INL/EXT-06-11848

Validation of HPPCALC

Jeffrey R. Belt

October 2006

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/EXT-06-11848

Validation of HPPCALC

Jeffrey R. Belt

October 2006

Idaho National Laboratory
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Abstract

HPPCALC 2.1 was developed to analyze the raw data from a PNGV Hybrid Pulse Power Characterization (HPPC) test and produce seven standard plots that consist of resistance, power and available energy relationships. The purpose of the HPPC test is to extrapolate the total power capability within predetermined voltage limits of a prototype or full production cell regardless of chemistry with respect to the PNGV goals as outlined in the PNGV Testing Manual, Revision 3. The power capability gives the Electrochemical Energy Storage team the tools to compare different battery sizes and chemistries for possible use in a hybrid electric vehicle.

The visual basic program HPPCALC 2.1 opens the comma separated value file that is produced from a Maccor, Bitrode, or Energy Systems tester. It extracts the necessary information and performs the appropriate calculations. This information is arranged into seven graphs: Resistance versus Depth of Discharge, Power versus Depth of Discharge, Power versus Energy, Energy versus Power, Available Energy versus Power, Available Energy versus Power, and Power versus Depth of Discharge. These are the standard plots that are produced for each HPPC test.

The primary metric for the HPPC test is the PNGV power, which is the power at which the available energy is equal to 300 Wh. The PNGV power is used to monitor the power degradation of the battery over the course of cycle or calendar life testing.

General Information for HPPCALC-XL Version 2.1

Program Installation & Setup

HPPCALC-XL runs under Windows 95, Windows 98, Windows NT, and Windows 2000. It will not run under earlier versions of Windows.

To install the program, run SETUP.EXE (from the installation floppy disk or CDROM, whichever is provided) and follow the prompts. This can be done just as other Windows programs are installed, either by using the RUN command on the Start Menu or by double-clicking on SETUP.EXE in a Windows Explorer window. The default installation directory for the program is \Program Files\HPPCALC-XL. This directory can be changed by the user during installation.

The first time the program is installed on a given computer, the installation routine may need to update some Windows system files. If this happens, the SETUP program will need to be restarted by the user after these files are updated. (No undesirable side effects have been noted from updating these files on a number of computers, but it is not possible to test all possible configurations.)

Uninstalling the Program

The program can be uninstalled in the same fashion as other well-behaved Windows programs, by opening the Windows Control Panel and using the Add/Remove Programs option. Note that it treats all required Windows system files as shared files, so these will not be removed if they have been installed previously by some other program. If there are results files generated by the program which are still in the program directory, neither these nor the directory can be removed by Windows; the user must delete these files manually.

Starting the Program

HPPCALC-XL will be installed on your Windows Start Menu as "INEEL HPPC Calculation Program". It can also be started by double-clicking on HPPCALC-XL. EXE in an Explorer window. Note that several files other than HPPCALC-XL.EXE are installed in the program directory. These files must remain in the same directory as the executable program file in order for the program to work properly.

Description of Program Operation During Use

1. A title screen with the program name and INEEL logo will appear when the program starts. If you click on this screen, the program will continue immediately; otherwise program execution continues after about 6 seconds. See Appendix A

2. A file selection menu will be displayed. Choose an HPPC data file to be processed, by navigating through the directory structure if necessary and clicking on the selected file. (If this data file is in UNIX text file format without DOS-type line delimiters, there will be a short delay while the program creates a temporary file with line delimiters. This temporary file will be deleted after the program has finished with it.)

3. A User Input form with several sections will be displayed, See Appendix B. The name of the selected input data file is displayed for information. The allowed or required user choices are as follows:

    a. Select Data File Type (MANDATORY) – select one of the available choices. For Version 2.1, these include the following types of comma-separated-value (CSV) files:

1. "*ADAPT complete data file*" – these are files which have been downloaded from the links provided in the INEEL ADAPT data file archive system from the corresponding individual data file pages.
2. "*Downloaded ADAPT .CSV file*" – these are files which have been downloaded from the INEEL ADAPT screen which allows selecting individual variables. These files must include all the variables shown in the ADAPT variable list down to "Mode", EXCEPT for the "record number." (Note that these are commonly in UNIX text file format.)
3. "*Maccor raw data file*" – these are text (not binary) files which are produced as direct output from Maccor cell testers. They can be obtained either directly from the test laboratory or by downloading them from the ADAPT "tote sheet" pages for the cell or battery of interest.
4. "*Bitrode .CSV file*" -- these are raw data files in CSV format which are produced by the INEEL Bitrode module testers.
5. "*Energy Systems*" -- these are raw data files in CSV format which are produced by the INEEL Energy Systems testers.

Because these file types are generally specific to particular types of INEEL testers, Option (3) is the only one of these choices which is likely to be useable by non-INEEL users at this time. For the convenience of potential users who only wish to see how this program works, a few sample data files of types (1) and (3) have been provided on the installation disk. These are non-proprietary data files derived from DOE-sponsored testing, i.e., they are NOT Protected Battery Information.

b. Select Battery Type (MANDATORY) – select one of the available choices which describes the type of cell or battery whose HPPC data is being analyzed. Selection is done by simply clicking on a given line so that it is highlighted. The purpose for this selection is to determine the minimum and maximum voltage to be used for calculations. Additionally, the type of cell or battery is automatically included in the title for each of the seven output graphs.

   If the data file is not an instance of any of the available choices, the user must exit the program and add an appropriate description and minimum and maximum voltage to the text file MAXVOLTS.DAT, which is installed in the same directory with the program. When this modified file has been saved, the new entry will appear in the list box the next time the program is run. (For Version 2.1, this text file is limited to a total of 50 battery types.)

c. Short Description or Comment (OPTIONAL) – can be typed in the text box provided. This text will then be saved with the calculation results for user information. Note that the program will automatically save the name of the file processed, the data and time processed, and a number of parameter values such as the max and min voltages used for calculations. This short description is added in parenthesis to the chart title for all seven output graphs.

d. After these selections are made, clicking on "Proceed" allows the program to continue processing the data file. Clicking on "Cancel" instead will terminate the program execution.

e. The button labeled "Display Data File Viewer" will bring up a simple text viewer showing the first few (typically 100 to 200) lines in the selected data file. The file can be paged through using "Next" and "Previous" buttons. This viewer must be closed before returning to the user input form, because the data file is open while the text is displayed. Note that the viewer actually displays blocks of 10,000 characters, so the first and/or last lines displayed may be incomplete.

