ONTARIO POWER GENERATION

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ENGINEERING & MODIFICATIONS BUSINESS CASE SUMMARY	

Darlington DCC Replacement 16 - 33977

Full Release (Phase 1) Business Case Summary D-BCS-69100-10001-R001

1/ RECOMMENDATION:

We recommend an additional release of $16.0M ([redacted] total including contingency) for the Darlington Digital Control Computer (DCC) Replacement Project.

The business objective of this project is to avoid a shutdown of a unit due to the unavailability of the CPUs in a dual DCC configuration due to either a component failure or a lack of available spares. A shutdown of this nature would be lengthy as a replacement DCC would have to be engineered and installed. This objective is consistent with the Darlington DCC Life Cycle Strategy as defined in NK38-REP-69000-10001.

The existing DCC hardware is obsolete and will not operate for very much longer with the required system availability. An associated project (Replacement of Obsolete Computer Components 33509) has been successful in replacing some of the subsystems (memory, power supplies, mag tape units etc) whose reliability or maintainability was threatening the overall DCC performance. However the limit of useful subsystem replacement has been reached and it is necessary to replace the core of the DCC system.

A partial release of $6.1M was approved in Sep 2003 to replace the Sequence of Events (SEM) and Common Processes (CP) computer, and perform initial preliminary engineering for the replacement of the Darlington DCC's. At the time, it was assumed that we could use "off the shelf" PDP-11/70 emulators for all 3 applications. However, after spending $1.2M of the current release, to complete the preliminary engineering (including the "design challenge" process) we have identified serious design issues that prevent the use of "off the shelf" technology in a nuclear control application.

We are now recommending the re-design of an existing PDP emulator from Quickware, with QA oversight from an independent and external source. Although the need to redesign (with oversight) has driven the estimated cost of the project from $14.8M to $22.1M, a rigorous RFP process has determined this to be the most viable and cost effective solution for all 3 applications. Moving to a full release at this time will allow us to keep costs down and ensure compatibility amongst the 3 systems. (See Attachment B for details).

This project is listed in the 2006-2010 Business Plan at $82.2M; with $15.5M allocated for this work and $66.7M targeted for DCC replacement under a Life Extension program beyond 2010. This funding request is intended to sustain the operation of the control computers until retubing takes place. Only minimal functional improvements will be made. This request is consistent with the 2006 Budget; however, changes in the estimate for the 2007 to 2011 timeframe will need to be addressed in the next Business Plan. A Project Execution Plan (PEP) will be approved by ~~19 May 2006~~ 2 Jun 2006.

$000's Capital		Including Contingency	Excluding Contingency			Excluding Contingency
Released to Date:	Full (Phase 1)	6,050	5,261	Mar-06	Spent Life to Date:	1,231
Requested Now:	Full	16,006	13,921	2006-2010	Apprd Business Plan (Tot Proj):	15,521
Cumulative Release:	Total to Date	22,056	19,182	2006-2010	Business Plan Variance:	3,661
Total Project Estimate:	+30% to -15%	22,056	19,182	2006	Budget (Current Year)	2,727
Current Year Estimate:	2006	3,134	2,726	2006	Budget Variance (Current Yr)	(1)
Type of Investment:	Sustaining	N/A	N/A	Cumulative Release Remaining:		17,951
NPV:			N/A	Contingency on Remaining Release:		[redacted]
IRR:			N/A	Contingency % on Remaining Release:		

Submitted By:

P R Charlebois
EVP and Chief Nuclear Officer — Date:

Finance Approval:

D. Power
Director Investment & Business Planning — Date:

Line Approval (Per OAR Element 1.1 Project in Budget):

J. Hankinson
President & CEO — Date:

2/ BACKGROUND & ISSUES

Darlington DCCs

Project 33977 addresses several issues, which present risk to the continuing performance and operation of the Darlington Digital Control Computer (DCC) systems:

- Hardware obsolescence. The current computers are of obsolete 1970s technology (DEC PDP11 minicomputers).
- Diminishing support from the industry. There is no OEM support and, unlike other CANDU stations, the hardware and software used at Darlington are unique. The few manufacturers of PDP emulators are ceasing production, and PDP expertise is disappearing quickly.
- The availability of spare parts in the marketplace has dwindled to a very small number of suppliers, and the quality and history of available spares is questionable.
- Certain key components, such as computer backplanes, are prone to wear out as a result of troubleshooting activities. This situation will deteriorate with time. The backplanes are cannot be reproduced.
- Pending shortage of in-house engineering resources. Large numbers of the original design team are eligible for retirement.
- The skill set required to repair the PDP equipment is disappearing, and the skills are not taught in trade schools.

