     2464.64     1.955     240.81     195.97    631.00     672.08      41.08       237.08   3855.21
 17.00      237.08     2467.50     1.952     240.77     195.93    672.08     713.20      41.13       236.80   3853.96
 18.00      236.80     2470.40     1.949     240.74     195.89    713.20     754.38      41.17       236.52   3852.67
 19.00      236.52     2473.33     1.946     240.70     195.86    754.38     795.60      41.22       236.24   3851.37
 19.50      236.24     2476.29     1.943     240.67     195.82    795.60     816.23      20.64

THIS PERIOD WAS ITERATED FORWARD
```

BATTERY ENDURANCE CALCULATIONS

SHIP PROOF SHIP DATE 13 OCTOBER 1983

BATTERY TYPE TLX-39-B DERATING FACTOR 0.8000 INTERVAL TIME SPAN 1.00 MINS

PERIOD NUMBER 2 POWER PROFILE LOAD 400.00 KW TIME 68.83 MINS

INTERVAL (MINS)	VOLTS	CURRENT (AMPS)	RATE	INITIAL VOLTS	FINAL VOLTS	AMP-HR BEGIN	AMP-HR END	AMP-HR USED	NEW-CAL VOLTS	BATTERY RATING
	231.66	1720.68	2.900	249.54	202.58		2731.09		231.61	3992.60
1.00	231.61	1727.01	2.889	249.48	208.01	2702.31	2731.09	28.78	233.86	3991.21
2.00	233.86	1710.39	2.919	249.65	202.71	2673.80	2702.31	28.51	232.32	3994.73
3.00	232.32	1721.79	2.898	249.53	208.14	2645.10	2673.80	28.70	234.44	3992.36
4.00	234.44	1706.20	2.927	249.69	202.76	2616.66	2645.10	28.44	232.91	3995.55
5.00	232.91	1717.42	2.906	249.58	202.62	2588.04	2616.66	28.62	232.99	3993.29
6.00	232.99	1716.78	2.908	249.58	202.63	2559.43	2588.04	28.61	233.26	3993.42
7.00	233.26	1714.82	2.911	249.60	202.66	2530.85	2559.43	28.58	233.54	3993.83
8.00	233.54	1712.74	2.915	249.62	202.68	2502.30	2530.85	28.55	233.83	3994.26
9.00	233.83	1710.68	2.919	249.64	202.71	2473.79	2502.30	28.51	234.10	3994.67
10.00	234.10	1708.65	2.923	249.66	202.73	2445.31	2473.79	28.48	234.38	3995.07
11.00	234.38	1706.66	2.926	249.68	202.76	2416.87	2445.31	28.44	234.65	3995.46
12.00	234.65	1704.69	2.930	249.70	202.78	2388.46	2416.87	28.41	234.91	3995.84
13.00	234.91	1702.76	2.934	249.72	202.81	2360.08	2388.46	28.38	235.18	3996.21
14.00	235.18	1700.85	2.937	249.74	202.83	2331.73	2360.08	28.35	235.44	3996.57
15.00	235.44	1698.97	2.941	249.76	202.86	2303.41	2331.73	28.32	235.69	3996.91
16.00	235.69	1697.12	2.944	249.78	202.88	2275.13	2303.41	28.29	235.95	3997.25
17.00	235.95	1695.30	2.948	249.80	202.90	2246.87	2275.13	28.26	236.20	3997.57
18.00	236.20	1693.50	2.951	249.82	202.93	2218.65	2246.87	28.23	236.44	3997.89
19.00	236.44	1691.73	2.954	249.84	202.95	2190.45	2218.65	28.20	236.69	3998.20
20.00	236.69	1689.98	2.958	249.85	202.97	2162.28	2190.45	28.17	236.93	3998.49
21.00	236.93	1688.25	2.961	249.87	202.99	2134.15	2162.28	28.14	237.17	3998.78
22.00	237.17	1686.55	2.964	249.89	203.02	2106.04	2134.15	28.11	237.41	3999.07
23.00	237.41	1684.87	2.967	249.91	203.04	2077.96	2106.04	28.08	237.64	3999.34
24.00	237.64	1683.21	2.970	249.92	203.06	2049.90	2077.96	28.05	237.87	3999.60
25.00	237.87	1681.57	2.973	249.94	203.08	2021.88	2049.90	28.03	238.10	3999.86
26.00	238.10	1679.95	2.976	249.96	203.10	1993.88	2021.88	28.00	238.33	4000.12
27.00	238.33	1678.35	2.979	249.97	203.12	1965.90	1993.88	27.97	238.55	4000.36
28.00	238.55	1676.77	2.982	249.99	203.14	1937.96	1965.90	27.95	238.78	4000.60
29.00	238.78	1675.21	2.985	250.00	203.16	1910.04	1937.96	27.92	239.00	4000.83
30.00	239.00	1673.67	2.988	250.02	203.18	1882.14	1910.04	27.89	239.21	4001.05
31.00	239.21	1672.15	2.991	250.04	203.20	1854.27	1882.14	27.87	239.43	4001.27
32.00	239.43	1670.64	2.994	250.05	203.22	1826.43	1854.27	27.84	239.64	4001.48
33.00	239.64	1669.15	2.997	250.07	203.24	1798.61	1826.43	27.82	239.85	4001.69
34.00	239.85	1667.68	3.000	250.08	203.26	1770.81	1798.61	27.79	240.06	4001.89
35.00	240.06	1666.22	3.002	250.10	203.27	1743.04	1770.81	27.77	240.27	4002.09
36.00	240.27	1664.79	3.005	250.11	203.28	1715.30	1743.04	27.75	240.47	4002.28

```