4. If program execution is successful, a "Calculations Completed" screen will appear. This screen initially has 4 visible buttons, as follows:

   a. "WRITE to Excel Spreadsheet" will copy the calculated results to an Excel 97 or 2000 spreadsheet template and save the resulting spreadsheet with the same name as the original data file and an "XLS" extension. The file will be saved in the directory where HPPCALC-XL is installed. (This choice was made so that the program can be run using data files on CD-ROM disks or other read-only devices.)
   b. "WRITE to Text File" will save the calculated results to a text file with the same name as the original data file and a "TXT" extension. The file will be saved in the directory where HPPCALC-XL is installed. The file will be in CSV format (with quoted strings) so that it can be manually loaded into a spreadsheet if desired.
   c. "QUIT" will exit the program. If the results have not yet been saved either as a spreadsheet or a text file, the user will be asked to confirm this choice.
   d. "Process ANOTHER FILE" will return to the data file selection screen, where the user can choose another file to be processed. If the results have not yet been saved, the user will be asked to confirm this choice.
   e. If the data is saved to a spreadsheet, another button labelled "VIEW Excel Spreadsheet" will appear. Clicking this button will open a copy of Excel and display the spreadsheet which was just saved. This copy of Excel is not linked to the program, so it must/can be closed independently of HPPCALC-XL. Note that the spreadsheet will appear to contain only graphs of the calculated results; the numerical values calculated by the program are on a worksheet named "data" which is initially hidden. The unscaled the numerical values calculated by the program are on a worksheet named "unscaled data" which is initially hidden. The values extracted from the data, which can be used to verify the results of the program are on a worksheet named "lookup" which is initially hidden. This worksheet can be displayed if desired by using the Excel "Format/Sheet/Unhide" menu.

Data File Constraints & Requirements

Data files to be processed must conform to one of the defined formats described above. In addition, data files must generally contain at least one data record from the rest period just prior to the start of the HPPC discharge (i.e. C/1 discharge). This is primarily because the program uses this step as a flag to find the beginning of the test data (and to ignore all the unused header and data information which some data files contain.) If this initial data record prior to the start of discharge is not present, the data file can be manually edited before processing to add a dummy "Rest" record just before the first discharge step begins. Such a dummy record must contain the appropriate number of numeric values, separated by commas, up to and including units for the temperature "C". The numeric values can be all zeroes.

Additional data file formats could be added to the program if needed. However, this will require re-compiling and re-distributing the program. While it might have been possible to generalize the program such that arbitrary data file formats could be either determined automatically or defined by the user, this was not considered cost-effective for Version 2.1 due to the high degree of program complexity required. The program generally assumes that the data was acquired in accordance with the PNGV Testing Manual. A few common procedural errors are detected and indicated to the user, specifically those resulting from premature termination of the HPPC test. Processing will generally continue in these cases, but the resulting output should be carefully inspected for non-sensible results, especially the final values for data files that terminate prematurely.

Note that data file formats, especially for the Maccor testers, have been subject to a number of revisions over time as the tester manufacturers modify their system software. The number and order of data file variables required for this program to operate correctly is based on software versions in use at INEEL as of August 1999.

Other Program Constraints & Requirements

Use of the "WRITE Excel Spreadsheet" and "VIEW Excel Spreadsheet" output options requires the user to have Excel 97 installed on his/her computer. The "WRITE to Text File" option can be used if the correct version of Excel is not available. The resulting CSV file should be able to be loaded into almost any spreadsheet program. In particular, if the file is loaded into Excel 97, it will produce a data worksheet which is identical to that produced by the Excel Write option. The resulting data can be graphed or otherwise manipulated as desired by the user.

If the "WRITE Excel Spreadsheet" option is used and a previous version of the output spreadsheet exists in the target directory, Excel will ask whether it should be overwritten. If the Excel output option is chosen when a copy of the output spreadsheet is already open in Excel, the program will fail. If Excel is already open with a different spreadsheet, the "VIEW" option will open in another window of this existing copy of Excel.

The program does not check for available disk space, and it overwrites any previous versions of output text files without warning. It will not modify or overwrite any input data files (unless these are deliberately given .TXT extensions and stored in the same directory as the program executable, which is highly unlikely.)

As noted previously, output files are written to the directory where the program is installed (normally C:\Program Files\HPPCALC-XL, unless this is changed by the user during installation.) This prevents running the program directly from a CD-ROM drive, although the data files to be processed can be on such a drive. (This limitation could possibly be removed in future versions at the expense of some program complexity.)

Information Regarding Program Calculations

In general the calculations made by this program are intended to be a direct implementation of the corresponding equations and methods defined in Revision 2 of the PNGV Testing Manual. Any observed deviations should be reported to the author, Jeffrey R. Belt at beltjr@inel.gov, or to the INEEL program manager Chester Motloch at motlcg@inel.gov.

The program makes a number of assumptions about the data files in order to avoid having the user supply information manually. In particular, it assumes that the PNGV HPPC test procedure has been strictly followed, including the use of 10% DOD discharge intervals (including the pulse profiles). However, it will adjust if a different discharge interval is actually used. The capacity removed during the initial C/1 discharge period is assumed to be 10% DOD, and all succeeding DOD calculations are based on this value. This assumption is made because the total capacity removed is not normally accumulated in INEEL HPPC data files, i.e., the A-h variable is typically reset at the end of each 10% DOD interval.

The use of 18s discharge pulses and 2s initial regen pulses is required, and data must be available at about these times in each profile. If a data point is available at about 2s into the discharge pulse, the program also calculates the 2s discharge resistances and power capability; however, this is not mandatory. All pulse data points are ignored except those used for the calculations, i.e., those immediately prior to the start of discharge and regen pulses and the 2s and 18s (discharge only) points during the discharge and first regen pulse in each test profile. The resistances are calculated at 12 seconds during discharge and 10 seconds for the regen for dual mode applications.