The business case for the initial release for project 33977, approved in 2003, requested funding in the amount of $6.05M, including contingencies, and provided for the replacement of the five Sequence of Events (SEM) Computers and the Common Processes Computer (CP). The business case indicated that approval of a further amount, then estimated at $8.7M, would be requested later (in approximately 3 years) when a path forward was confirmed. This further funding would be required to complete the replacement of the Unit Computer DCCs and the Ramtek Display systems.

A highly skilled team, following a rigorous Software Quality Assurance (SQA) program, undertook the original design of the Darlington control software. This represents an enormous investment, both financially, and in expended time. Any attempt to recreate the software using modern Operating Systems and computer platforms would be extremely expensive and time consuming. Thus, at present, only solutions to the DCC maintenance and support issues that enable the investment in the control software to be retained are being considered.

At Darlington NGS, computers are used in Sequence of Event Monitoring Systems, the Common Processes monitoring System, the Unit DCCs and the Fuel Handling systems. All these systems use models from the Digital Equipment Corporation (DEC) family of PDP11 processors. Although this family was popular at the time of the Darlington engineering design, in the early 1980s, it is believed that Darlington represents the only instance in which this type of computer is used in a nuclear control application.

The provision of replacements for the Digital Equipment Corporation (DEC) line of processors is a specialty and declining field. Basically there are two types of replacement products:

- Hardware emulators, in which the instruction set of the original PDP11 is emulated in the replacement computer, using modern custom-designed hardware to replace the functions of the DEC equipment.
- Software Emulators, usually based on a PC platform, using a commercial, or custom operating system. The original DEC computer language is emulated by the PC, using the software resident in the "host computer".

Hardware emulators are relatively complex to design, and require considerable engineering knowledge and understanding of the operation of the original DEC computer hardware, and peripherals. While using modern technology, they do, however, provide for an almost exact emulation of the performance of the original DEC computer. As such, this would allow the transfer of the existing DCC control software to the emulator, with minimal issues with respect to instruction timing, while maintaining compatibility with the existing peripherals.

An RFP process was initiated, which identified Quickware as the most viable and cost effective provider of a hardware-based PDP Emulator, suitable for use in the Darlington DCCs. (Quickware has already provided an earlier model of hardware emulator used in the Fuel Handling systems at Darlington.) Subsequently an OPG internal design challenge process was initiated, which resulted in the development of a detailed design specification for the hardware emulator. The recommended approach will involve re-design of the original Quickware product to meet the additional requirements for operation in the Darlington DCCs.

At the time of the initial release of funds it was assumed that an "off the shelf" product would be able to replace the original DEC computers. However the detailed engineering performed under the initial release of funds identified serious design issues in the available off the shelf emulator products that would prevent their use in a nuclear application. The re-design of the Quickware project, under the oversight of a rigorous QA program, has been identified as the most cost effective and risk free approach. The cost estimate refinement resulting from the preliminary engineering activity, plus the identified increased engineering work due to the unavailability of a suitable existing product has resulted in an increase in estimated project costs from $12.9M to $19.2M.

Ramtek Display Systems

Under the initial release for project 33977, an experienced software consulting company determined that replacement of the existing aging display generators by modern compatible is feasible. The analysis also identified that the phased implementation of a replacement display system on the DCCs at power would be complex, and would best be carried out in conjunction with a future unit outage. It is therefore recommended that the Ramtek replacement should be first implemented in the SEM and CP systems.

Required Annunciation Improvements

Operational Experience Review of CANDU stations including Darlington Nuclear Generating Station, has demonstrated that original control room annunciation design does not fully support current operational goals and user needs in the main control room across all plant states. Improvements to the Darlington MCR Annunciation System (SCI 60312) are needed to improve alarm conditioning to inhibit nuisance alarms, which occur during reactor start-up/shutdown and during, upsets.