INTERVAL     VOLTS     CURRENT      RATE     INITIAL     FINAL     AMP-HR     AMP-HR     AMP-HR      NEW-CAL   BATTERY
 (MINS)                 (AMPS)                VOLTS      VOLTS      BEGIN       END       USED        VOLTS    RATING
37.00        240.47    1663.38     3.008     250.13     203.28    1687.57    1715.30     27.72       240.68   4002.46
38.00        240.68    1661.99     3.010     250.14     203.29    1659.87    1687.57     27.70       240.88   4002.64
39.00        240.88    1660.61     3.013     250.16     203.30    1632.20    1659.87     27.68       241.07   4002.81
40.00        241.07    1659.24     3.016     250.17     203.31    1604.54    1632.20     27.65       241.27   4002.98
41.00        241.27    1657.89     3.018     250.18     203.31    1576.91    1604.54     27.63       241.47   4003.15
42.00        241.47    1656.55     3.021     250.20     203.32    1549.30    1576.91     27.61       241.66   4003.31
43.00        241.66    1655.22     3.023     250.21     203.33    1521.71    1549.30     27.59       241.85   4003.46
44.00        241.85    1653.91     3.026     250.23     203.33    1494.15    1521.71     27.57       242.04   4003.61
45.00        242.04    1652.61     3.028     250.24     203.34    1466.61    1494.15     27.54       242.23   4003.76
46.00        242.23    1651.32     3.031     250.25     203.35    1439.08    1466.61     27.52       242.42   4003.91
47.00        242.42    1650.04     3.033     250.27     203.35    1411.58    1439.08     27.50       242.61   4004.05
48.00        242.61    1648.77     3.036     250.28     203.36    1384.10    1411.58     27.48       242.79   4004.18
49.00        242.79    1647.51     3.038     250.29     203.37    1356.65    1384.10     27.46       242.97   4004.31
50.00        242.97    1646.27     3.041     250.31     203.37    1329.21    1356.65     27.44       243.16   4004.44
51.00        243.16    1645.04     3.043     250.32     203.38    1301.79    1329.21     27.42       243.34   4004.57
52.00        243.34    1643.81     3.045     250.33     203.39    1274.39    1301.79     27.40       243.52   4004.69
53.00        243.52    1642.60     3.048     250.34     203.39    1247.02    1274.39     27.38       243.69   4004.81
54.00        243.69    1641.40     3.050     250.36     203.40    1219.66    1247.02     27.36       243.87   4004.93
55.00        243.87    1640.21     3.052     250.37     203.40    1192.32    1219.66     27.34       244.05   4005.04
56.00        244.05    1639.03     3.055     250.38     203.41    1165.01    1192.32     27.32       244.22   4005.15
57.00        244.22    1637.85     3.057     250.39     203.42    1137.71    1165.01     27.30       244.40   4005.25
58.00        244.40    1636.69     3.059     250.41     203.42    1110.43    1137.71     27.28       244.57   4005.36
59.00        244.57    1635.54     3.061     250.42     203.43    1083.17    1110.43     27.26       244.74   4005.46
60.00        244.74    1634.39     3.063     250.43     203.44    1055.93    1083.17     27.24       244.91   4005.56
61.00        244.91    1633.26     3.066     250.44     203.44    1028.71    1055.93     27.22       245.08   4005.65
62.00        245.08    1632.13     3.068     250.45     203.45    1001.51    1028.71     27.20       245.25   4005.74
63.00        245.25    1631.02     3.070     250.47     203.45     974.32    1001.51     27.18       245.41   4005.83
64.00        245.41    1629.91     3.072     250.48     203.46     947.16     974.32     27.17       245.58   4005.92
65.00        245.58    1628.81     3.074     250.49     203.47     920.01     947.16     27.15       245.74   4006.00
66.00        245.74    1627.72     3.076     250.50     203.47     892.88     920.01     27.13       245.91   4006.08
