ORAPA 3 PLANT CONCEPTUAL DESIGN EVOLUTION IN ACTION (LET THE ORE DICTATE THE PLANT THAT YOU BUILD!!)

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SUMMARY

Commencing with the Pre-Feasibility Study (PFS) conclusions, the Orapa 3 process design evolved through a phase of value-engineering studies. An overall re-evaluation of the originally proposed process design was necessary both in order to address the interim increase in target throughput from 9.8 Mtpa to 12 Mtpa as well as to increase capital efficiency. In the interests of clarity, the PFS process design for Orapa 3 has been omitted from this paper, as it is no longer relevant. Recognition is however due to those engaged in earlier phases of the Orapa 3 project with respect to fundamental mass-balancing modelling, and ore and diamond characterisation, which formed the basis for the process design that has evolved from feasibility study activities.

The background context for Orapa 3 is of an operation expected to yield operating utilisation and revenue improvements relative to the Orapa 2 operation. Delivering these without undue penalties to capital and operating cost required a shift in thinking, trading excess installed capacity for flexible circuit configuration.

The process design adopted is "layered", with the purpose of preserving Run Of Mine (ROM) throughput by reducing in-circuit arisings – particularly to the Dense Medium Separation (DMS) section – rather than simply installing additional DMS capacity on the expectation of low DMS availability.

Elsewhere, the ability to monitor and maintain critical sizing activities - particularly desanding – without impact on overall plant throughput is intended to motivate operators to avoid the temptation to trade quality for quantity.

At present, since an overall dynamic simulation of the Orapa 3 operation has still to be carried out, the design mass balance has been based on a relatively onerous combination of worst case feed type with 100% front-line process capacity in all plant sections. This means that, whilst the installed DMS capacity is based on routing 100% of sized scrubbing section product directly to the DMS, and with one DMS module always unavailable, the High Pressure Rolls Crushing (HPRC) capacity is based on allowing for 50% of this stream to be instead routed first to the HPRC section, at no more than 75% of maximum roll speed for the two units installed. This is an obvious "belt and braces" approach. Following the dynamic simulation exercise (currently in progress), it is likely that a less conservative approach will be taken. This will not affect the conceptual design of the process plant, being mostly an exercise in refining the number of DMS modules to be installed, and possibly reducing slightly the size of the HPRC roll units. Both of these will have positive capital and operating cost impacts.

DMS capacity, despite being split into coarse and fines streams, consists of identical modules. Two of the nine modules are set-up to receive either coarse or fine feed, the only difference being that fines modules are rated at lower capacity than the same modules treating coarse feed.

Final recovery section capacity is based on entirely wet primary diamond recovery technology. This greatly reduces both the cost of drying a large amount of recovery section feed and the dust-management issues associated with dry recovery technology.

In contrast to the Orapa 2 operations, a scavenging/audit grease belt section is included as a diamond recovery "goal-keeper" and to provide a process assurance function.

Key Features of Orapa 3 Plant

Key features of the Orapa 3 plant are summarised as follows, and discussed further in Section 6:

Main Plant Sections

- Parallel scrubbing and screening trains, which can also be fed asymmetrically to emulate a primary/secondary scrubbing configuration
- Single secondary cone crusher, solely for HPRC feed preparation
- Studded roll HPRC units, in a combined tertiary/recrushing duty
- Desanding section separated from the scrubbing and screening section
- Degritting section provided to reduce overall water consumption and optimise thickener performance and operability
- High-density thickeners of conventional design
- Simplified overall process water distribution system
- Pump fed DMS cyclones and dilute medium densification
- DMS capacity split into coarse, fines and swing modules, with however all modules of identical design
- Steady process water head tank for DMS sinks screens sprays and pump flushing
- Wet primary X-ray sorter based recovery section, with all recovery sorters of same basic design
- Automated grease belt back-up for fine X-ray sorter rejects

Recovery Section

- Stream/batch system allowing high utilisation of units processes while not excessively raising the height of the building.
- Modern but proven wet X-Ray sorters perform recovery of material with low pop-factors and grams per ejection.
- Dry re-concentration systems fed by external volume feeders at low rate from 3 to 30kg/h produce high diamond by weigh concentrates free of dust.
- Grease scavenging of prepared X-ray tails using advanced grease belt systems incorporating automated control and cleaning systems.
- Control of unit processes from a control room to allow a hands off operation.