Specific assessments of the Darlington Loss of Bulk Electrical System (LOBES) upset and outage related Operational tasks (i.e. Shutdown and startup, equipment out-of-service declaration) were conducted to characterize the annunciation system deficiencies and user needs. The Annunciation Improvements segment of Project #33977 will focus on the elimination of the identified conditioning and suppression deficiencies. Further, the Darlington Authorized Training Section has identified Turbine Trip as another upset that has excessive Operator workload demands due to Annunciation deficiencies analogous to the LOBES event. These nuisance alarms will also be addressed.

3/ ALTERNATIVES AND ECONOMIC ANALYSIS

Stop the Project **(Not Recommended)**

Stopping the project is not a viable option. The life limiting components at this point are the availability of the CPU backplane and the floating-point processor. Currently, the entire supply of healthy spares has been used. This is especially true for the CPU backplane. It is "wire wrapped" and the board contacts are made mechanically. The probability of these components breaking down will increase with time, in proportion to the number of card re-insertions, typically made during "troubleshooting". Another important factor is that, most likely, the members of the original DNGS design team, as well as the currently available hardware vendor will become un-available in the next 3-5 year timeframe, since the market demand is small and the existing experts in the technology are aging. "Stopping the project" now will cost the corporation considerably more in the future, as the result of eliminating the most economical and risk-free option.

Unavailability of the CPUs in a dual DCC configuration, due to either component failure, or lack of available spares, would cause a complete shutdown of that unit, with associated loss of production. The shutdown would be lengthy, until a replacement DCC could be engineered and installed.

Alternative 1 – Replace the PSP11 Computers in the DCCs by a Hardware Emulator **(Recommended)**

The preliminary engineering work, performed under the initial release of funds for this project, has identified a suitable hardware-based emulator, for use in the Sequence of Events (SEM) systems, the Common Processes (CP) system, and the DCCs. The proposed product is from the same company (Quickware) that supplied the emulators currently in use in the Fuel Handling Systems at Darlington NGS. Re-design of the product is required, and this work, by the vendor, should proceed, with QA oversight provided by another company (L-3 MAPPS) to minimize long-term support risks.

- Hardware emulation is accepted by the CNSC as a "low risk" replacement technique, thus no regulatory approval is likely to be required.
- L-3 MAPPS, who have submitted a joint proposal with Quickware, have a history of providing equipment and support to OPG (as CAE).
- L-3 MAPPS is developing nuclear support as a long-term corporate goal, and have received a long-term contract for the supply of a Varian Computer emulator, and associated long-term support, from the COG organization.
- L-3 MAPPS has the capability to continue the design effort associated with the PDP11 emulator design, testing and production, should unforeseen issues affect the capabilities of the Quickware organization.
- The QED 95, developed by Quickware, is currently in use on the Fuel Handling Systems at Darlington. (Note: this product can no longer be manufactured, due to obsolescence of certain parts, and also has limitations that would prevent its use in the Darlington DCCs).
- The Quickware organization has the capability to adapt the design of the redesigned emulator to address OPG technical concerns with respect to failure modes, error checking and detection, and packaging. The design can also utilize successful OPG initiatives, completed under project 33509, to resolve obsolete DCC equipment issues (e.g. power supply replacements).

A hardware-based emulation solution has a lower risk of issues developing with respect to compatibility with existing control software, than with a software emulator. This is consistent with the approach successfully used to replace the DCCs at Pickering A.

Alternative 2 - Delay the Recommendation (Not Recommended)

Action on this issue has already been delayed to the point where the availability of the most economical and least risky alternative could disappear. Further delay would lead to a level of DCC performance risk that is unacceptable to the overall objectives of OPG. In addition, experienced Darlington staff members who are critical for the success of the project will be lost due to retirement in the next few years. As well, the number of potential suppliers will also diminish as the demand for PDP11/70 compatible products declines. The cost of doing the project (if at all possible) will be substantially higher.

Alternative 3 - Do Less (Not Recommended)

The do less option involves the "piecemeal" replacement of equipment in the Darlington DCCs in order to resolve specific problems as they evolve. Project 33509, Obsolete Equipment Replacement, has already taken this approach, and has resulted in providing solutions to maintenance, and longer-term support issues associated with the memory, Moving Head Disk (MHD) Mag Tape unit (MT) and Power Supplies. Project 33509 has taken this "do less" approach to its limit of effectiveness, and now the maintenance and long-term support issues associated with the CPUs themselves and the Display systems must be addressed.

