

CANDU Fuel Burnup and Power Rating 2012 Update

NWMO TR-2013-02

February 2013

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AMEC NSS

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ABSTRACT

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Abstract

Burnups and maximum experienced powers for fuel bundles that have been discharged from Ontario Power Generation, Bruce Power, Hydro-Quebec, and New Brunswick Power reactors were extracted from all available digital archives. The data were statistically analyzed and plotted as frequency histograms.

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1. INTRODUCTION

Used fuel burnups and maximum power ratings are important parameters for deep geological disposal of spent fuel. They largely determine the inventory of radionuclides present in the fuel as well as the fraction of fission products that are able to migrate to the fuel gap and grain boundaries.

In 2006 an Ontario Power Generation report was issued that summarized the burnups and maximum (bundle) power ratings for CANDU fuel discharged from the Darlington, Pickering A & B, and Bruce A & B reactors during the period from 1970 to 2006 (Wilk & Cantello, 2006). The discharged fuel bundle data for each station's reactors were combined and plotted as frequency histograms of burnup and maximum power rating for the time periods 1970-1979, 1980-1989, 1990-1999 and 2000-2006. Also presented were the maximum, median, 90th, 95th and 99th percentile burnups and maximum power ratings for each station (for each time period), as well as the total number of bundles discharged from each reactor over the entire period (1970-2006).

The purpose of this work is to update the previous report by including more recent data for those reactors (2006-2012) as well as including all available data for Hydro-Quebec (Gentilly-2) and New Brunswick Power (Point Lepreau) reactors.

2. DATA EXTRACTION

For all Ontario Power Generation (OPG) and Bruce Power (BP) reactors, fuel bundle data were extracted via Unix and FORTRAN scripts from SORO's (Wilk, 2005) digital archives on the AMEC NSS Unix LAN. Burnup and power rating data are available from reactor start-up to 2012 for all OPG and Bruce Power reactors with the exception of Pickering A from 1973-1987. Care was taken to assess the effects of inter-unit recycling, whereby bundles discharged from one reactor are inserted into another one, and then discharged from that second reactor. Such bundles appear twice in SORO's discharged bundle records, and scans of the records (such as for this report) incorrectly double-count such bundles unless some complex data filtering is applied. Considering the relatively small number of such bundles (see Table 1) in comparison with the total number discharged from a station, the programming effort required to perform the required filtering was considered unwarranted. For example, by far the greatest number of inter-unit recycled bundles occurred for Bruce A, where 1504 bundles were inter-unit recycled, corresponding to an error of ~0.3% in the Bruce A histograms.

The bundle data provided by Hydro-Québec were contained in several files, each spanning a different period of operating history, with separate files for burnups and bundle serial numbers, bundle powers, and fuelling history. Bundle discharge dates were not included in the present study. Exit burnups were available for the period from 1983 (startup) to July 2012. However, the maximum experienced bundle powers were available only from September 2007 to July 2012. A PERL script was prepared to track bundle movements (by serial number) and to extract the available exit burnups and maximum bundle powers for the discharged bundles. Since the burnups had been provided in units of MWh/bundle, they were converted to MWh/kgU by dividing by the mean mass of uranium per bundle (19.2 kg, as provided by Hydro-Quebec staff).

The data files provided by New Brunswick Power for the Point Lepreau reactor included histories of bundle burnups, bundle powers, and refuelling operations. A Perl script was prepared to read the data and extract exit burnups and maximum experienced bundle power for all discharged bundles for which a complete history was available. This restricted the analysis to refuelling histories from 1994 to 2012 and excluded the years from start-up (1983) to 1993. Bundle discharge dates were not extracted for the present study.

3. DATA ANALYSIS

All extracted data were analyzed by a Matlab script that calculated some basic statistical parameters and generated histograms of exit burnup and maximum power rating.

Table 1 shows, for each station, the number of discharged bundles that contributed to the statistical analysis. Date ranges were not available for the Gentilly-2 and Point Lepreau bundles.

Table 2 shows the maximum, median, 90th percentile, 95th percentile, and 99th percentile burnups and power ratings for the data grouped by station and decade, as well as for the aggregate of all data (i.e. all stations together). Note that the partitioning of data by decade for Gentilly-2 and Point Lepreau bundles was not provided for this study.

Figures 1-8 and 9-16 show the histograms of exit burnup and maximum power rating, respectively. Figures 1 and 9 are for the aggregate of all data. They present the information by station for the entire time period.

Note that the histogram bin widths are 10 MWh/kgU for burnups and 10 kW for bundle powers. The MATLAB binning convention is to include a value that exceeds the left edge of the bin but is smaller than or equal to the right edge of the bin. The tick marks along the horizontal axis align with bin edges.

It should also be noted that all of the above discharge burnups and bundle power ratings are predicted (simulated) quantities based on various theoretical models and calculational tools. As such, they possess inherent uncertainties. OPG and Bruce Power have compliance allowances of about 5% for maximum bundle powers (across the core), but maximum bundle powers experienced by discharged bundles could be in error by more than that. Based on sensitivity to modelling details and expert opinion, bundle powers could be in error by up to 10%. SORO-predicted bundle burnups are expected to be, on average, more accurate than SORO-predicted bundle powers.

The data files that were used for preparing the tables and histograms have been written to a DVD and will be transmitted to NWMO along with this report. Each file contains a header that identifies the meanings of the data columns.

Table 1: Discharged Bundles Summary Data

Reactor	Start Date (yyyymmdd)	End Date (yyyymmdd)	Bundles Discharged	Inter-unit Recycled Bundles
Bruce A Unit 1	19770821	19980601	91690	1443
Bruce A Unit 2	19770210	20120513	78629	0
Bruce A Unit 3	19780507	20120827	133921	13
Bruce A Unit 4	19790510	20120812	127925	48
		Total	432165	1504
Bruce B Unit 5	19850708	20120828	148181	4
Bruce B Unit 6	19840913	20120828	147363	0
Bruce B Unit 7	19860625	20120828	140654	32
Bruce B Unit 8	19870730	20120827	134801	36
		Total	570999	72
		BP Total	1003164	
Pickering A Unit 1	19880524	20120826	39665	0
Pickering A Unit 2	19890611	20070528	24488	0
Pickering A Unit 3	19870106	20081013	26164	0
Pickering A Unit 4	19870107	20120826	37490	0
		Total	127807	0
Pickering B Unit 5	19830814	20120827	87318	0
Pickering B Unit 6	19840607	20120826	87460	0
Pickering B Unit 7	19850531	20120823	83628	0
Pickering B Unit 8	19860805	20120826	78093	0
		Total	336499	0
Darlington Unit 1	19910505	20120826	109381	8
Darlington Unit 2	19901031	20120828	110309	0
Darlington Unit 3	19930407	20120827	104657	65
Darlington Unit 4	19930926	20120826	102229	0
		Total	426576	73
		OPG Total	890882	
Gentilly-2 ¹		HQ Total	124392	
Point Lepreau ²		NBP Total	54840	
		Overall Total	2073278	

¹ The Gentilly-2 data spans the period 1983-2012.

² Point Lepreau data spans the period 1994-2012.

Table 2: Maximum, Median, and Percentiles for Burnups and Power Ratings

Reactor	Start of Decade	Burnup (MWh/kgU)					Bundle Power Rating (kW)				
		median	90th	95th	99th	max	median	90th	95th	99th	max
Bruce A	1970	133	231	248	279	355	566	740	771	811	876
	1980	203	259	270	296	706	703	836	861	898	1000
	1990	192	264	274	297	657	604	793	828	864	924
	2000	206	275	284	304	384	678	818	831	852	889
	2010	218	274	282	296	349	719	819	830	847	882
	all	195	263	275	297	706	658	820	843	884	1000
Bruce B	1980	179	215	229	268	492	670	732	746	769	810
	1990	190	216	224	251	407	633	711	727	750	811
	2000	190	218	226	244	435	633	677	688	706	765
	2010	189	220	228	252	452	652	695	703	718	768
	all	188	217	226	252	492	638	703	721	750	811
Pickering A	1980	198	233	247	289	518	499	587	610	654	741
	1990	204	267	286	318	521	556	647	661	683	758
	2000	198	265	278	294	434	554	639	654	671	703
	2010	210	276	285	297	348	564	640	652	669	691
	all	202	264	281	306	521	547	639	655	676	758
Pickering B	1980	188	218	228	249	479	550	623	639	668	738
	1990	193	225	236	259	595	554	621	636	662	726
	2000	190	225	235	253	548	547	603	615	633	678
	2010	195	229	237	253	466	548	607	619	639	681
	all	191	224	235	254	595	550	614	628	656	738
Darlington	1990	195	230	241	262	321	674	735	749	771	835
	2000	204	240	249	267	391	700	761	774	797	849
	2010	204	242	252	272	304	709	769	782	804	841
	all	201	237	247	267	391	690	755	770	794	849
Gentilly-2 ¹		174	212	226	244	346	653	804	830	859	919
Point Lepreau ²		170	211	228	248	321	653	782	805	839	1057
Aggregated		192	238	254	283	706	624	750	786	847	1057

¹ The Gentilly-2 exit burnups span 1983-2012, but the bundle powers span 2007-2012. See the text.