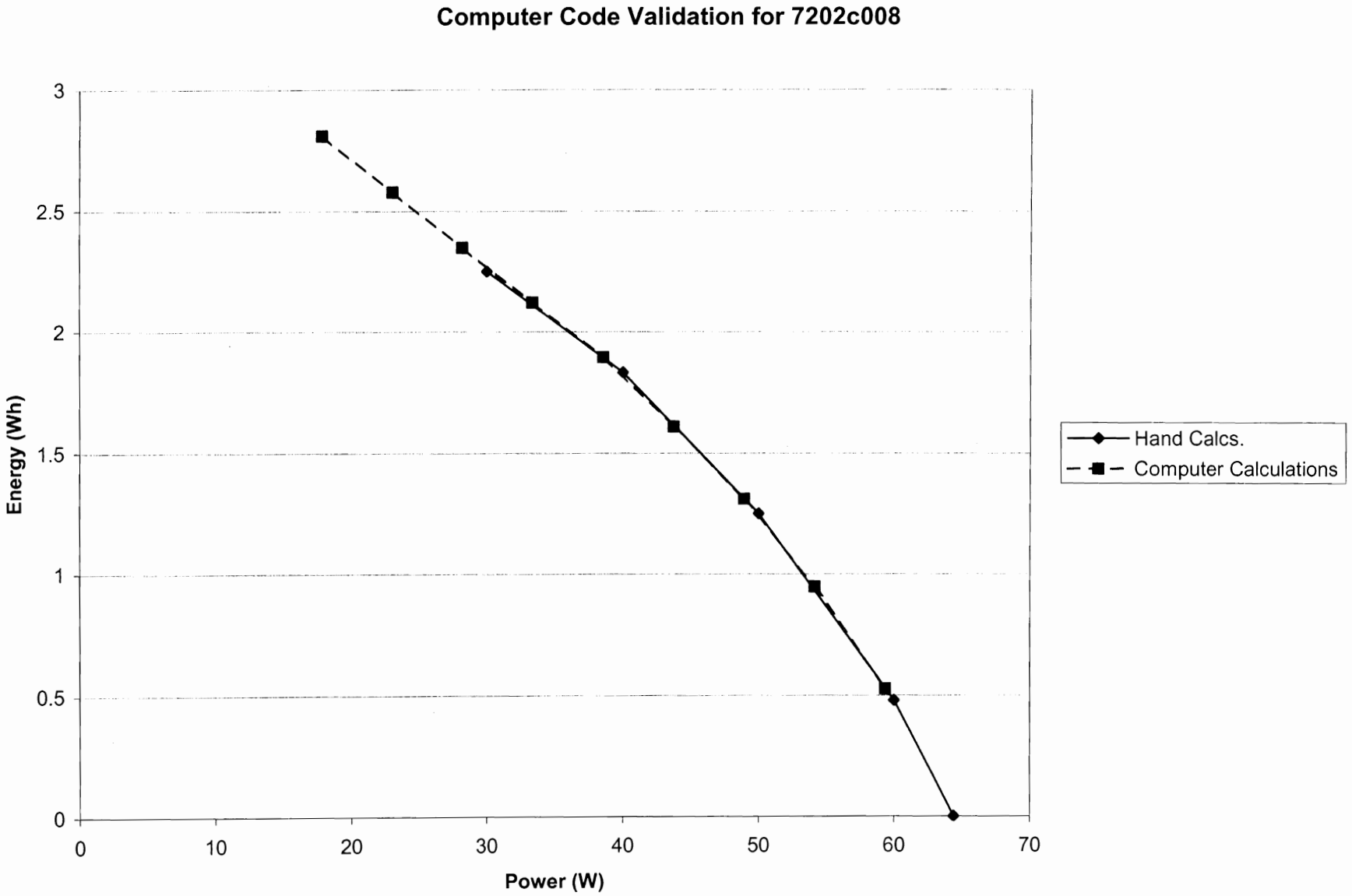
The program verifies only the length of the pulses; it does not verify the shape of the pulse profile, nor does it verify that current is constant during the pulses. This allows it to be used with HPPC data files based on either the current-step or power-step versions of the HPPC test profile (Power Assist or Dual Mode versions). However, this means that it may calculate resistances and power capabilities for pulses where voltage limiting occurs. Strictly speaking, these calculated results are not 'correct'. The data points where this condition has been observed to date generally do not deviate excessively from the normal resistance and power curves, but the user should be aware of this behavior.