Alternative 4 - Do More (Not Recommended)

Complete DCC Replacement by Modern Digital Control System (Not Recommended)

An alternative approach to the use of PDP emulators as replacements for the CPUs in the Darlington DCCs would be to replace the complete DCC via a modern digital control system. This would offer newer technology and better support from the industry.
However, in this approach, there are a number of significant implications:

- The DCC control software would have to be re-written, which would require a large software team, working within a rigorous QA program. This is not be required if the existing CPUs are replaced by emulators. Additionally there may be process complications in faithfully transferring the control implementation from the existing control system
- There may be high risk in obtaining CNSC licensing approval (completely new control software).
- Significant, and very costly, re-arrangement of the field wiring would be required in a complete DCC replacement.
- Unlike alternative 1, the complete replacement of the DCC by a modern digital control system cannot be performed in a staged manner, and thus an extensive outage would be required, such as that available in retubing. Planned outages of sufficient duration are not planned within the period during which DCC replacement must occur.
- This approach would be resource intensive, and would require lead times considerably longer than those for alternative 6. Thus the risks of outages due to DCC failure would increase significantly beyond 2010, if this approach were to be taken.

These disadvantages outweigh the benefits and the cost of this alternative (even if outages of sufficient duration were available) would be several times greater than of the recommended alternative, should we decide to extend the life of the station by way of a re-tubing initiative.

A complete DCC replacement by this approach is included in the long-term business planning for Darlington, with a conceptual cost of $60M. This approach would only be re-examined if a decision to extend the life of the station by retubing were made.

Alternative 5 – Other - Replace the PDP 11 Computers in the DCCs by a Software Emulator (Not Recommended)

This alternative offers comparable overall cost to the recommended alternative (hardware emulator) based on current estimates. However, even though the costs are comparable, this alternative has considerably greater technical and regulatory risks.

The system architecture would be much more complex than the current DCC implementation. It would involve three interacting systems (SimH, Operating System, and a new hardware platform). Ensuring that the fault tolerance and fault detection of a software-based emulator is equal to or better than the existing PDP 11/70, would be difficult. The nuclear regulator will likely have significant concerns since the use of a software-based emulator in a nuclear plant is "uncharted territory" and only hardware-based emulators have ever been used for DCC replacement on a nuclear unit.

- The various failure detection and handling schemes inherent in the current, PDP11 based design, would need to be re-assessed.
- Several new failure modes will be introduced by the introduction of a software emulation product, and will require significant assessment (e.g. issues with the newly introduced operating system, instruction timing incompatibilities etc.).
- The interface with the DEC Unibus is a weak point in most software emulators, and will require significant engineering and development to ensure a secure design is in place.
- There are uncertainties with respect to the discovery of new significant technical issues, as the design develops. This in turn would result in greater uncertainty and risk with respect to cost and schedule.

A detailed study was undertaken to compare the hardware and software emulation alternatives. Report NK38-REP-69100-10004, dated 10 February 2006, was produced, and concluded that the hardware emulator is the best approach based on DCC unavailability risk.

Alternative 6 – Other – Replace the Darlington DCCs using the Varian DCC emulator being produced for Pickering B and other CANDU stations as part of a COG joint project. (Not Recommended)

The Varian emulator cannot run the Darlington DCC software. Redesigning the Darlington DCC software to run on the Varian Emulator is probably infeasible, would cost several times more than the recommended alternative, and would incur substantially greater regulatory and technical risk.

Alternative 7 – Other -

4/ THE PROPOSAL

This project will replace the PDP11 computer based control systems and the display system with emulator based systems that will:

- Ensure the reliability (99.9%) of the DCC, Common Process Computer (CP) and Sequence of Events Monitoring (SEM) Computers for the current life of the station;
- Provide needed annunciation improvements;
- Prevent obsolescence and avoid shortage of spare parts;
- Provide an upgrade path for future plant life extension (beyond 20 years), if necessary.

The recommended approach is:

- Obtain a replacement as soon as possible.