² Point Lepreau data spans the period 1994-2012.

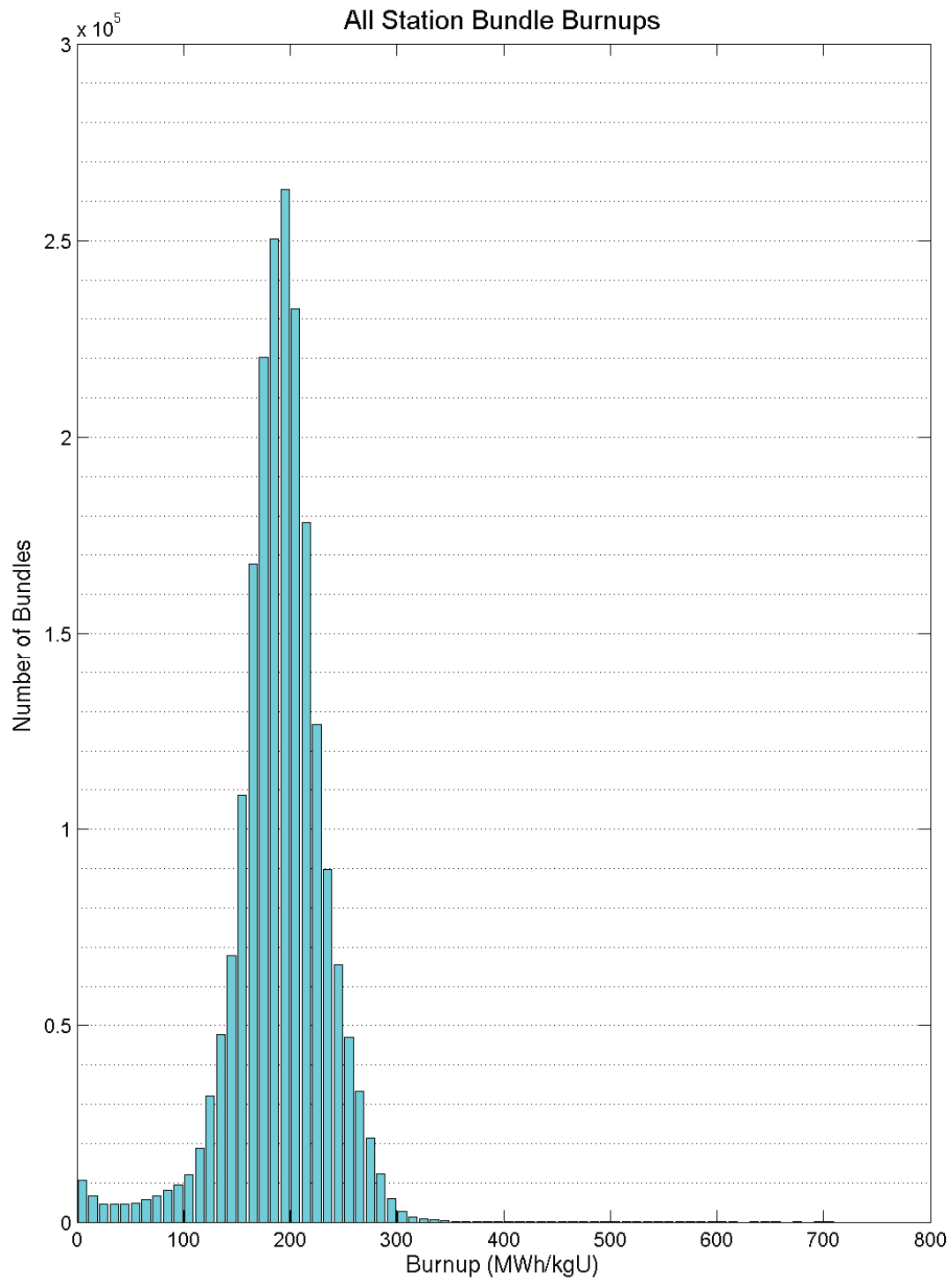


Figure 1: Bundle Burnups for All Stations

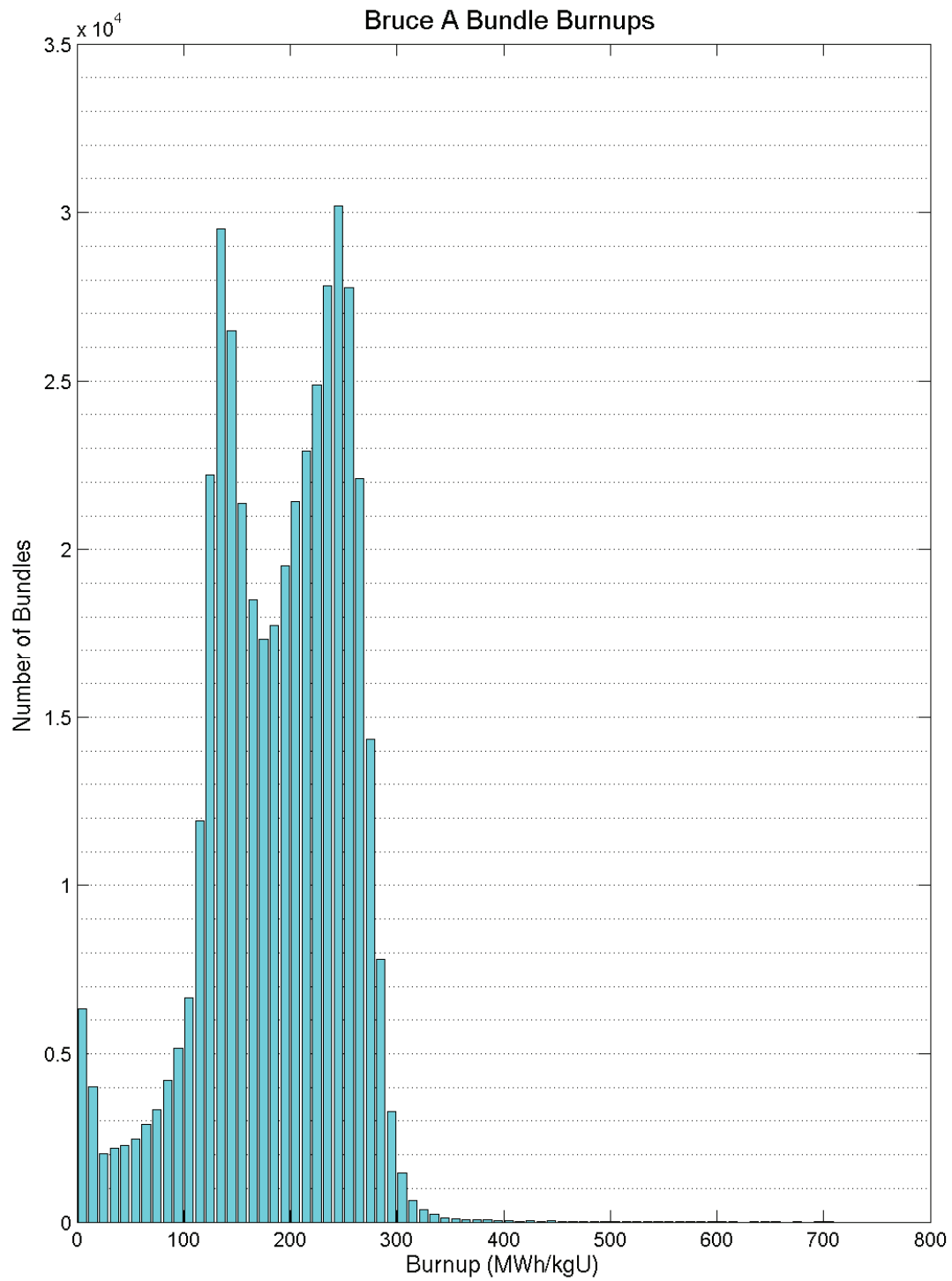


Figure 2: Bruce A Bundle Burnups

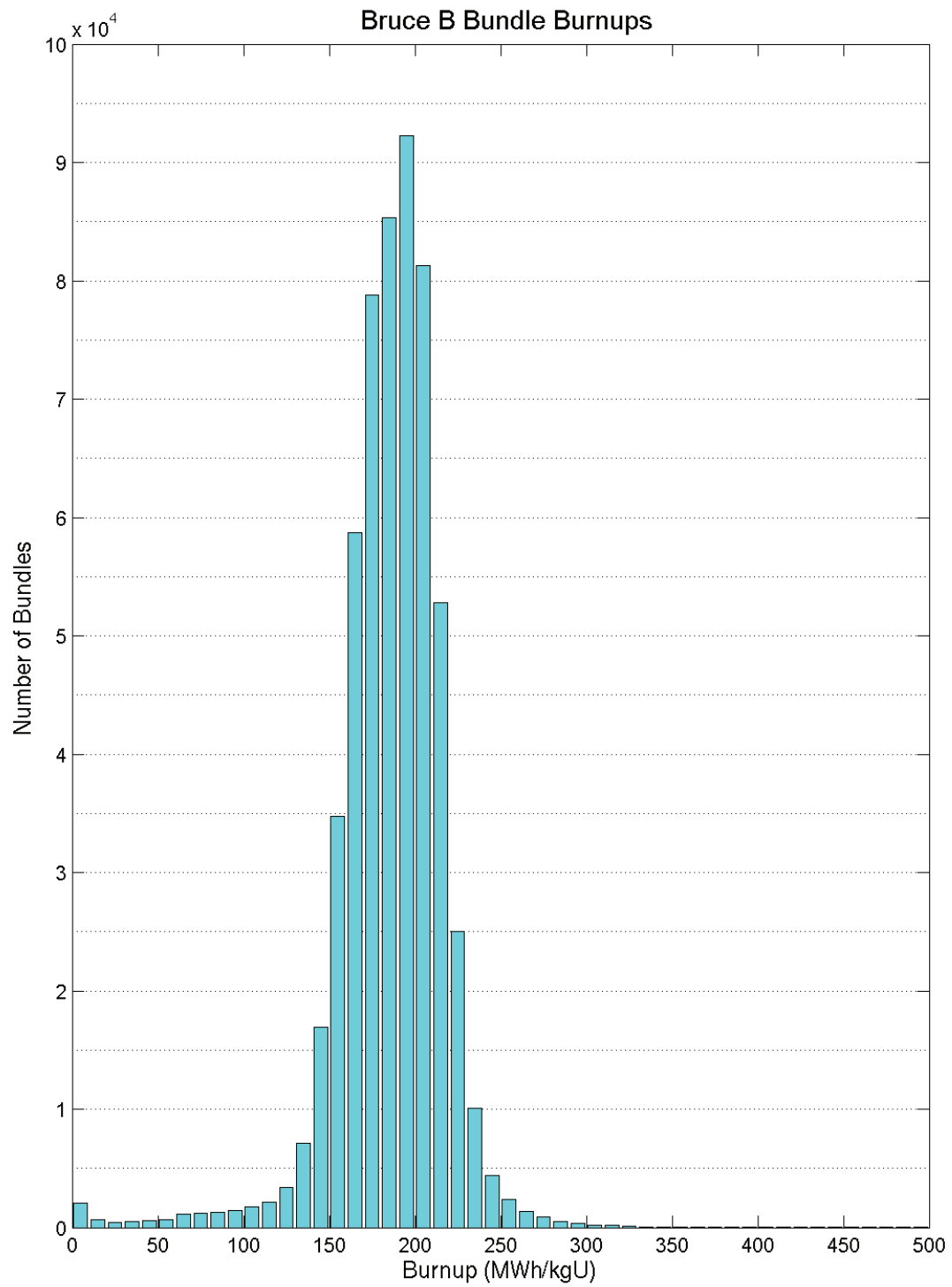


Figure 3: Bruce B Bundle Burnups

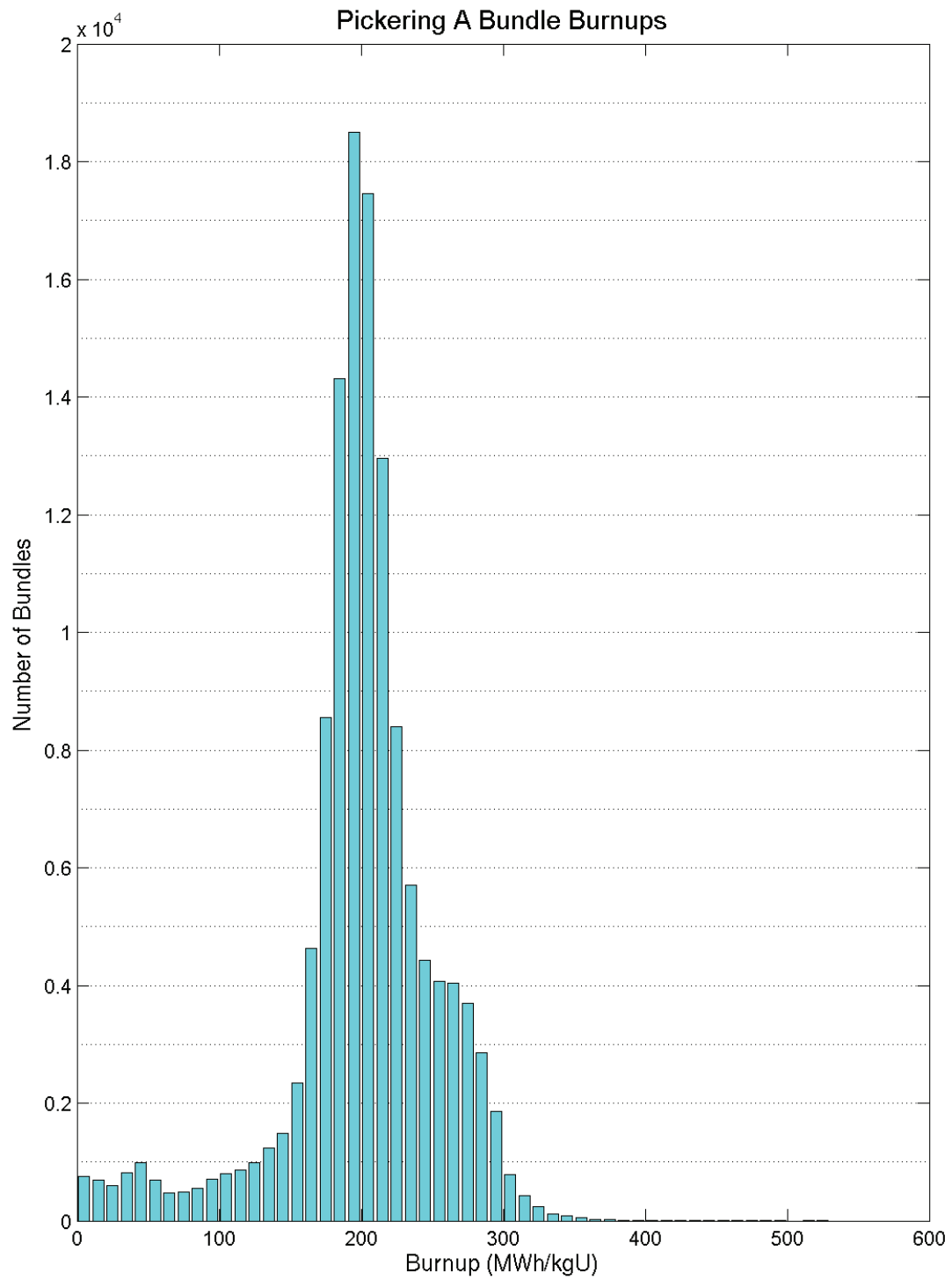