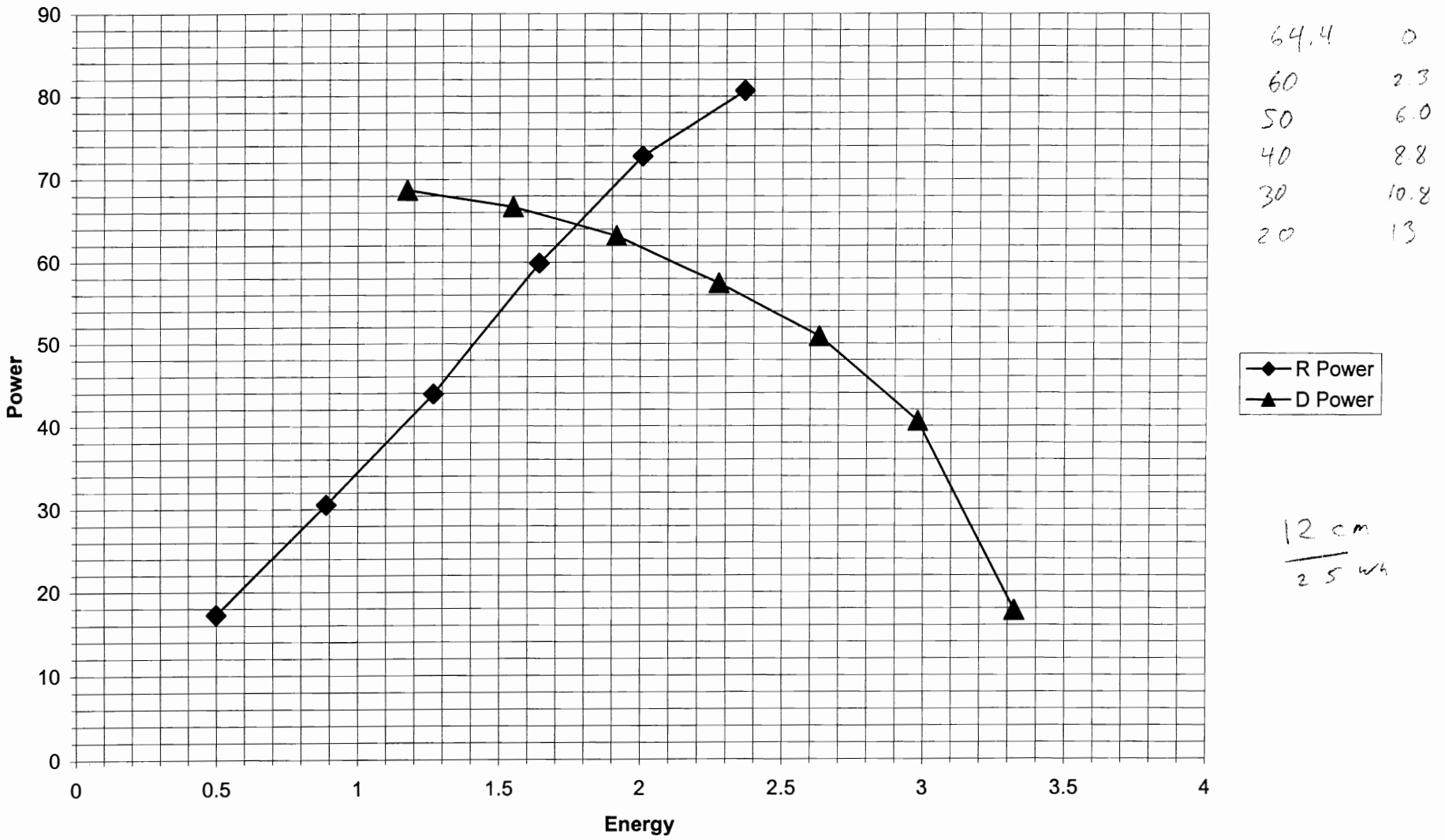
Pulse power capabilities are calculated according to the PNGV Testing Manual formulas, using local linearly interpolated OCV values for regen power capability. ("Local linear interpolation" refers to the use of the OCV values for the previous and next discharge pulses in the test sequence.) If regen data points exist at higher DOD values than the last discharge OCV point, the last 2 discharge OCV points will be extrapolated. In both this case and the available energy calculations discussed below, such extrapolation can result in the calculated values differing significantly from the "best fit". However, these generally occur at the extremes of DOD where the cell behavior is both less critical and not so well characterized due to other limitations of the HPPC test.

Available energy is calculated as the difference between the discharge and regen energy vs power curves, with values linearly interpolated between the points of both curves (i.e., no polynomial or other curve-fitting is used.) See Appendix E of Revision 3 of the PNGV Testing Manual for more information on this calculation. Available Energy calculations are done for both Power Assist and Dual Mode regen-to-discharge power targets. The available energy calculations are only performed over a power range whose upper limit is the Pulse Power Limit (where Available Energy goes to zero) and whose lower limit is the last useable data point on the discharge or regen curves (whichever is higher). This means that the program does not extrapolate Available Energy outside the HPPC data points (although it will extrapolate the curves to find the corresponding Pulse Power Limit.) This limitation can occasionally result in Available Energy being calculated over a very small range of power values, or in extreme cases not at all.

The Pulse Power Limit (a single-value metric of pulse power capability) is calculated based on linear interpolation between points on both the discharge and regen power capability curves. Note that the Pulse Power Limit reported by the program is calculated using the actual regen power capability curve, i.e., it is effectively based on a regen-to-discharge power ratio of 1.0 rather than the 30/25 and 40/65 ratios used for Available Energy calculations. (However, the appropriate pulse power limit values based on scaled regen power requirements are used for calculating Available Energy.) Note that Pulse Power Limit does not relate directly to the PNGV program power goals. It is a reporting convenience which is used primarily for laboratory cells, which may be difficult or premature to scale to full-size batteries for comparison with the PNGV power and energy goals.

For cells that use a battery scaling factor, the PNGV pulse power is calculated. This value is the scaled power at which the available energy equals the PNGV energy goal, 300 Wh.


Computer Code Validation for 7202c008
Energy (Wh)
Power (W)
0
0.5
1
1.5
2
2.5
3
0
10
20
30
40
50
60
70
Hand Calcs.
Computer Calculations



64.4	0
60	2.3
50	6.0
40	8.8
30	10.8
20	13

12 cm / 25 m/s

HPPC Results file created by: Project1

Input File: 7202c008.002 59.11596 53.24059

Comment: P72 ATD Gen. 2 1 Ah LiIon Cell 02 () 70.93915 41.40935

Processing Date/Time: 2/23/2001 ######## 0.545686 1.365143

549.767 1098.786

10% DOD	Max V	Min V	Idis Final	PPL	% DODppl	Scaling Fa	PA PPL
0.100001	4.1	3	4.999619	66.71679	39.81802	0	64.54161
						435.9155	936.026

DOD	OCV	Rdis	Pdis	WHdis	Rdis2s	Pdis2s	Rdis12s	Pdis12s
0	4.099641							
10	4.008545	0.038209	79.18731	0.400725	0.023194	130.4508	0.033336	90.7624
20	3.91928	0.036925	74.68672	0.791936	0.022827	120.8169	0.032591	84.6198
30	3.848936	0.037081	68.68255	1.174542	0.022768	111.8581	0.0328	77.64699
40	3.761044	0.03424	66.68035	1.549182	0.021606	105.6714	0.030387	75.13531
50	3.682002	0.03238	63.18798	1.916051	0.02051	99.75412	0.028442	71.93486
60	3.627985	0.032809	57.42124	2.276631	0.020509	91.86044	0.028773	65.47677
69.99999	3.583429	0.034395	50.88758	2.631761	0.02112	82.87314	0.029932	58.47454
79.99999	3.52697	0.038973	40.56421	2.98159	0.022981	68.79211	0.033611	47.03597
89.99999	3.435264	0.073493	17.76754	3.32334	0.031711	41.1783	0.056424	23.14237