  In terms of having a replacement as soon as possible with least risk, the hardware-based emulation option (Quickware/L-3 MAPPS) is the best choice. The software-based emulation approach (SimH) requires a much greater internal engineering effort as well as larger schedule and regulator risk. Hence the following is recommended:

- Keep the DCC healthy (complete the planned improvements per Project 33509). The fewer number of stalls, the fewer number of times the DCC needs to be disturbed. This will reduce the possibility of accidental damage to DCCs (especially the backplanes whose connections are made mechanically);
- Continue searching for "used" spare parts qualified for use.
- Implement the replacement as soon as possible:
  - Complete negotiations with L-3 MAPPS/Quickware to clarify and resolve the remaining price structure, and terms and conditions issues.
  - Award the contract to L-3 MAPPS for development of a PDP11 based emulator, based on enhancement of the Quickware design;
  - Complete discussions with L-3 MAPPS with respect to detailed work plans and schedules, to ensure the proposed project is adequately resourced to meet the required schedule.

Proceed with the design and procurement of an emulator for the Ramtek display systems.

Proceed with the design and implementation of Annunciation Improvements, to address nuisance alarms received during turbine trip events and during planned outages.

Milestones Finish Date (D/M/Y)	Description
2-Jun-06	Revise PEP and obtain approval
26-May-06	Award of contract for hardware emulator
15-Oct-07	Re-design of hardware emulator complete
21-Jan-08	Prototype hardware emulator available
24-Nov-08	Functional testing of emulator complete
30-Jun-09	Emulators installed in SEM systems
31-Dec-09	Emulator installed in CP
30-Jun-11	Emulator installed in DCCs
31-Dec-09	Ramtek replacement design complete
30-Jun-11	Ramtek replacement installation in DCCs
31-Dec-08	Annunciation improvement software programming complete
31-Dec-10	Annunciation improvements installed

5/ QUALITATIVE FACTORS

Completion of this project will result in more reliable DCC performance. This will result in:

- The reduction of maintenance effort.
- The elimination of spare parts shortages.
- In conjunction with project 33509, the return the health status of the DCC and CP computers to green (from yellow) and maintain them at that level.
- The improvement of the Annunciation Alarm Conditioning, eliminating the operator work-around caused by nuisance annunciation messages.
- The introduction of newer technology, which will be easier to support and maintain by less experienced staff, greatly reducing the requirement for legacy knowledge.

6/ RISKS

Description of Risk	Description of Consequence	Risk Before Mitigation	Mitigating Activity	Risk After Mitigation
Unforeseen problems in redesign of hardware emulator	Development costs could increase	Medium	Use fixed price contracts wherever possible. Note:The Design Challenge has already been completed and the project scope is well defined.	Low
Unforeseen problems in design of Ramtek replacement. Note: Little preliminary engineering has been performed in this area, therefore the risk remains.	Development costs could increase	High	Develop synergy with Fuel Handling project, which also requires a solution to the Ramtek replacement issue.I	Medium
Increased project scope due to undiscovered problems occuring.	Potential increase in cost, and schedule delays. Project Charter and contracts must be re-done.	Low	Detailed design specification confirmed and agreed upon before re-design of emulator.	Low
Problems occuring in re-design phase of emulator.	SEM in-service delayed. DCCs in-service possibly delayed	Medium	Negotiate contract with service providers to ensure that payment schedule encourages timely acheivement of milestones. SimH retained as back-up plan.	Low
Unforeseen problems revealed in testing of redesigned emulator.	SEM in service delayed. DCC's possibly delayed.		QA Service provider can apply additional technical resourses.	Low
Loss of key staff members in design team for emulator.	Project would be delayed, but with limited cost implications. (Fixed price contracts in place with service providers).	Medium	Knowledge will be transfered to the QA service provider in the initial engineering phase. The QA service provider could then continue to manage the remaining work.	Low
Loss of experienced staff in the DCC section, due to retirement.	Project would be delayed.	Medium	Several junior engineers will be exposed to new technology on this project.	Low
Lack of HFE resources, and DCC	Schedule delayed.	Medium	Identify risk early in project. Bring in external resources	Low