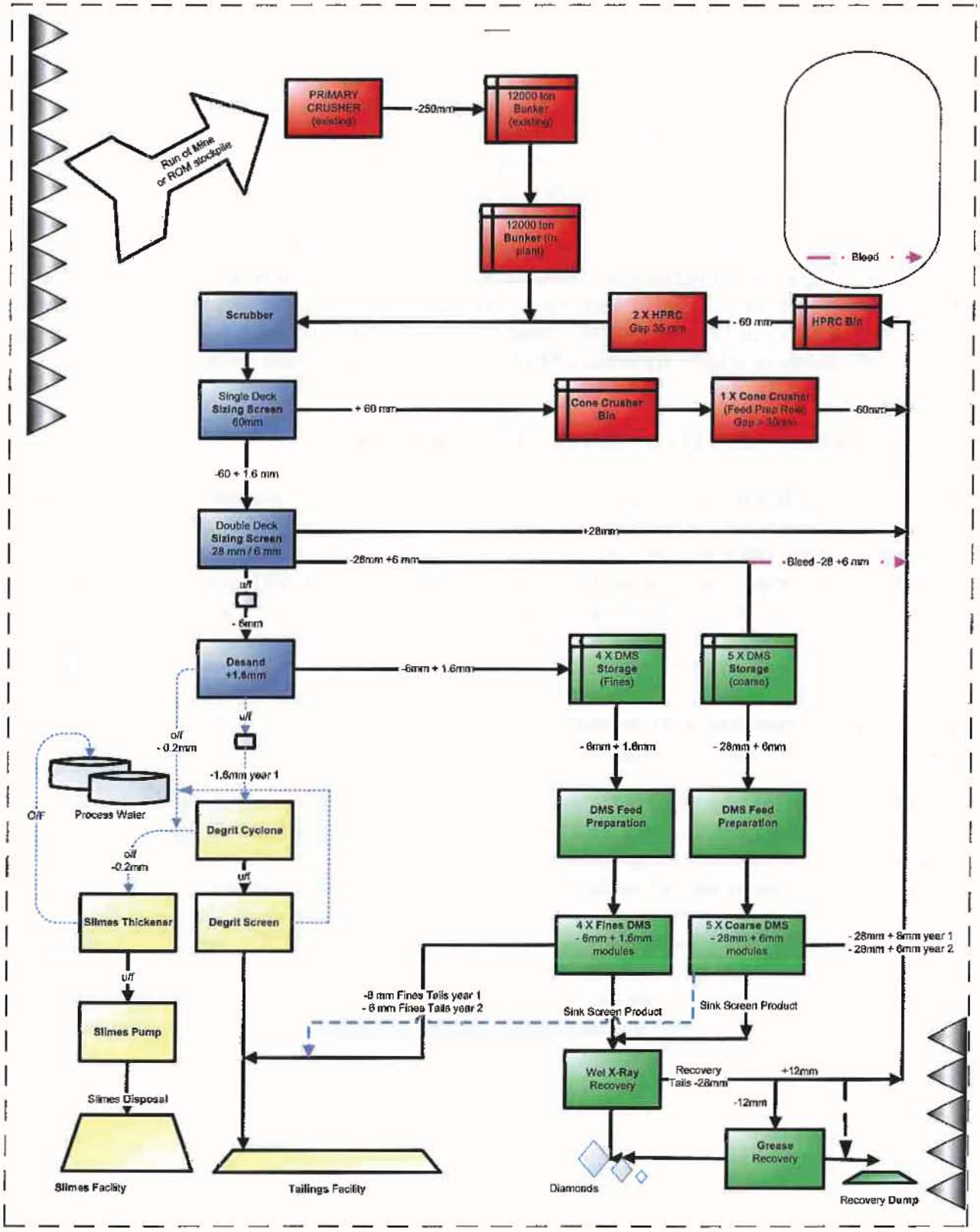
1.0 INTRODUCTION

The point of departure for the events discussed in this paper was a critical review of the previously proposed design and related cost-reduction suggestions put forward by others. The volutionary process represented by the Feasibility Study was undertaken by Fluor with the full engagement of Debswana's project team. Workshops were held with key stakeholders, including Orapa Mine management and De Beers Project Assurance, at critical decision points.
Value engineering studies were carried out to evaluate potential opportunities for capital cost reduction, although at all times within the context of minimising risk to plant utilisation, which is benchmarked against an international standard higher than that currently achieved by the Orapa 2 Plant. This presented a challenge and was a driving force towards the adopted "layered" design philosophy where run of mine (ROM) capacity is protected at reduced DMS section capacity through the ability to selectively crush DMS feed or reject coarse DMS floats.