DOD	OCV (inter	Rregen	Pregen	WHregen	Rregen Du	Pregen Du	Vreginit
12.49807	3.986246	0.0225	20.72824	0.499338	0.031533	14.79062	3.967041
22.49891	3.901701	0.022177	36.66058	0.888292	0.031495	25.814	3.878843
32.49955	3.826967	0.02124	52.70411	1.268955	0.032308	34.64927	3.799802
42.49992	3.741284	0.020469	71.8518	1.641562	0.029055	50.6183	3.720455
52.50003	3.668498	0.020266	87.29893	2.006757	0.028241	62.64404	3.651789
62.50003	3.616846	0.020468	96.78207	2.365885	0.028403	69.74409	3.598993
72.50002	3.569314	0.021122	103.0105	2.719772	0.029587	73.53843	3.55108
82.50002	3.504043	0.023276	104.9773	3.067966	0.032147	76.00893	3.486534
92.50002	3.412337	0.029134	96.7748	3.406867	0.038818	72.63186	3.387198

Pwr 30	AE 30/25	Pwr 35	AE 35/45	Pdis 30/25	Pdis 35/45
17.76754	2.80953	23.14237	2.710774	17.27354	19.01651
22.96465	2.579367	28.65412	2.480678	30.55049	33.18943
28.16178	2.349204	34.16587	2.244658	43.92009	44.54906
33.35889	2.121352	39.67762	1.981124	59.8765	65.08067
38.55602	1.895467	45.18937	1.727426	72.74911	80.54233
43.75313	1.609325	50.70111	1.488895	80.65172	89.67097
48.95025	1.310994	56.21286	1.220301	85.84206	94.54941
54.14737	0.9468	61.72461	0.886272	87.48109	97.72577
59.34449	0.527236	67.23636	0.485908	80.64567	93.38382
64.54161		72.74811	0.000166		

HPPC Results file created by: Project1

Input File: 7202c008.002

Comment: P72 ATD Gen. 2 1 Ah LiIon Cell 02 ()

Processing Date/Time: 02/23/01 8:03 PM

	Assist	Dual
Pdis Goal	59.116	53.241
Preg Goal	70.939	41.409
E Goal	0.546	1.365
# Cells	549.767	1098.786

10% DOD	Max V	Min V	Idis Final	PPL	% DODppl	Scaling Fa	PA PPL
0.100001	4.10	3.00	4.999619	66.71679	39.81802	550.0	64.54161
						435.916	936.026

DOD	OCV	Rdis	Pdis	WHdis	Rdis2s	Pdis2s	Rdis12s	Pdis12s
0	4.0996							
10	4.008545	0.038209	43553.02	220.3989	0.023194	130.4508	0.033336	49919.32
20	3.91928	0.036925	41077.7	435.5647	0.022827	120.8169	0.032591	46540.89
30	3.848936	0.037081	37775.4	645.998	0.022768	111.8581	0.0328	42705.84
40	3.761044	0.03424	36674.19	852.05	0.021606	105.6714	0.030387	41324.42
50	3.682002	0.03238	34753.39	1053.828	0.02051	99.75412	0.028442	39564.17
60	3.627985	0.032809	31581.68	1252.147	0.020509	91.86044	0.028773	36012.22
69.99999	3.583429	0.034395	27988.17	1447.469	0.02112	82.87314	0.029932	32161
79.99999	3.52697	0.038973	22310.32	1639.874	0.022981	68.79211	0.033611	25869.78
89.99999	3.435264	0.073493	9772.145	1827.837	0.031711	41.1783	0.056424	12728.3

DOD	OCV (inter	Rregen	Pregen	WHregen	Rregen Du	Pregen Du	Vreginit
12.49807	3.986246	0.0225	11400.53	274.6361	0.031533	8134.839	3.967041
22.49891	3.901701	0.022177	20163.32	488.5606	0.031495	14197.7	3.878843
32.49955	3.826967	0.02124	28987.26	697.9255	0.032308	19057.1	3.799802
42.49992	3.741284	0.020469	39518.49	902.8591	0.029055	27840.06	3.720455
52.50003	3.668498	0.020266	48014.41	1103.716	0.028241	34454.22	3.651789
62.50003	3.616846	0.020468	53230.14	1301.237	0.028403	38359.25	3.598993
72.50002	3.569314	0.021122	56655.76	1495.874	0.029587	40446.14	3.55108
82.50002	3.504043	0.023276	57737.52	1687.381	0.032147	41804.91	3.486534
92.50002	3.412337	0.029134	53226.14	1873.777	0.038818	39947.52	3.387198

Pwr 30	AE 30/25	Pwr 35	AE 35/45	Pdis 30/25	Pdis 35/45
9772.145	1545.241	12728.3	1490.926	9500.445	10459.08
12630.56	1418.652	15759.77	1364.373	16802.77	18254.19
15488.98	1292.062	18791.23	1234.562	24156.05	24501.99
18347.39	1166.744	21822.69	1089.618	32932.07	35794.37
21205.81	1042.507	24854.15	950.0844	40012.01	44298.28
24064.22	885.1287	27885.61	818.8923	44358.45	49319.03
26922.64	721.0464	30917.07	671.1655	47213.14	52002.18
29781.05	520.7402	33948.54	487.4494	48114.6	53749.17
32639.47	289.9799	36980	267.2495	44355.12	51361.1
35497.89		40011.46	0.091136		

DisVolt 0	DisAmp0	DisVolt1	DisAmp1	RegVolt0	RegAmp0	RegVolt1	RegAmp1	StepWh	DisWh
4.008545		3.817502	5	3.967041		4.051423	3.750286	0.400725	0.096301
3.91928		3.734646	5.000191	3.878843		3.962005	3.749905	0.791936	0.09419
3.848936		3.663538	4.999809	3.799802		3.879454	3.750095	1.174542	0.092442
3.761044		3.589838	5.000191	3.720455		3.797208	3.749714	1.549182	0.090527
3.682002		3.520104	5	3.651789		3.727779	3.749714	1.916051	0.088751
3.627985		3.463951	4.999619	3.598993		3.675746	3.749905	2.276631	0.087378
3.583429		3.411459	4.999809	3.55108		3.630274	3.749332	2.631761	0.086134
3.52697		3.332113	4.999809	3.486534		3.573816	3.749905	2.98159	0.08433
3.435264		3.067826	4.999619	3.387198		3.496452	3.750095	3.32334	0.079652

PGoal302	EGoal302	PGoal404	EGoal4040					
4437.236	40.9591	5001.433	128.2419	25000	0	0	300	
8874.472	81.9182	10002.87	256.4837	25000	1545.241	35497.89	300	
13311.71	122.8773	15004.3	384.7256					
17748.94	163.8364	20005.73	512.9674					
22186.18	204.7955	25007.16	641.2093					
26623.42	245.7546	30008.59	769.4512					
31060.65	286.7137	35010.03	897.693					
35497.89	327.6729	40011.46	1025.935					