resources familiar with annunciation.			if necessary.	
The company proposed for the emulator re-design work is small, with the core expertise currently residing with a single person.	Loss of a key resource could lead to a return to the preliminary design stage.	Medium	A second agency, L-3 MAPPS, has been commissioned to work with the emulator designer to ensure that the key design elements are captured in the event of loss of this resource.	Low
Emulator could include a component with a short life span that cannot be replaced.	Emulators would have to be replaced before their projected life.	Medium	The design challenge processs specified that only components with a reliable life span shall be used in the redesigned emulator.	Low
				N/A
Any software or firmware used in the emulator will have to be qualifiable to software category two.	CNSC approval process could cause delays.	Medium	A hardware-based emulator will be pursued to minimise software changes. This approach is easier to validate and confirm.	Low
No risks identified.				
No risks identified.				
The replacement does not meet the business objectives	The detailed design work must be repeated. Increased failure rate for DCC's would be likely while the re-design is performed, with possible associated production loss.	Medium	L-3 MAPPS commissioned to oversee the emulator re-design work, and monitor progress and achievement of intermediate design milestones.	Low

7/ POST IMPLEMENTATION REVIEW PLAN

Type of PIR:	Targeted Final AFS Date:	Targeted PIR Approval Date:	PIR Responsibility (Sponsor Title)
Simplified	Dec 2010	Jun 2011	E Hung Section Manager Darlington DCCs

	Measurable Parameter	Current Baseline	Targeted Result	How will it be measured?	Who will measure it? (person / group)
1.	DCC Emulator Passes Acceptance Test.	Existing PDP11 performance.	Funtionality demonstrated by system tests.	Suite of tests based on performance of original system.	QA oversight provider, in conjunction with Darlington DCCs staff.
2.	Emulator Functions in SEM systems, CP and DCCs.	Existing PDP11 Operation	SEM, CP and DCC S/W and H/W Check programs function normally in an extended test. Same or better operation using system utilities to measure system loading and performance.	Monitor for system stalls, and errors detected.	Darlington DCCs staff.
3.	Number of System Stalls reduced.	System Health is "White".	System Health returns to "Green".	System health reports..	System engineer.
4.	System spares situation returns to "Healthy" state.	Some parts in short supply.	Sufficient Spares to reach End of Life.	Inventory of Spares is acceptible.	Darlington DCCs/. Control Maintenance
5.	Frequency of nuisance alarms during startup and shutdown.	Established by historical data	Significant reduction in number of nuisance alarms.	Ops acceptance of reduction in alarms.	MCR system engineer

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Darlington DCC Replacement 16 - 33977

Partial Release Business Case Summary D-BCS-33977-10001-R001

Attachment "A" **Project Cost Summary**

$000's Capital	LTD Prior Years	2005	2006	2007	2008	2009	2010	2011	2012	Total
Project Management (OPG)	238		189	189	189	189	108	81		1,183
Engineering & Drafting (OPG)	282		678	1,370	1,183	705	303	118		4,639
Material	[redacted]									
Installation – PWU, BTU										
Contract – Project Mgmt										
Contract - Design										
Contract - Installation										
Contract - Other										
Interest (Capital Project Only)										
Sub Total (excl Contingency)										
Contingency										
Grand Total	1,243		3,139	6,340	4,133	4,261	2,214	432		22,034
2006-2010 Business Plan	1,175		2,727	2,600	2,631	3,415	2,973		-	15,521
Variance to Business Plan (excl Contingency)	(94)		(1)	2,239	963	308				6,861

Removal Costs Included In above	0
Definition Costs Included In above	0
Estimate Name, Quality, etc	Budget Estimate +30% to -15%
Design Complete:	Up to ~ 15%

Reviewed By:

E Hung
Project Manager
Date: May 16/06

Approved By:

R Hohendorf
Eng & Mods Manager (Strat IV)
Date: May 17, 2006

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ATTACHMENT "B" **TOTAL PROJECT COST VARIANCE TABLE**

$000's Choose One	Last Release day/mth/yr	This Release day/mth/yr	Variance	Explanation
Project Management (OPG)	1,038	1,183	145	Longer project duration
Engineering & Drafting (OPG)	3,637	4,639	1,002	Additional verification required for new product
Installation – (OPG)	257	260	3	
Material				
Contract – Project Mgmt				
Contract - Design				
Contract - Installation				
Contract - Other				
Interest (Capital Project Only)				
Sub Total (excl Contingency)				
Contingency				
Grand Total	14,819	22,058	7,238	