67.00        245.91    1626.63     3.079     250.51     203.48     865.77     892.88     27.11       246.07   4006.16
68.00        246.07    1625.56     3.081     250.52     203.48     838.68     865.77     27.09       246.23   4006.24
68.83        246.23    1624.49     3.083     250.54     203.49     816.23     838.68     22.45

INDETERMINATE PERIOD


THIS PERIOD WAS ITERATED BACKWARD
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                              BATTERY ENDURANCE CALCULATIONS

                         SHIP PROOF SHIP                 DATE  13 OCTOBER 1983

                  BATTERY TYPE TLX-39-B            DERATING FACTOR   0.8000  INTERVAL TIME SPAN   1.00 MINS

                   PERIOD NUMBFR  3  POWER PROFILE      LOAD     600.00 KW      TIME      20.00 MINS

 INTERVAL     VOLTS     CURRENT      RATE     INITIAL     FINAL     AMP-HR     AMP-HR     AMP-HR      NEW-CAL   3ATTERY
  (MINS)                 (AMPS)                VOLTS      VOLTS     BEGIN       END        USED        VOLTS     RATING
             190.02     3143.49     1.468     235.10     189.96               3692.80                 189.96    3692.80
   1.00      189.96     3158.50     1.459     234.99     189.85    3634.54    3687.18     52.64       196.59    3687.18
   2.00      196.59     3052.03     1.525     235.76     190.66    3583.67    3634.54     50.87       200.99    3724.64
   3.00      200.99     2985.23     1.568     236.26     191.18    3533.92    3583.67     49.75       203.50    3745.23
   4.00      203.50     2948.47     1.592     236.53     191.47    3484.78    3533.92     49.14       205.20    3755.58
   5.00      205.20     2923.92     1.608     236.72     191.67    3436.04    3484.78     48.73       206.58    3762.10
   6.00      206.58     2904.49     1.621     236.87     191.83    3387.64    3436.04     48.41       207.77    3767.03
   7.00      207.77     2887.80     1.632     237.00     191.96    3339.51    3387.64     48.13       208.85    3771.10
   8.00      208.85     2872.92     1.642     237.12     192.09    3291.62    3339.51     47.88       209.84    3774.61
   9.00      209.84     2859.38     1.651     237.23     192.20    3243.97    3291.62     47.66       210.75    3777.70
  10.00      210.75     2846.91     1.660     237.33     192.30    3196.52    3243.97     47.45       211.62    3780.45
  11.00      211.62     2835.31     1.668     237.42     192.40    3149.26    3196.52     47.26       212.43    3782.94
  12.00      212.43     2824.44     1.675     237.50     192.49    3102.19    3149.26     47.07       213.20    3785.21
  13.00      213.20     2814.21     1.682     237.59     192.58    3055.28    3102.19     46.90       213.94    3787.28
  14.00      213.94     2804.52     1.689     237.66     192.66    3008.54    3055.28     46.74       214.65    3789.19
  15.00      214.65     2795.30     1.695     237.74     192.74    2961.95    3008.54     46.59       215.32    3790.96
  16.00      215.32     2786.52     1.701     237.81     192.81    2915.51    2961.95     46.44       215.97    3792.60
  17.00      215.97     2778.11     1.707     237.88     192.88    2869.21    2915.51     46.30       216.60    3794.13
  18.00      216.60     2770.04     1.713     237.94     192.95    2823.04    2869.21     46.17       217.21    3795.57
  19.00      217.21     2762.29     1.718     238.01     193.02    2777.00    2823.04     46.04       217.80    3796.91
  20.00      217.80     2754.82     1.723     238.07     193.08    2731.09    2777.00     45.91

THIS PERIOD WAS ITERATED BACKWARD
```

EXAMPLE NO. 5

Problem. Determine the one-hour rating of a battery having general characteristics similar to GUPPY I, Mod C and capable of supporting the following power profile, assuming the battery is derated to 80 percent of its new capacity.