Figure 4: Pickering A Bundle Burnups

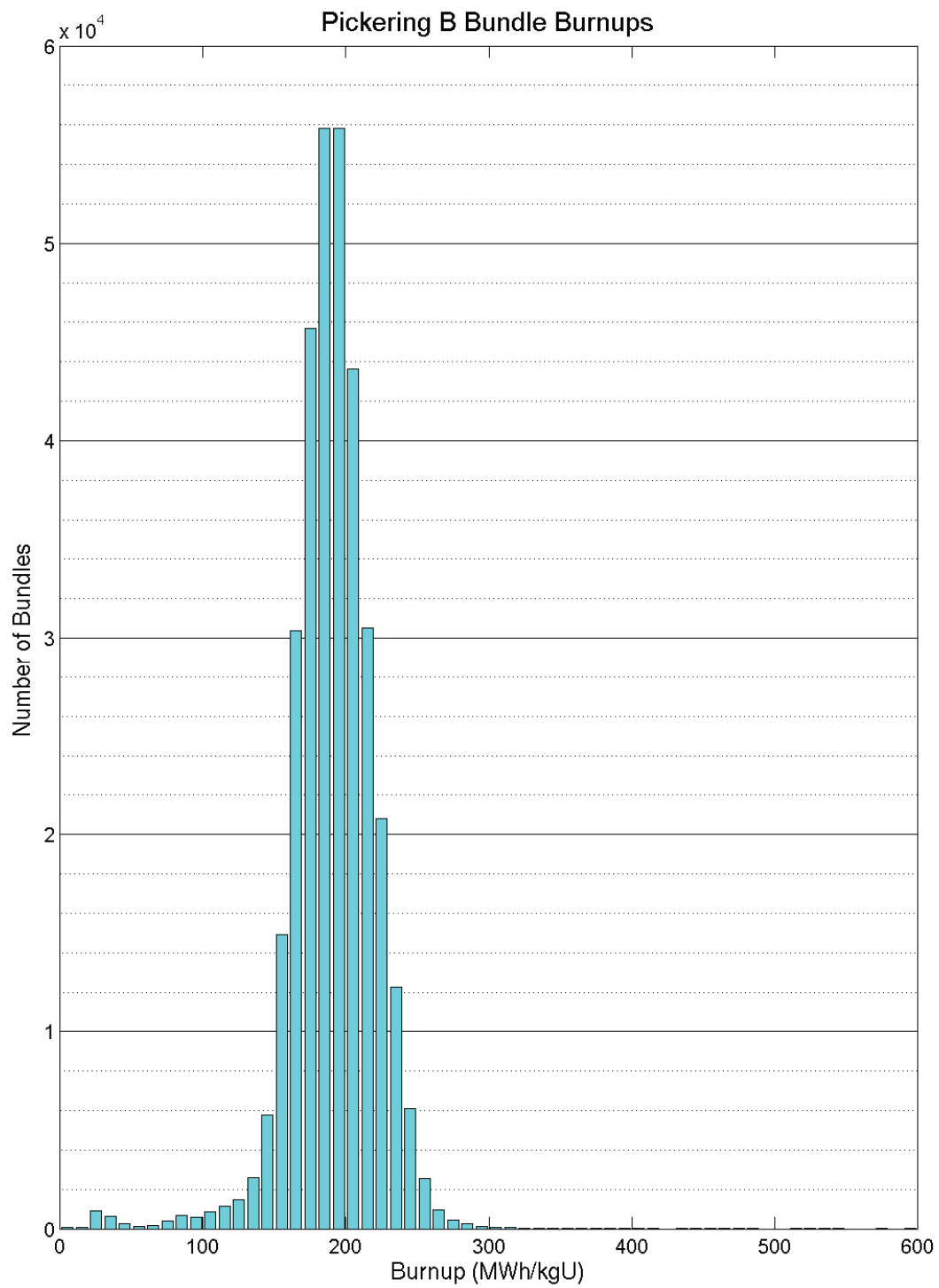


Figure 5: Pickering B Bundle Burnups

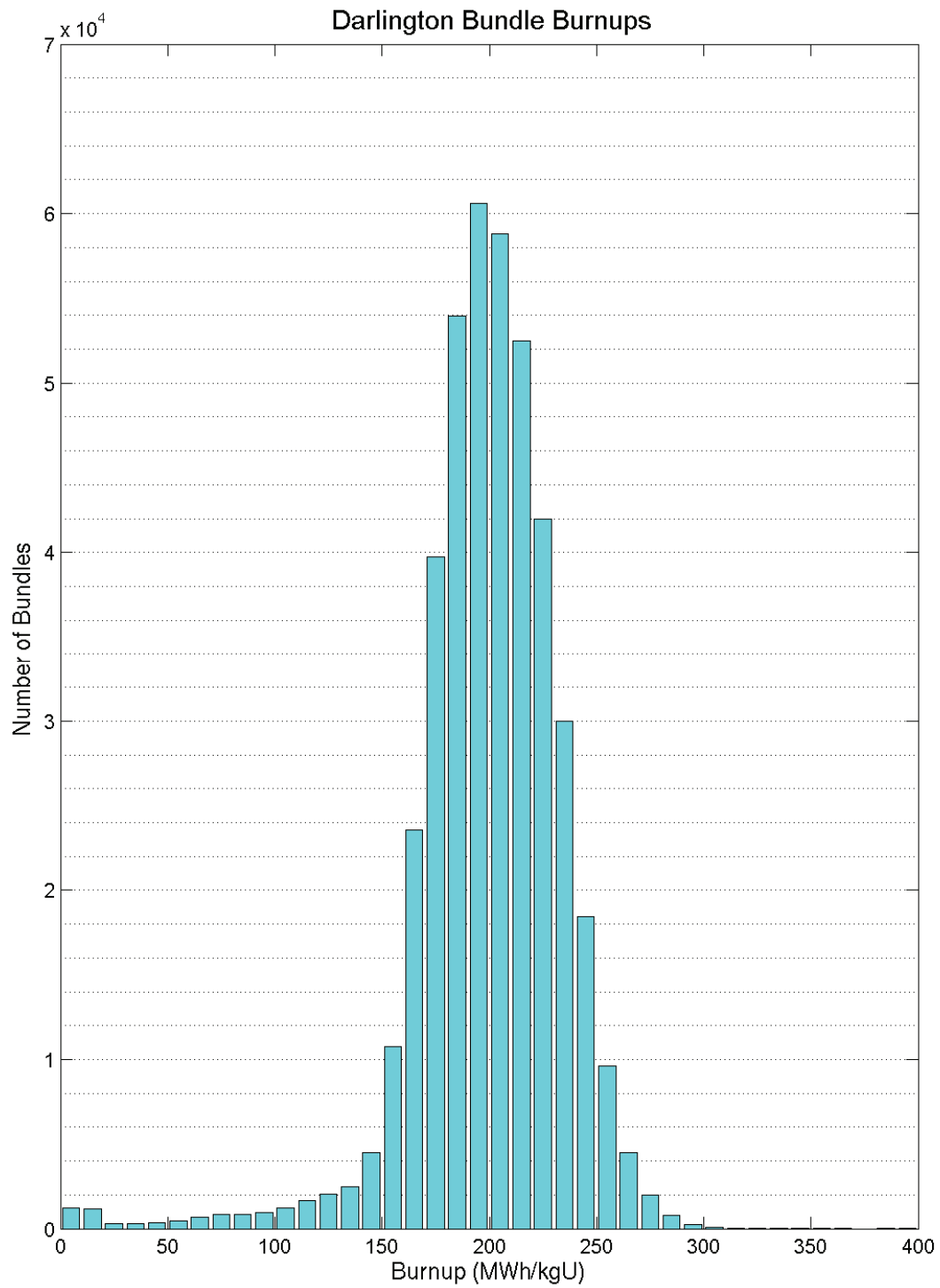


Figure 6: Darlington Bundle Burnups

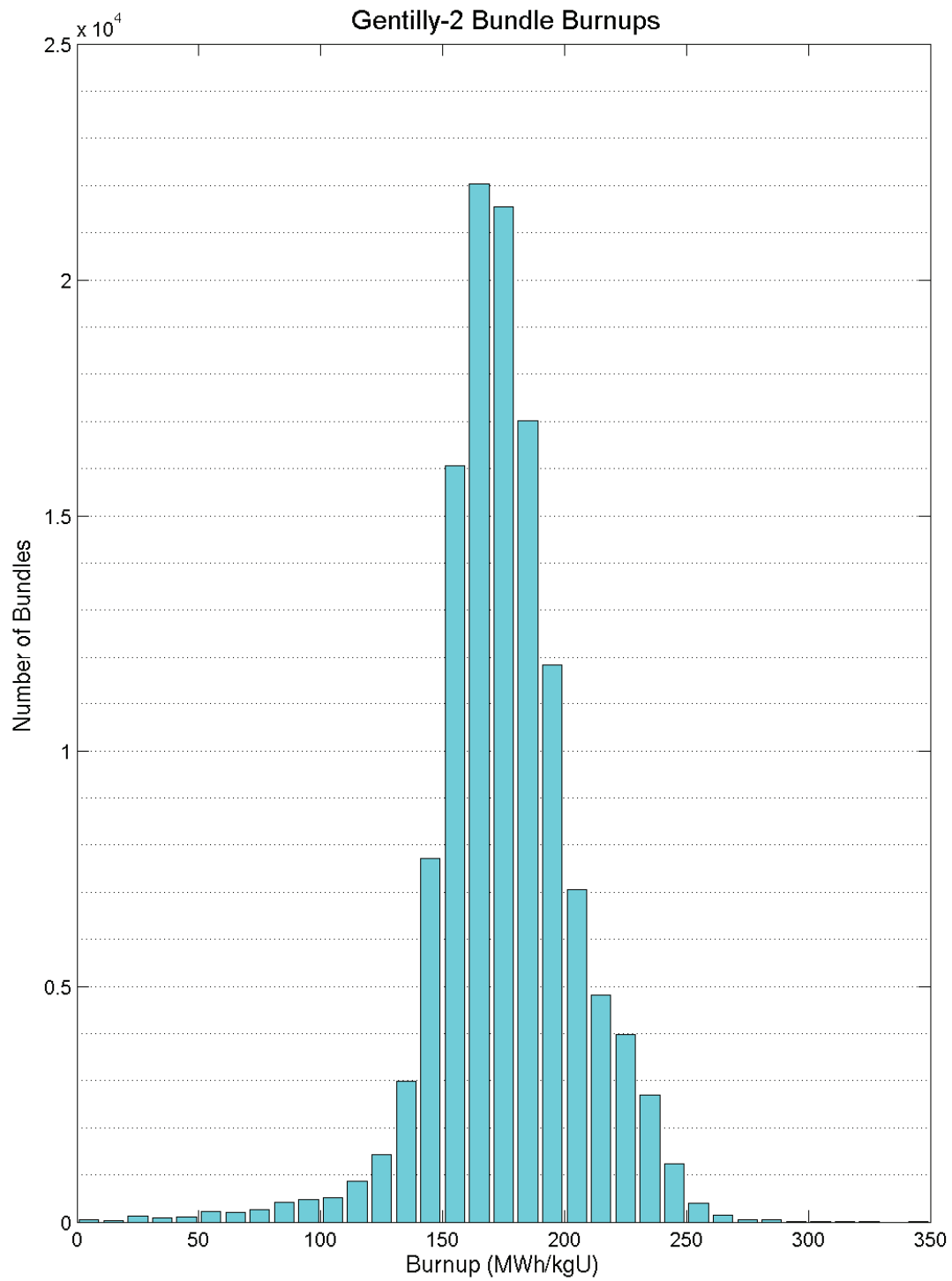


Figure 7: Gentilly-2 Bundle Burnups

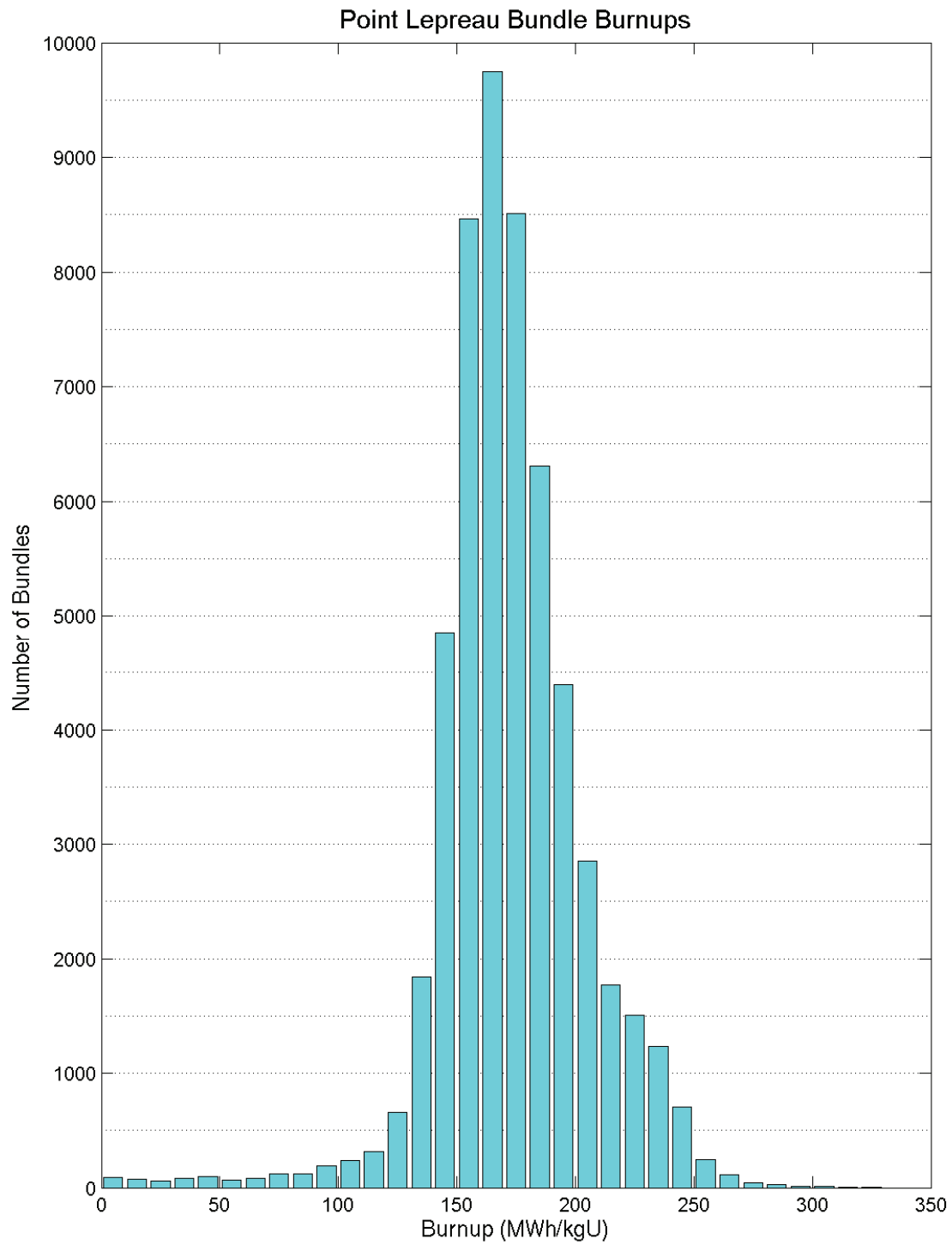