DisVolts1	DisAmps1	DisV12sec	DisA12sec	RegV1Dua	RegA1Dua	regV2Dual	regA2Dual	stepAh	disAH
4.008545		3.838102	5.112917	3.967041		4.085298	3.749332	0.100001	0.024981
3.91928		3.752651	5.112726	3.878843		3.996948	3.749714	0.200002	0.024989
3.848936		3.681239	5.112726	3.799802		3.920958	3.750095	0.300004	0.024996
3.761044		3.605707	5.111963	3.720455		3.829404	3.749714	0.400005	0.024999
3.682002		3.536583	5.112726	3.651789		3.757687	3.749714	0.500006	0.025001
3.627985		3.480888	5.112345	3.598993		3.705501	3.750286	0.600007	0.025001
3.583429		3.430381	5.113108	3.55108		3.662013	3.749523	0.700008	0.025001
3.52697		3.355154	5.111963	3.486534		3.60708	3.749523	0.800009	0.025001
3.435264		3.146868	5.1112	3.387198		3.532769	3.749714	0.900011	0.025001

.497026

.886126

1.266984

1.639709

2.004803

2.364009

2.717895

3.065919

3.402992

Verification of Calculations for HPPCALC

Filename: 7202c008.002

Output Filename: 7202c008PA 6 sig digs

$R_{Dis,10\%} = \frac{(4.008545 - 3.817502)}{(0 - 5)} = 0.0382086$ ✓

$R_{Dis,20\%} = \frac{(3.91928 - 3.734646)}{(0 - 5.000191)} = 0.0369254$ ✓

$R_{Dis,30\%} = \frac{(3.848936 - 3.663538)}{(0 - 4.999809)} = 0.0370810$ ✓

$R_{Dis,40\%} = \frac{(3.761044 - 3.589838)}{(0 - 5.000191)} = 0.0342399$ ✓

$R_{Dis,50\%} = \frac{(3.682002 - 3.520104)}{(0 - 5)} = 0.0323796$ ✓

$R_{Dis,60\%} = \frac{(3.627985 - 3.463951)}{(0 - 4.999619)} = 0.0328093$ ✓

$R_{Dis,70\%} = \frac{(3.583429 - 3.411459)}{(0 - 4.999809)} = 0.0343953$ ✓

$R_{Dis,80\%} = \frac{(3.52697 - 3.332113)}{(0 - 4.999809)} = 0.0389729$ ✓

$R_{Dis,90\%} = \frac{(3.435264 - 3.067826)}{0 - 4.999619} = 0.0734932$ ✓

$R_{reg,10\%} = (3.967040 - 4.051423) / (0 - 3.750286) = 0.02250042$

$R_{reg,20\%} = (3.878843 - 3.962005) / (0 - 3.749905) = 0.02217710$

$R_{reg,30\%} = (3.799802 - 3.879454) / (0 - 3.750095) = 0.02124000$

$R_{reg,40\%} = (3.720455 - 3.797208) / (0 - 3.749714) = 0.02046903$

$R_{reg,50\%} = (3.651789 - 3.727779) / (0 - 3.749714) = 0.02026555$

$R_{reg,60\%} = (3.598993 - 3.675746) / (0 - 3.749905) = 0.02046799$

$R_{reg,70\%} = (3.55108 - 3.630274) / (0 - 3.749332) = 0.02112216$

$R_{reg,80\%} = (3.486534 - 3.573816) / (0 - 3.749905) = 0.02327579$

$R_{reg,90\%} = (3.387198 - 3.496452) / (0 - 3.750095) = 0.02913366$

	Dis Ah	10% Discharge	Step Ah
		0.1	
1st Pulse –	0.024981	0.1	0.1
2nd " –	0.024989	0.1	0.2
3rd " –	0.024996	0.1	0.3
4th " –	0.024999	0.1	0.4
5th " –	0.025001	0.1	0.5
6th " –	0.025001	0.1	0.6
7th " –	0.025001	0.1	0.7
8th " –	0.025001	0.1	0.8
9th " –	0.025001	0.1	0.9

Regen Pulse	Energy / Ah		Ah1	Ah2	Wh1	Wh2
No. 1	0.124981	Ah	0.122233	0.125011	0.488668	0.499598
2	0.224989	"	0.222237	0.225015	0.877792	0.888482
3	0.324996	"	0.322241	0.325018	1.25869	1.269154
4	0.424999	"	0.422244	0.425022	1.63148	1.641725
5	0.525001	"	0.522248	0.525026	1.996865	2.00692
6	0.625001	"	0.622252	0.62503	2.356126	2.366029
7	0.725001	"	0.722256	0.725034	2.710184	2.719945
8	0.825001	"	0.82226	0.825038	3.058591	3.068166
9	0.925001	"	0.922263	0.925041	3.398034	3.407268

Interpolated Regen Voltages (for Power Calc.)

Pulse 10%: $\frac{4.008545 - 3.91928}{0.1 - 0.2} = \frac{4.008545 - X_{10}}{0.024981}$ $X_{10} = 3.986246$

20%: $\frac{3.91928 - 3.848936}{0.2 - 0.3} = \frac{3.91928 - X_{20}}{0.024989}$ $X_{20} = 3.901702$

30%: $\frac{3.848936 - 3.761044}{0.3 - 0.4} = \frac{3.848936 - X_{30}}{0.024996}$ $X_{30} = 3.826967$

40%: $\frac{3.761044 - 3.682002}{0.4 - 0.5} = \frac{3.761044 - X_{40}}{0.024999}$ $X_{40} = 3.741284$

50%: $\frac{3.682002 - 3.627985}{0.5 - 0.6} = \frac{3.682002 - X_{50}}{0.025001}$ $X_{50} = 3.668497$

60%: $\frac{3.627985 - 3.583429}{0.6 - 0.7} = \frac{3.627985 - X_{60}}{0.025001}$ $X_{60} = 3.6168456$

70%: $\frac{3.583429 - 3.52697}{0.7 - 0.8} = \frac{3.583429 - X_{70}}{0.025001}$ $X_{70} = 3.569314$