Power Profile

Period	I	II	III
KW	585	400	600
Time(hrs)	.325	1.5	.333

Step No. 1. Calculate the total kilowatt-hours required by multiplying the power in each period by the time and adding them together:

Period	kW	Time	kWh
I	585	.325	190
II	400	1.5	600
III	600	.33	200
		Total	990

Step No. 2. Divide the total required capacity by the derating factor to determine the required capacity for a new battery:

990 ÷ 0.8 = 1237 kWh

Step No. 3. Divide the required capacity by the final rate to determine the equivalent battery rate for the final period:

1237 ÷ 600 - 2.06 hours

Step No. 4. From Figure 4 it is seen that the ratio between the one-hour rate and the 2.06 hour rate is 0.65. Dividing the final rate by this ratio will give the desired one-hour kilowatt rating:

600 ÷ .65 = 923 kW

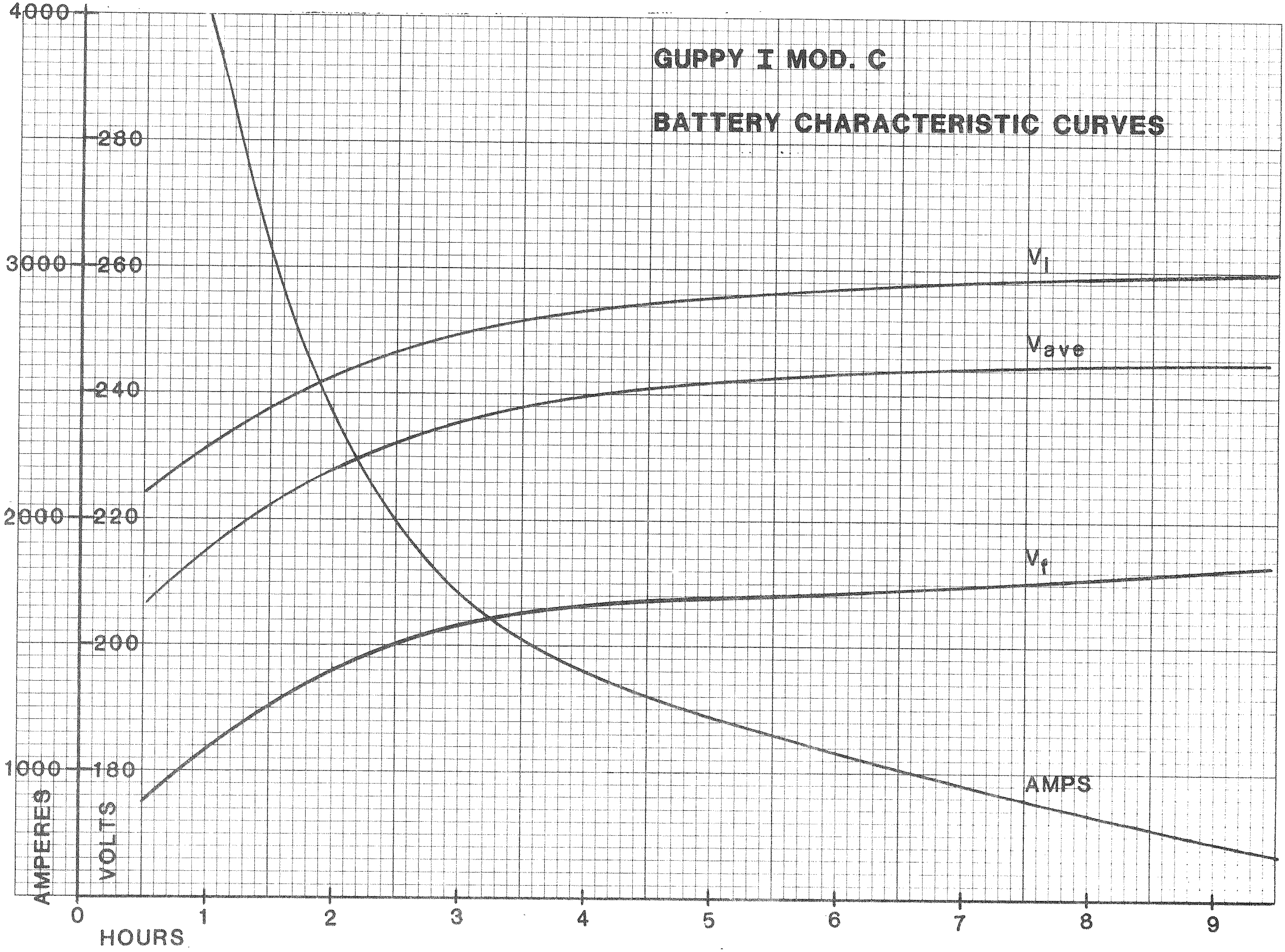
Step No. 5. A GUPPY I, Mod C battery has a one-hour rate average kilowatt capacity of 787 kW. Therefore the required battery is larger than a GUPPY I, Mod C battery by a factor of:

923 ÷ 787 = 1.17

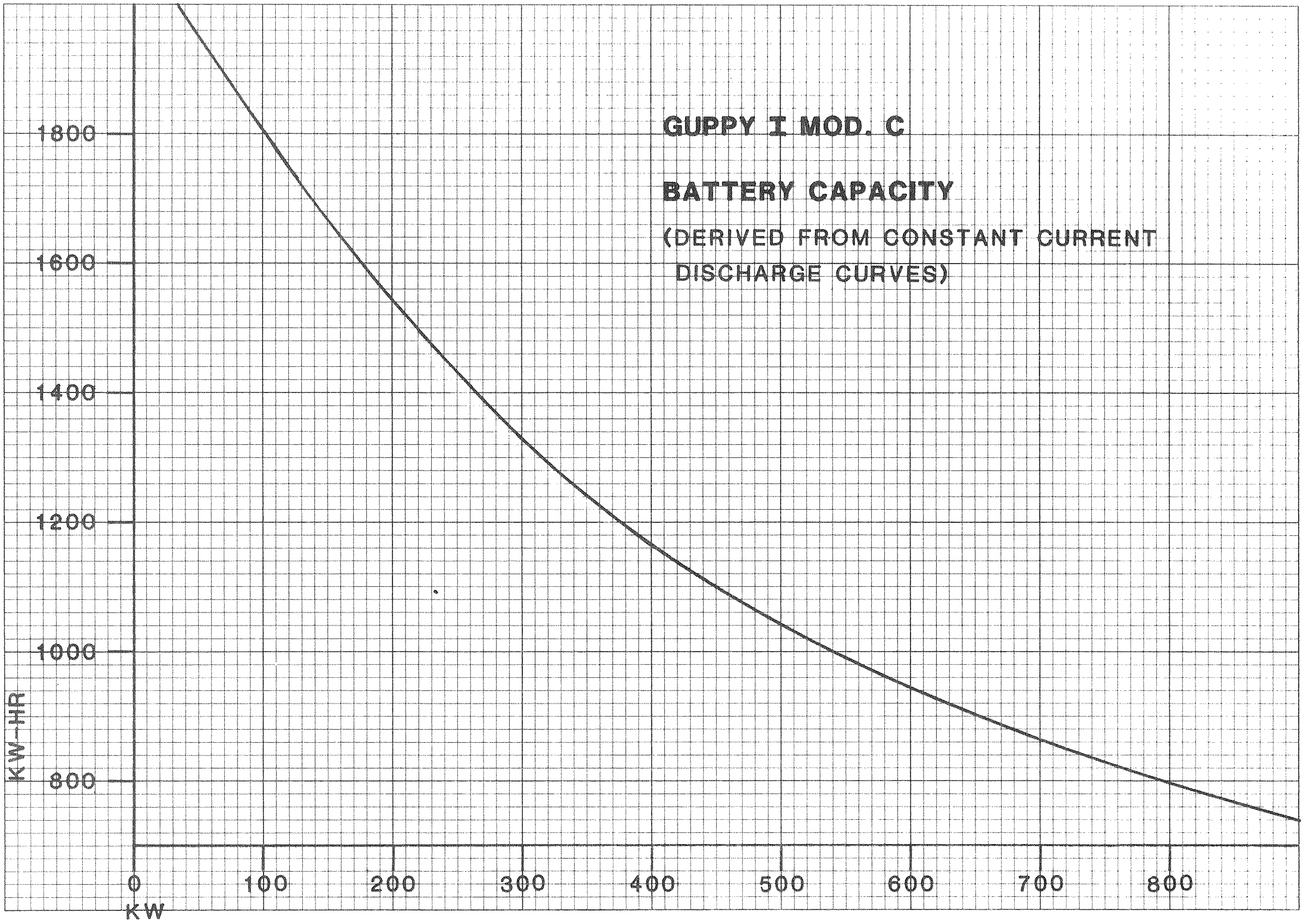
Step No. 6. Increase this value by 10 percent which gives a factor of 1.27.