Figure 8: Point Lepreau Bundle Burnups

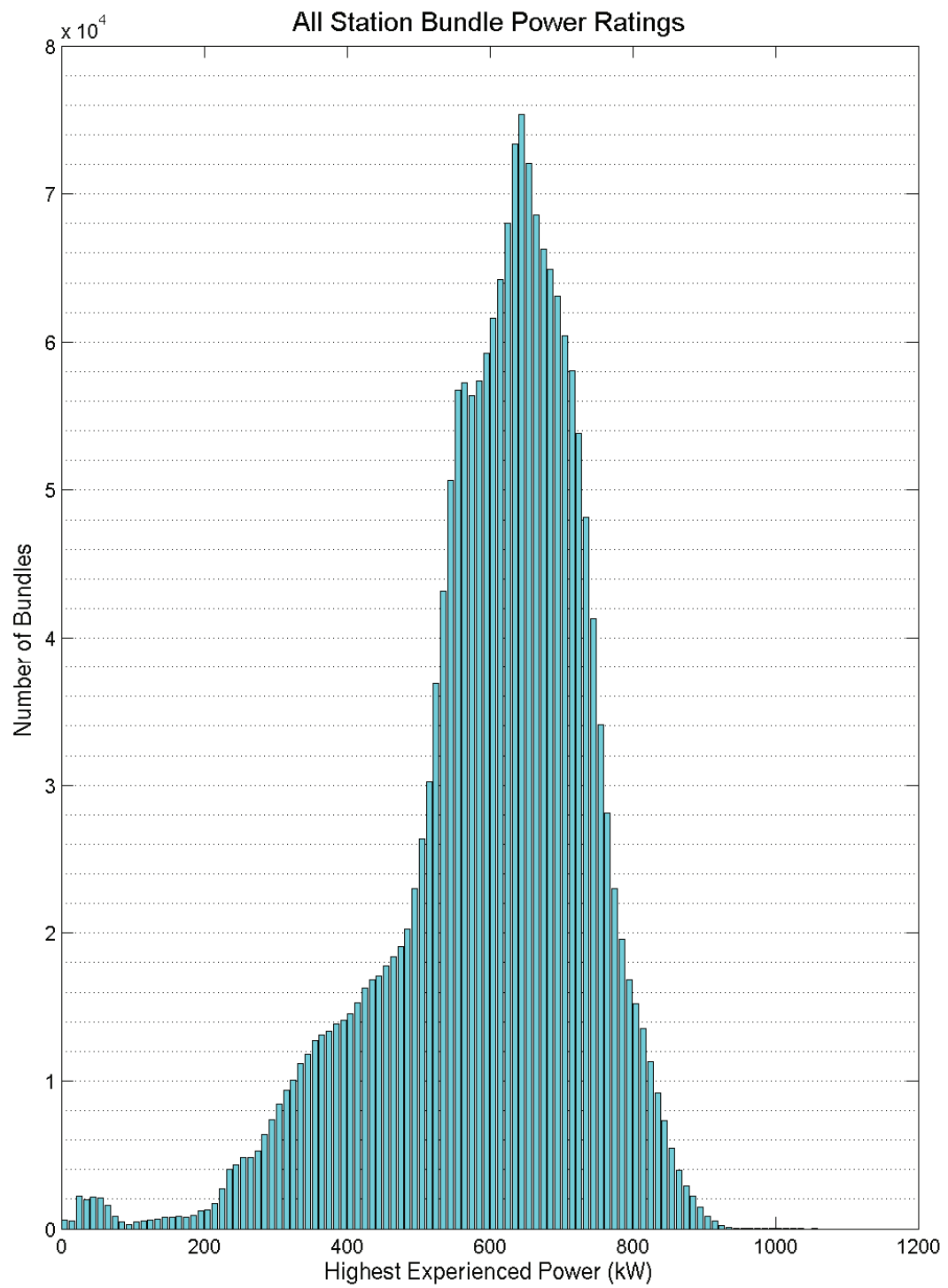


Figure 9: All Station Bundle Power Ratings

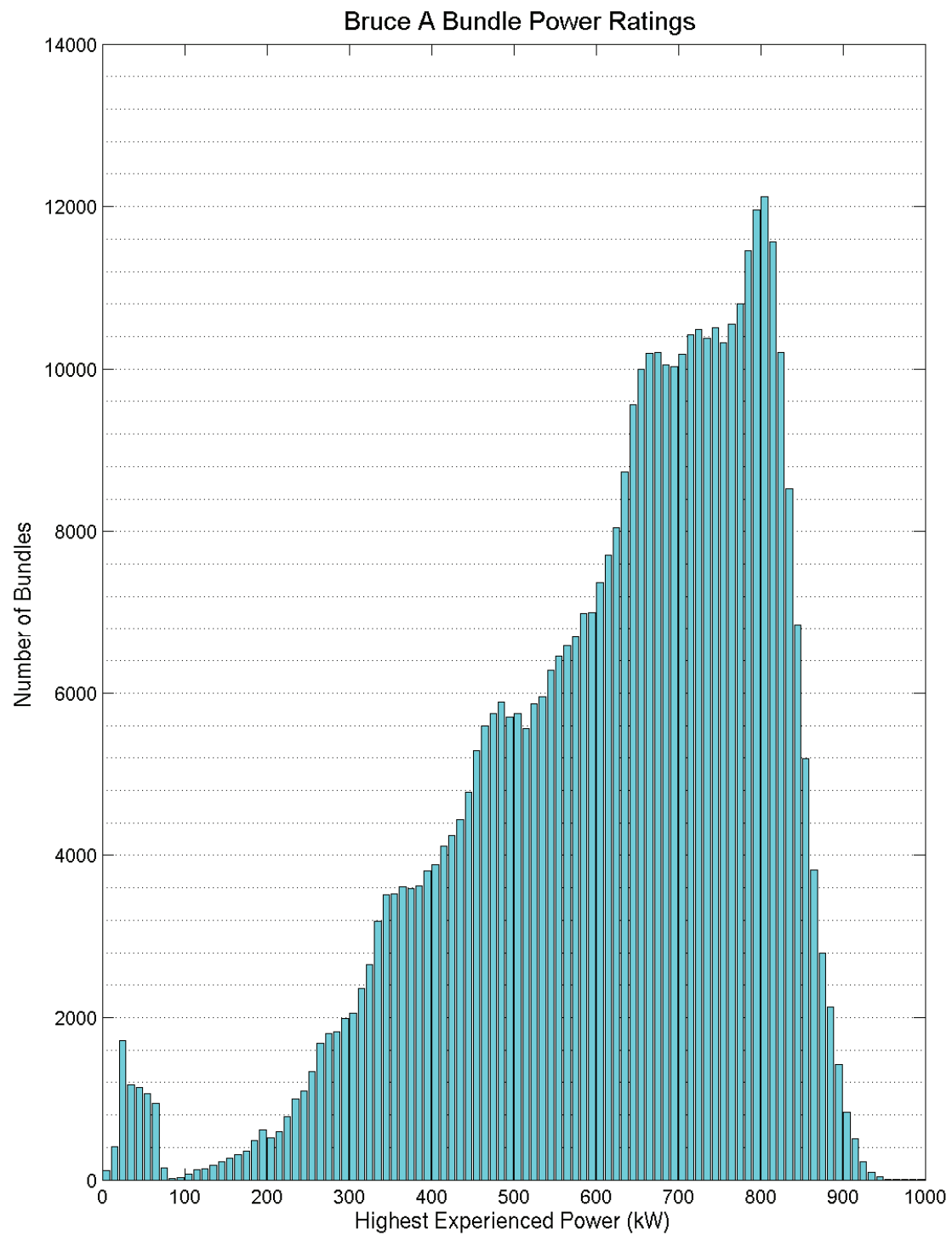


Figure 10: Bruce A Bundle Power Ratings

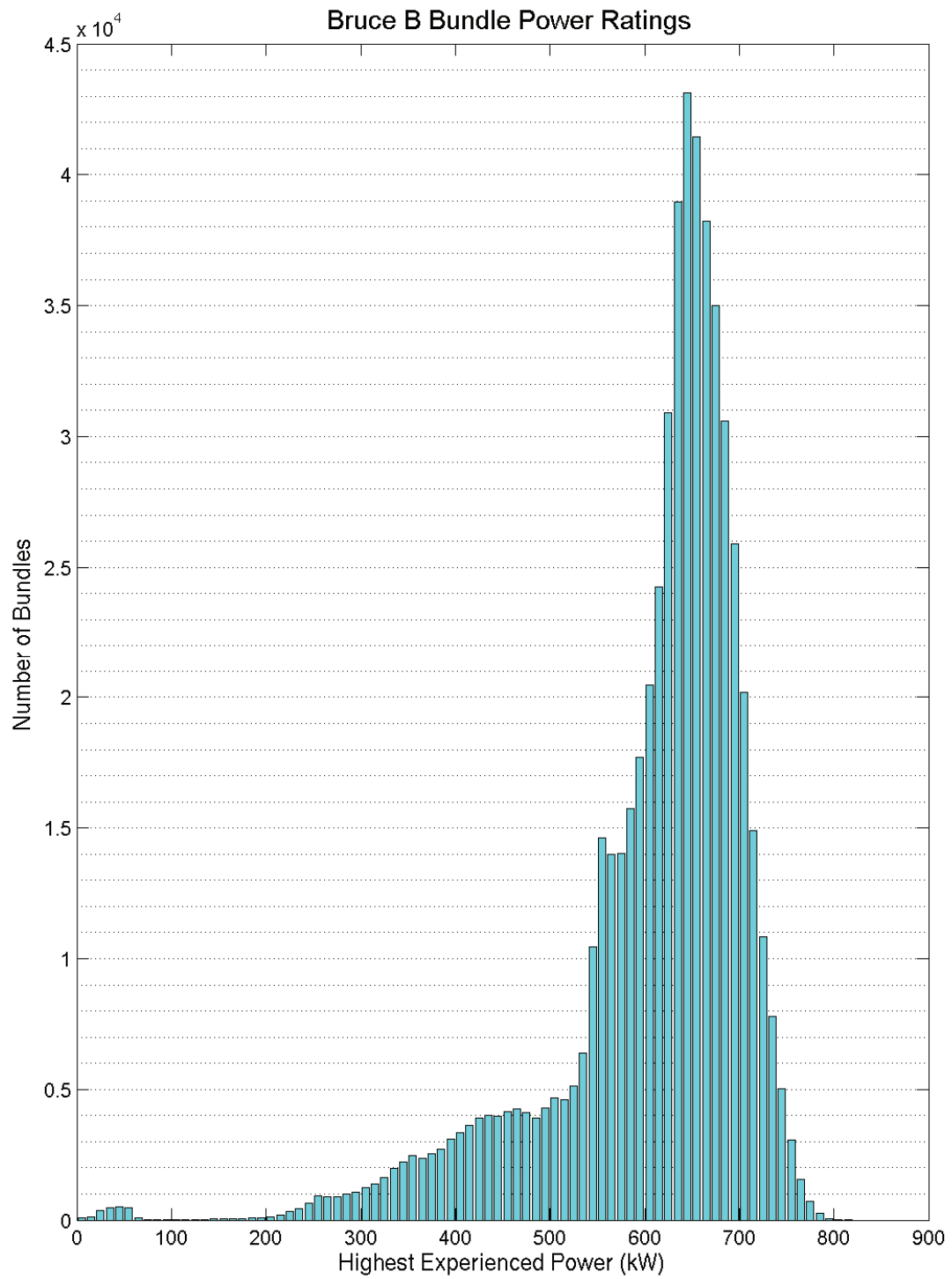


Figure 11: Bruce B Bundle Power Ratings

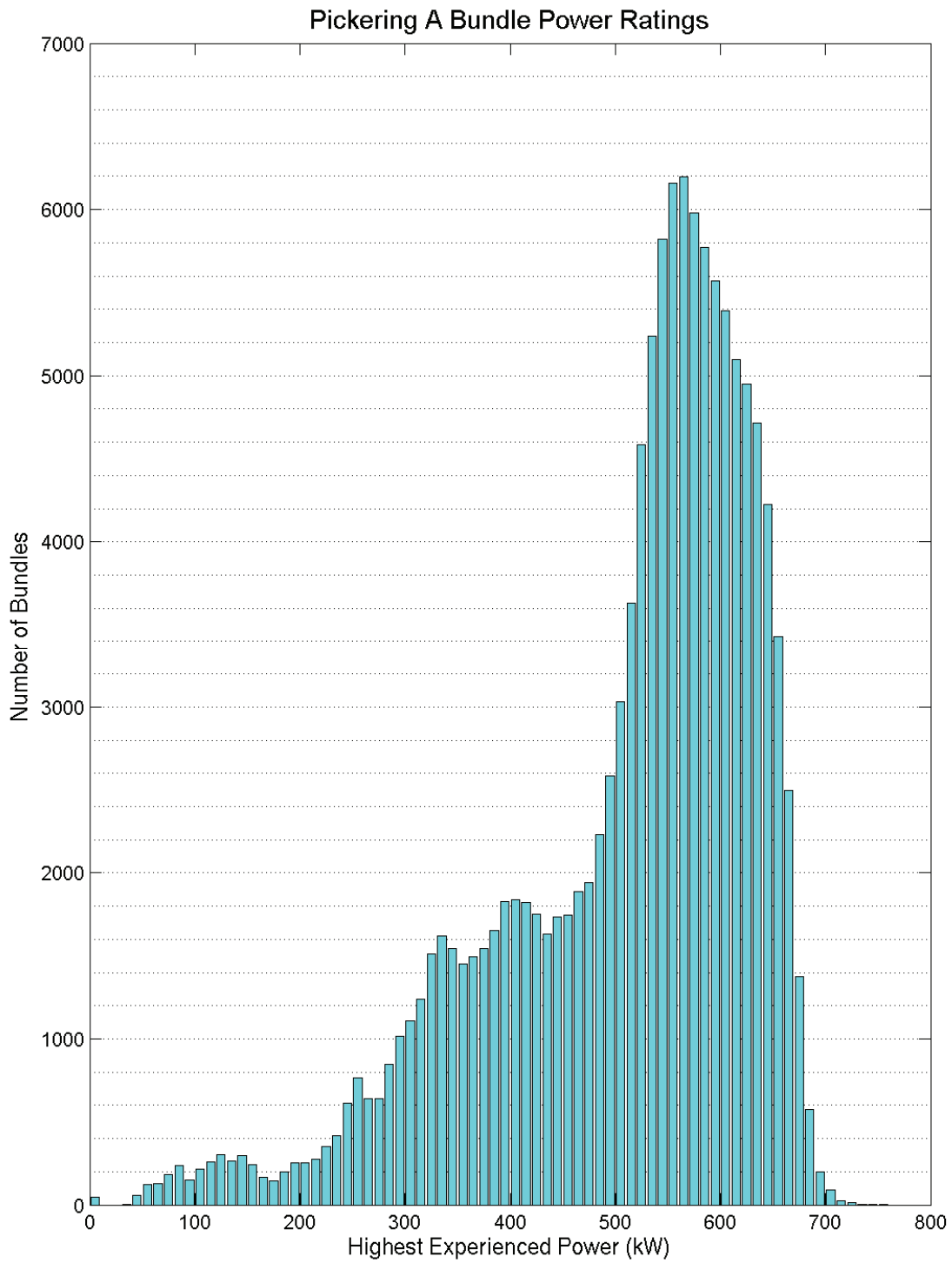