80%: $\frac{3.52697 - 3.435264}{0.8 - 0.9} = \frac{3.52697 - X_{80}}{0.025001}$ $X_{80} = 3.504043$

90%: $\frac{3.52697 - 3.435264}{0.8 - 0.9} = \frac{3.435264 - X_{90}}{0.025001}$ $X_{90} = 3.412337$

Regen Power $V_{min} = 3.0$ $V_{max} = 4.1$

Pulse 1: $4.1 (4.1 - 3.986246) / 0.02250042 = 20.72812$

2: $4.1 (4.1 - 3.901702) / 0.02217710 = 36.66042$

3: $4.1 (4.1 - 3.826967) / 0.0212400 = 52.70411$

4: $4.1 (4.1 - 3.741284) / 0.02046903 = 71.85175$

5: $4.1 (4.1 - 3.668497) / 0.02026555 = 87.29900$

6: $4.1 (4.1 - 3.6168456) / 0.02046799 = 96.78206$

7: $4.1 (4.1 - 3.569314) / 0.02112216 = 103.0109$

8: $4.1 (4.1 - 3.504043) / 0.02327579 = 104.97705$

9: $4.1 (4.1 - 3.412337) / 0.02913366 = 96.7753$

Discharge Power $V_{min} = 3.0$

Pulse 1: $3.0(4008545 - 3.0)/0.0382086 = 79.18728$

2: $3.0(3.91928 - 3.0)/0.0369254 = 74.68680$

3: $3.0(3848936 - 3.0)/0.0370810 = 68.68229$

4: $3.0(3.761044 - 3.0)/0.0342399 = 66.680452$

5: $3.0(3.682002 - 3.0)/0.0323796 = 63.18812$

6: $3.0(3.627985 - 3.0)/0.0328093 = 57.42137$

7: $3.0(3.583429 - 3.0)/0.0343953 = 50.88739$

8: $3.0(3.52697 - 3.0)/0.0389729 = 40.56434$

9: $3.0(3.435264 - 3.0)/0.0734932 = 17.76752$

Discharge Energy / Ah

		Ah1	Ah2	Wh1	Wh2
Pulse 1	0.1 Ah	0.100014	0.097232	0.400952	0.389953
2	0.2 "	0.197236	0.200014	0.781308	0.792054
3	0.3 "	0.29724	0.300018	1.164233	1.174753
4	0.4 "	0.397243	0.400021	1.539016	1.549313
5	0.5 "	0.497247	0.500025	1.906148	1.916247
6	0.6 "	0.597251	0.600029	2.266818	2.276757
7	0.7 "	0.697255	0.700033	2.622149	2.631947
8	0.8 "	0.797259	0.800037	2.972126	2.981757
9	0.9 "	0.897263	0.90004	3.314365	3.323708

Discharge energy

$$\frac{Wh2 - Wh1}{Ah2 - Ah1} = \frac{X - Wh1}{Ah_x - Ah1}$$

Pulse 1 $E_1 = 0.400917$

2 $E_2 = 0.792008$

3 $E_3 = 1.174702$

4 $E_4 = 1.549252$

5 $E_5 = 1.916177$

6 $E_6 = 2.276679$

7 $E_7 = 2.63186$

8 $E_8 = 2.981661$

$E_9 = 3.323609$

Regen Energy

Pulse 1	E =	0.499481
2	E =	0.888383
3	E =	1.269069
4	E =	1.641628
5	E =	2.006829
6	E =	2.365926
7	E =	2.71983
8	E =	3.068041
9	E =	3.407134

Regen Power curve $P = 8.12E^2 + 36E + 5.0476$

Discharge Power Curve $P = -8.0899E^4 + 64.774E^3 - 194.94E^2 + 247.7E - 42.992$

Available Energy (from Graph)