Step No. 7. A proof by the iterative method as described in paragraph 313-1-h.3. and example No. 3 or No. 4 should be made. For this proof, the power in each period must be divided by the factor 1.27 before using the GUPPY I, Mod C curves, and one period should be set as the indeterminate period.

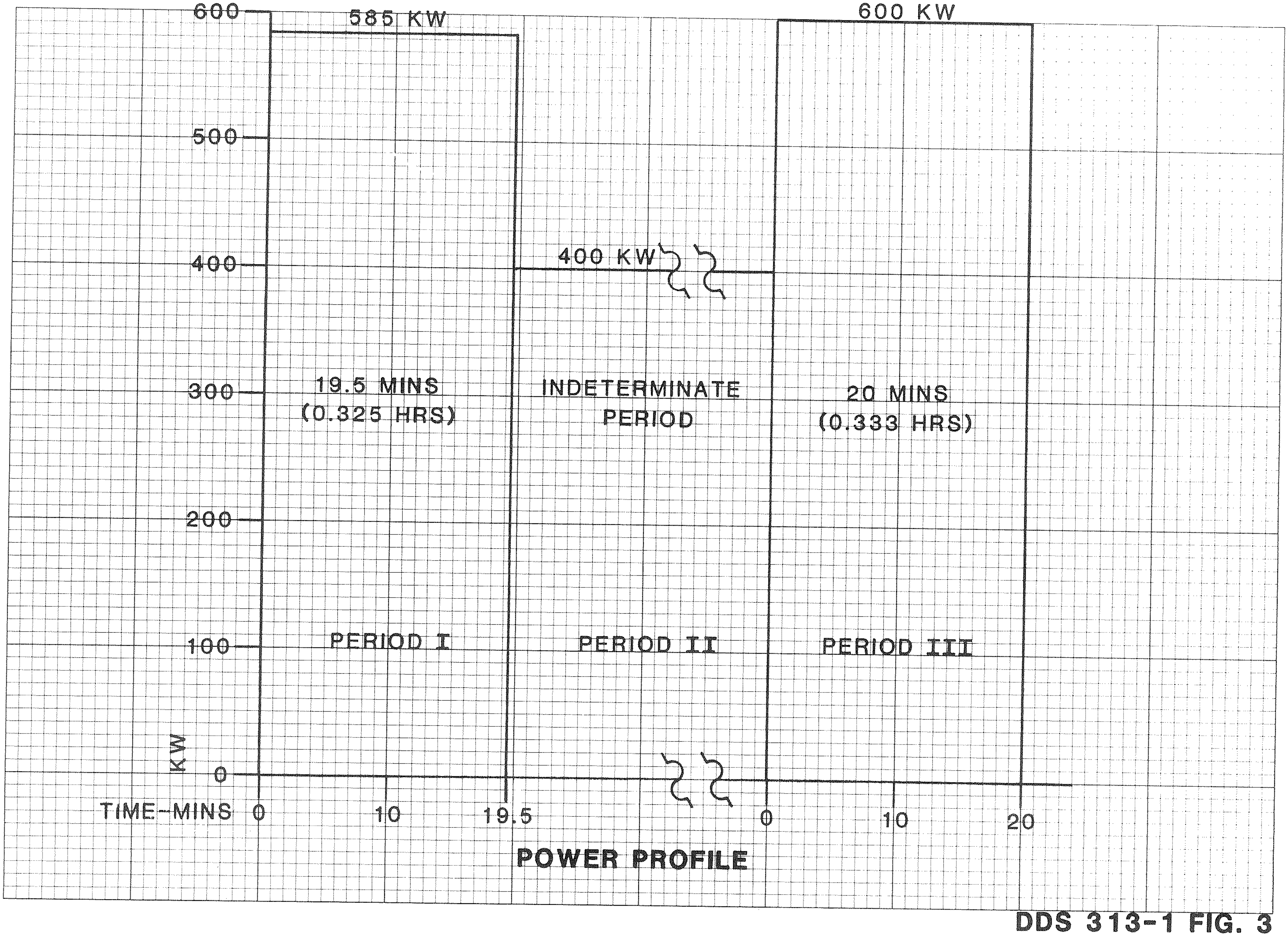
Step No. 8. If the time available for the indeterminate period as determined by Step No. 7 is substantially less than or greater than the defined time for that period increase or decrease the factor 1.27 as appropriate and recalculate by the iterative method using the new adjusted power profile. Repeat the process to the accuracy desired. (Note: If many adjustments are necessary Step No. 8 should be attempted only if the Battery Endurance Calculation Computer Program described in 313-1-h-3.d is available).