Figure 12: Pickering A Bundle Power Ratings

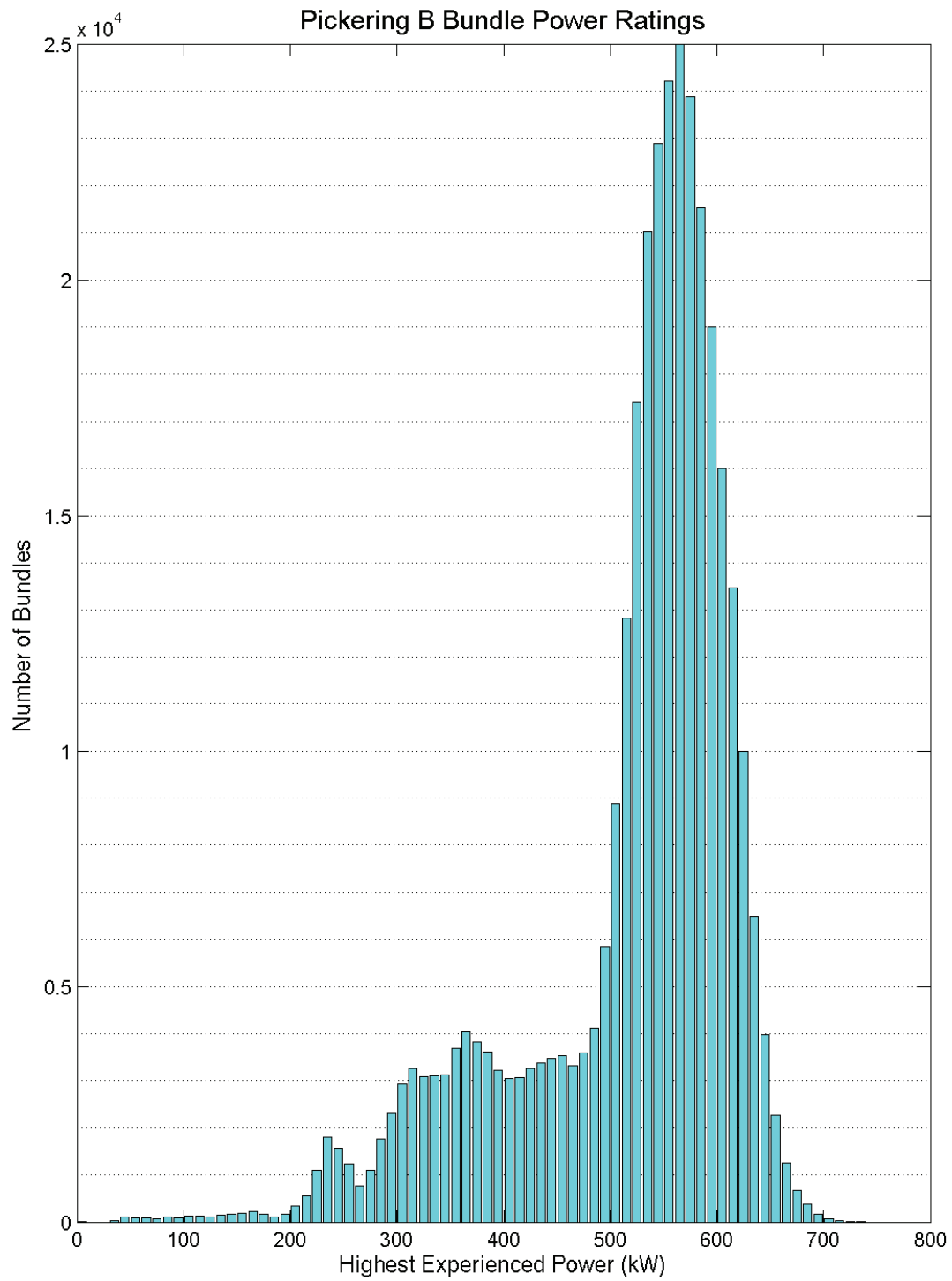


Figure 13: Pickering B Bundle Power Ratings

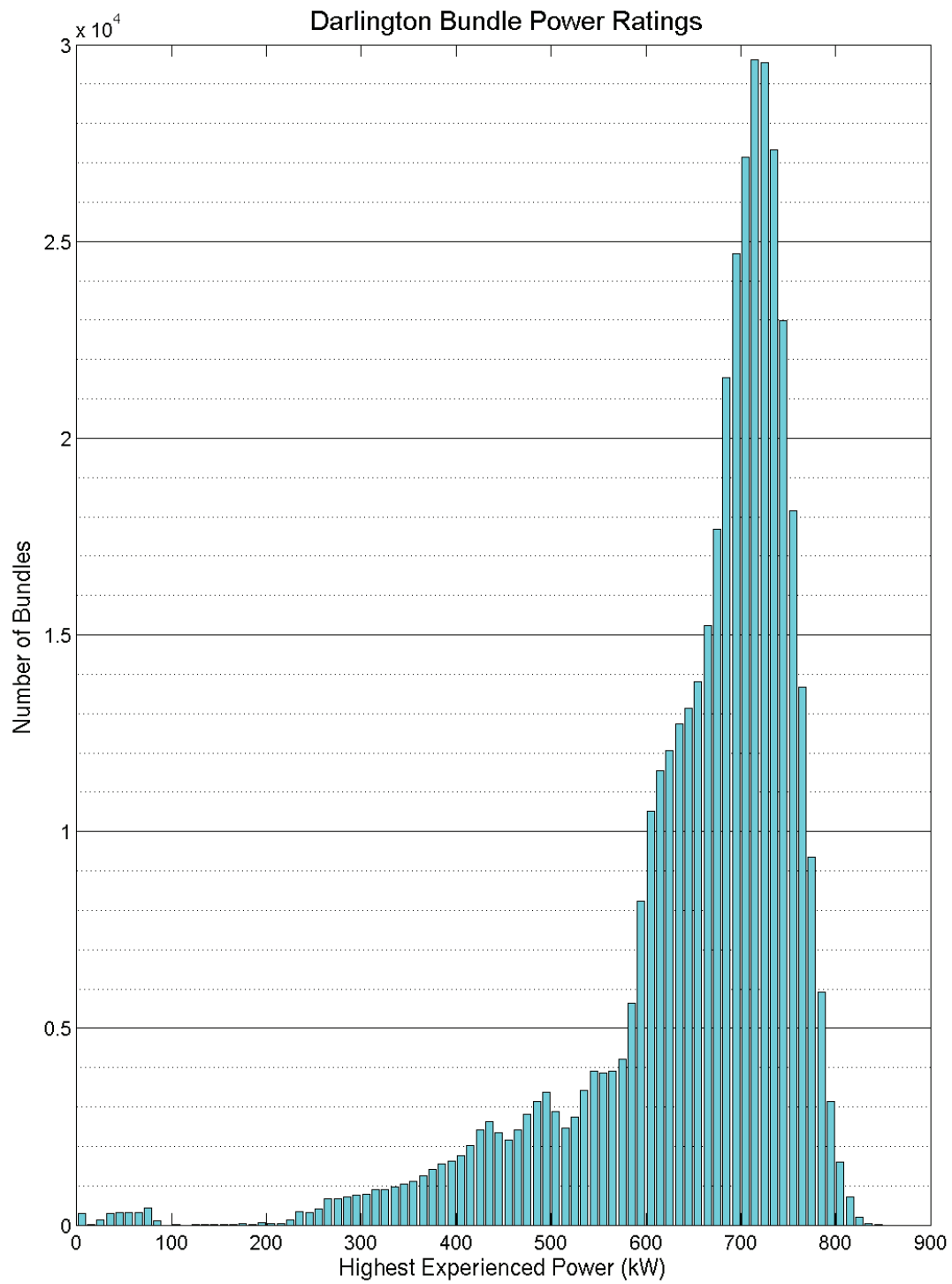


Figure 14: Darlington Bundle Power Ratings

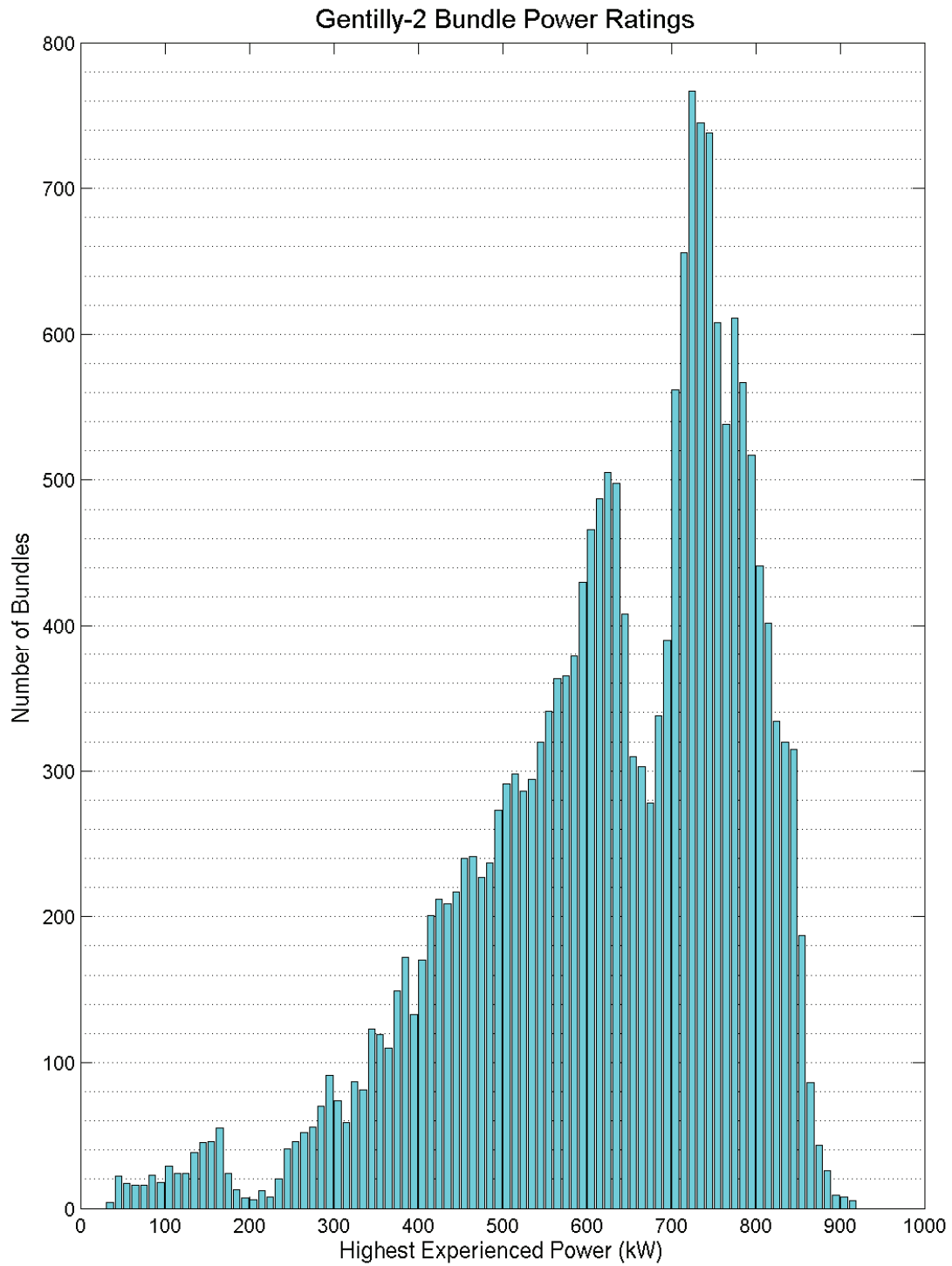


Figure 15: Gentilly-2 Bundle Power Ratings

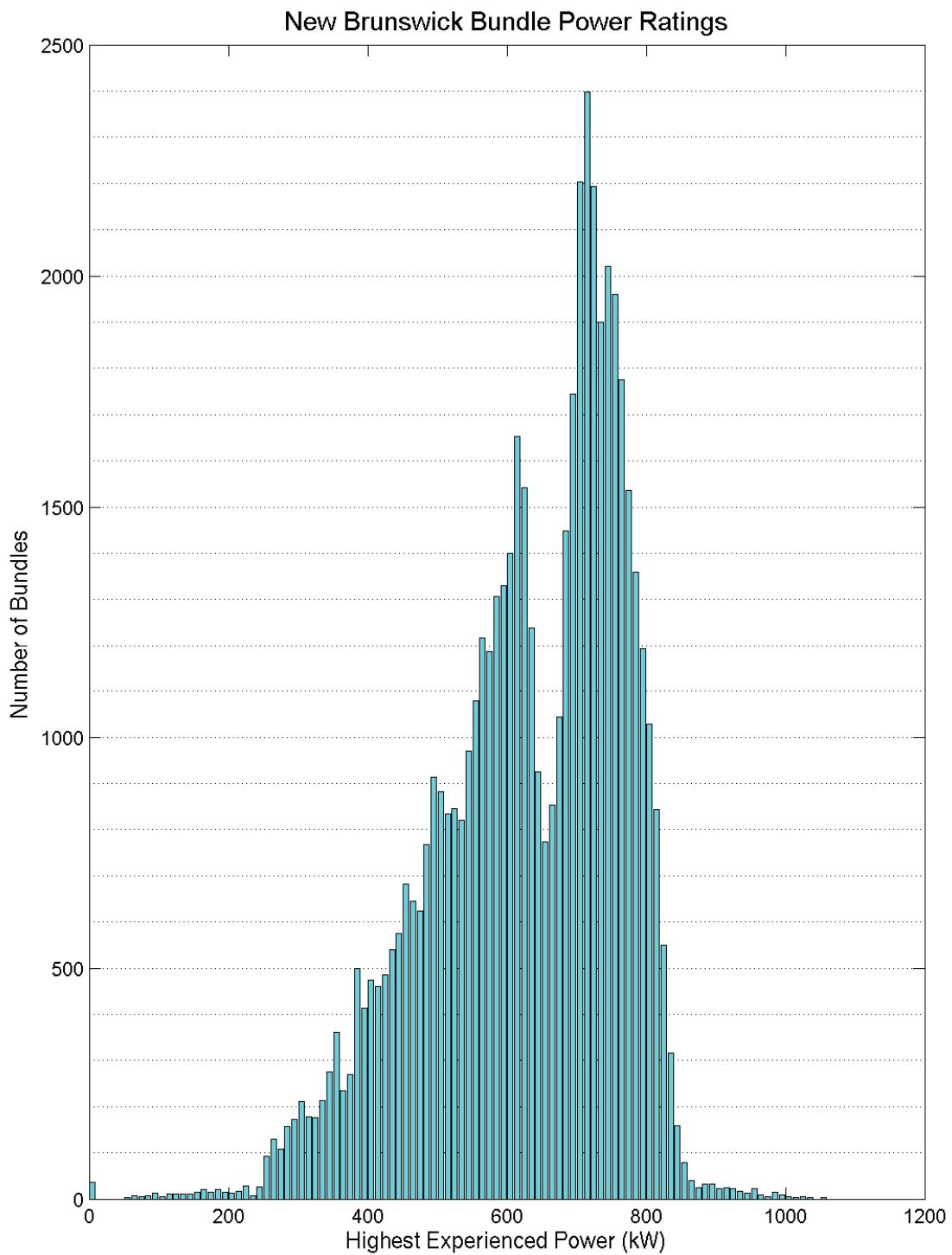


Figure 16: Point Lepreau Bundle Power Ratings

4. CONCLUSIONS

Burnups and maximum experienced powers for fuel bundles that had been discharged from Ontario Power Generation, Bruce Power, Hydro-Quebec, and New Brunswick Power reactors were extracted from all available digital archives. For each station, the data were statistically analyzed and plotted as frequency histograms.

The total number of discharged fuel bundles that were used in this statistical analysis is 2,073,278. Each utility's contribution to this total was as follows: 48.4% from Bruce Power, 43.0% from Ontario Power Generation, 6.0% from Hydro-Quebec, and 2.6% from New Brunswick Power.

REFERENCES

- Wilk, L., G. Cantello. 2006. Used Fuel Burnups and Power Ratings for OPG Owned Used Fuel. Prepared by Nuclear Safety Solutions Limited for Ontario Power Generation. Ontario Power Generation Report 06819-REP-01300-10121-R00. Toronto, Canada.
- Wilk, L. 2005. SORO Theory Manual. AMEC NSS Manual G0027/MA/002 R00. Toronto, Canada.