Energy	Power
0	644
0.479166	60
1.250	50
1.833	40
2.25	30
2.708	20

APPENDIX A

INEEL

INEEL EHV Program

HPPC Data File Processor

Windows 95/98/NT/2000

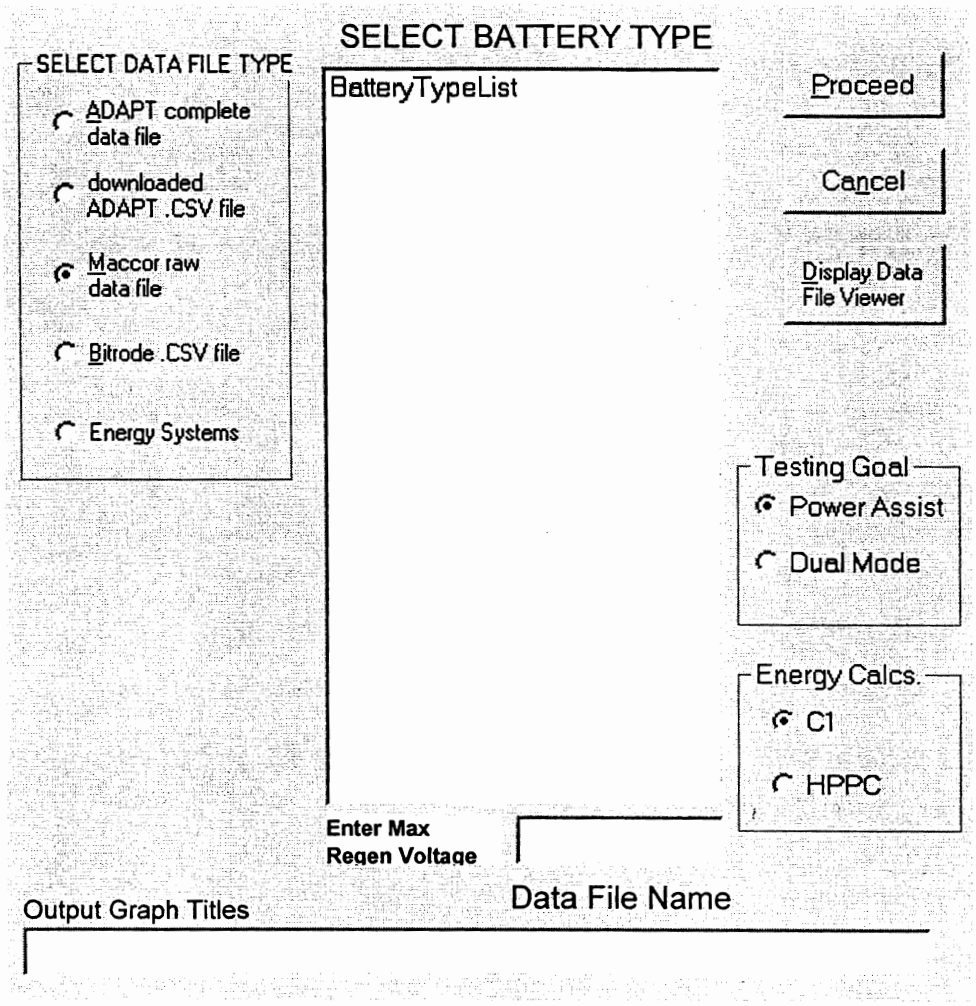
Version 2.1

March 2001

Jeffrey R. Belt
G. L. Hunt

Warning: Initial Release - Verify before reporting results from this program

APPENDIX B


SELECT BATTERY TYPE
SELECT DATA FILE TYPE
ADAPT complete data file
downloaded ADAPT .CSV file
Maccor raw data file
Bitrode .CSV file
Energy Systems
BatteryTypeList
Proceed
Cancel
Display Data File Viewer
Testing Goal
Power Assist
Dual Mode
Energy Calcs.
C1
HPPC
Enter Max Regen Voltage
Data File Name
Output Graph Titles

INEEL

INEEL EHV Program

HPPC Data File Processor

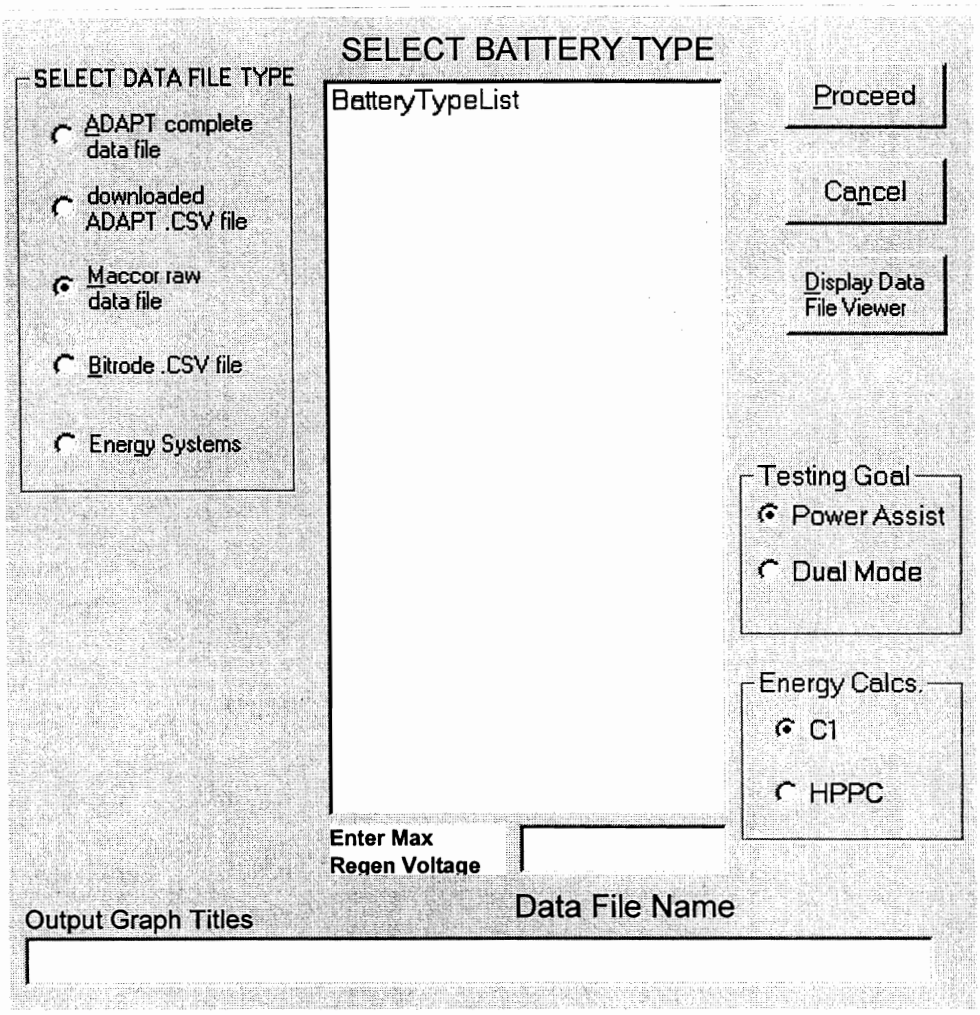
Windows 95/98/NT/2000

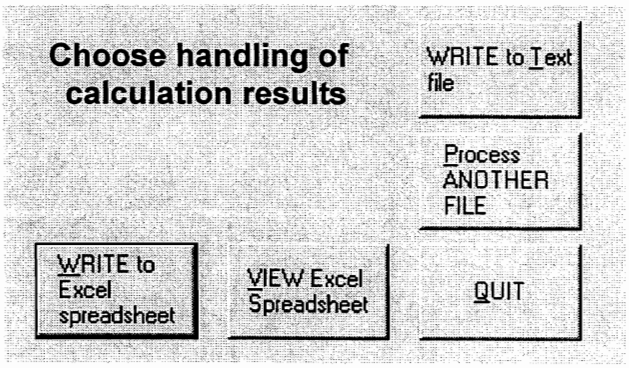
Version 2.1

March 2001

Jeffrey R. Belt
G. L. Hunt

Warning: Initial Release - Verify before reporting results from this program


SELECT BATTERY TYPE
SELECT DATA FILE TYPE
ADAPT complete data file
downloaded ADAPT .CSV file
Maccor raw data file
Bitrode .CSV file
Energy Systems
BatteryTypeList
Proceed
Cancel
Display Data File Viewer
Testing Goal
Power Assist
Dual Mode
Energy Calcs.
C1
HPPC
Enter Max Regen Voltage
Data File Name
Output Graph Titles


Choose handling of calculation results
WRITE to Text file
Process ANOTHER FILE
WRITE to Excel spreadsheet
VIEW Excel Spreadsheet
QUIT