DDS 313-1 FIG.1

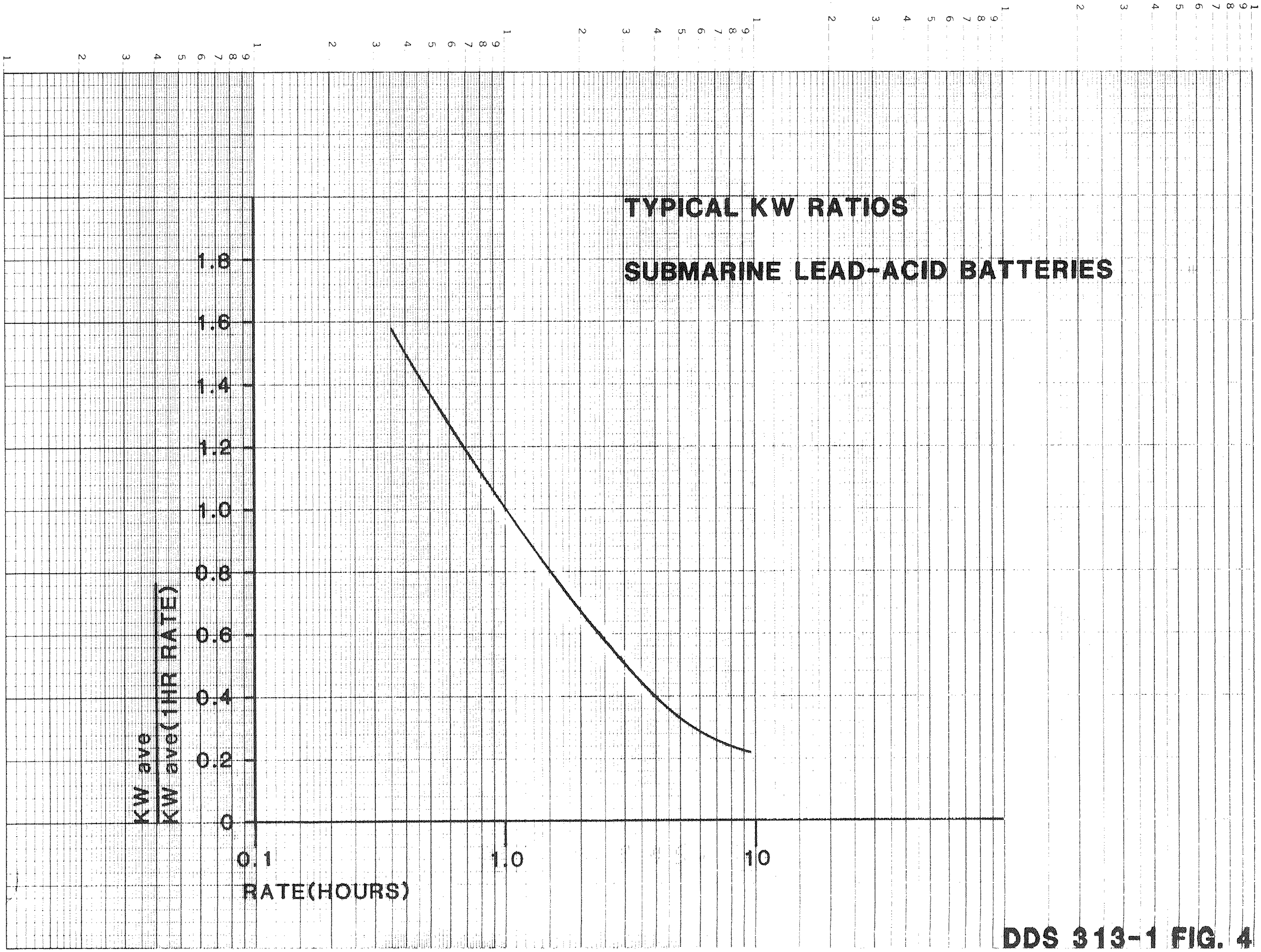


DDS 313-1 FIG. 2



POWER PROFILE

DDS 313-1 FIG. 3



TYPICAL KW RATIOS

SUBMARINE LEAD-ACID BATTERIES

DDS 313-1 FIG. 4

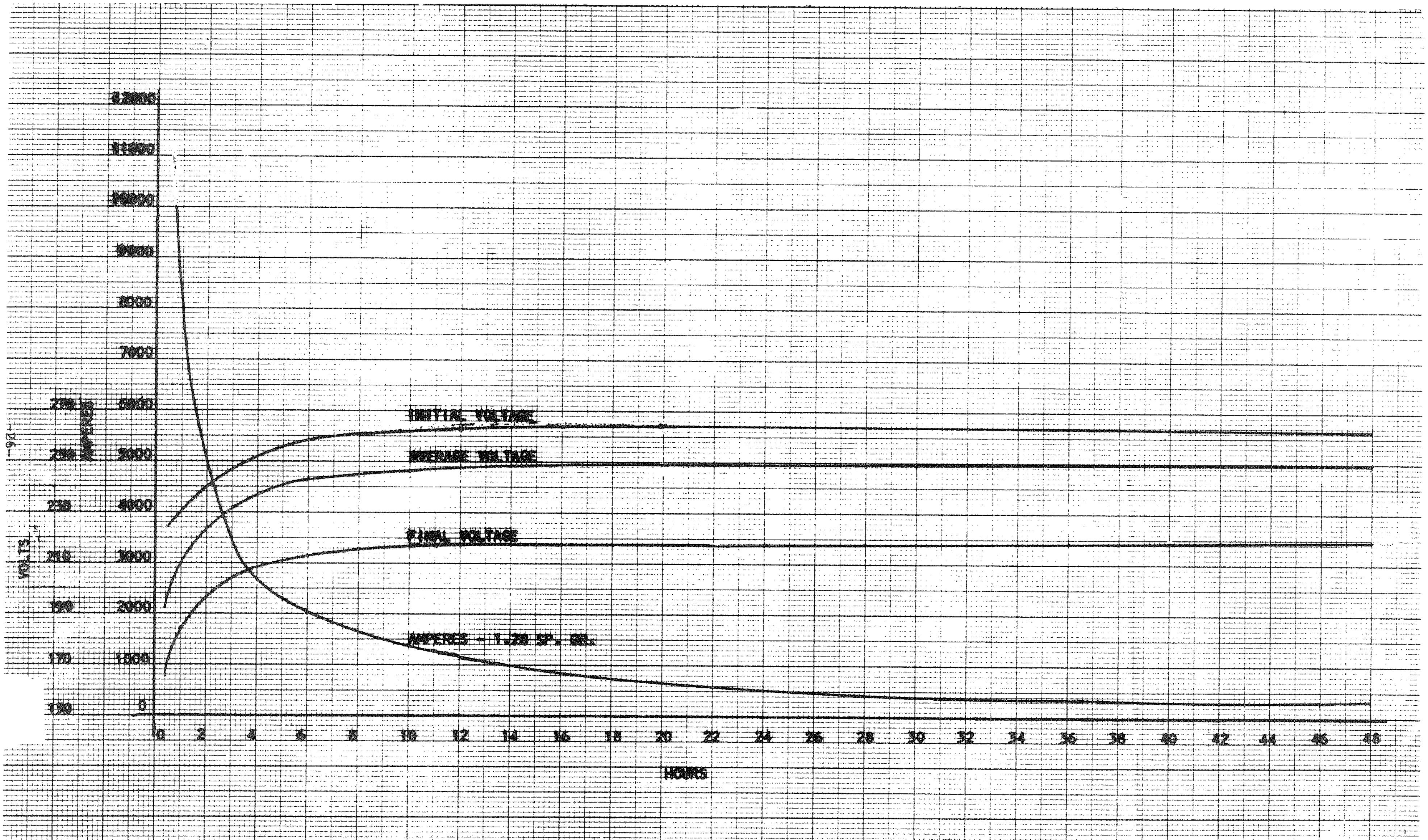


FIGURE 5. C & D SCC-57 BATTERY CHARACTERISTICS CURVES