2.0 CURRENT DEVELOPMENTS – JANUARY 2010

Following completion of the feasibility study phase conceptual process design, a dynamic simulation exercise was carried out to confirm in-circuit material storage requirements and indicate if further DMS section capacity reduction might be possible without compromising the overall goal of Orapa 3 to achieve 12 Mtpa throughput of Orapa AK1 primary crushed ore. A capital cost reduction workshop was held in December 2009 to review the outcome of the dynamic simulation exercise and determine which recommendations would be incorporated into the plant design. As expected, significantly reducing the capacity of the feed silo, from 12,000 tons to nominally 2,000 tons, presented no throughput risk, nor did the removal of one DMS module. These measures were adopted and engineering is currently in progress to detail the changes to support cost estimating.

An additional option identified at the workshop, outside the scope of the dynamic simulation, is to remove the dedicated Orapa 3 final recovery section, instead upgrading the existing CARP. Although work is currently in progress to define the CARP modifications, which are based on testwork carried out in parallel to the Orapa 3 design development, order of magnitude costing indicates that it is an attractive way forward. Consequently, without changing the process flowsheet, the overall plant plot-plan was modified to capture the benefits of excluding constraints imposed by the final recovery section. A significantly more compact layout was achieved without compromising access requirements. Along with the other cost reduction concepts, this has now become the basis for the feasibility study engineering development.


Run of Mine or ROM stockpile
PRIMARY CRUSHER (existing)
-250mm
12000 ton Bunker (existing)
12000 ton Bunker (in plant)
Bleed
Scrubber
2 X HPRC Gap 35 mm
- 60 mm
HPRC Bin
Single Deck Sizing Screen 60mm
+ 60 mm
Cone Crusher Bin
1 X Cone Crusher (Feed Prep Rolls Gap > 30mm)
-60mm
-60 + 1.6 mm
Double Deck Sizing Screen 28 mm / 6 mm
+28mm
-28mm +6 mm
Bleed -28 +6 mm
u/f
- 6mm
Desand +1.6mm
-6mm + 1.6mm
4 X DMS Storage (Fines)
5 X DMS Storage (coarse)
o/f
- 0.2mm
-1.6mm year 1
- 6mm + 1.6mm
- 28mm + 6mm
O/F
Process Water
Degrit Cyclone
DMS Feed Preparation
DMS Feed Preparation
o/f
-0.2mm
u/f
Slimes Thickener
Degrit Screen
4 X Fines DMS - 6mm + 1.6mm modules
5 X Coarse DMS - 28mm + 6mm modules
- 28mm + 8mm year 1
- 28mm + 6mm year 2
u/f
-8 mm Fines Tails year 1
- 6 mm Fines Tails year 2
Sink Screen Product
Sink Screen Product
Slimes Pump
Wet X-Ray Recovery
Recovery Tails -28mm
+12mm
-12mm
Slimes Disposal
Grease Recovery
Slimes Facility
Tailings Facility
Diamonds
Recovery Dump

3.0 MASS BALANCE DEVELOPMENT

3.1 Main Plant Mass Balance

Prosim is a windows-based dynamic flow sheet simulator which was developed for mine to mill simulation by Metso Minerals in collaboration with Debswana Diamond Company. It uses MinOOcad software. In ProSim, the ore characteristics are key inputs resulting in a suite of treatment recipes as outputs. The following are important characteristics of Prosim;

- Uses state-of-the-art population balance models – applies law of conservation of mass.
- The models are calibrated with plant data and validated with other independent plant data and equipment supplier specifications.
- Sometimes parameters can be calculated with the results from discrete element modelling and computational fluid dynamics simulations in High Fidelity Simulation (physics based) which ensures high accuracy.
- Has the capability for running up to 200 times real-time, enabling the running of a year's mine plan in a matter of hours.
- Iteratively reduce mine plan into treatment recipes and highlights production bottlenecks or constraints in a flowsheet.

Mass balance modelling for the Orapa 3 process plant was undertaken by the Orapa Expansion Project process team. During the pre-feasibility study, models were developed using both Prosim and the De Beers Diamond Wizard tool. The models were calibrated for the Orapa 2 flowsheet using data obtained from Orapa 2 operations, including the results of the 100% basalt breccia testwork carried out at Orapa Mine. Information from HPRC and scrubber testwork carried out in Germany was also incorporated into the model. Following an exercise to compare Prosim and Diamond Wizard models, it was concluded that the model outputs were sufficiently convergent for the Prosim platform to be used for further investigations, with however some concerns regarding the prediction of thickener feed arisings, which the Prosim model under estimates as a result of the relatively unsophisticated modelling approach in this area. Fortunately sufficient data was available from Orapa 2 operations to provide valuable input into the design for this stream.

At the conclusion of the PFS, the model had been used to define the mass balance arisings for the target of 9.8 Mtpa for the PFS proposed flowsheet and as a basis for process equipment sizing. Dynamic simulation of the plant flowsheet and materials handling facilities was carried out to determine surge capacities required between process sections.

The Prosim model served from the inception of the feasibility study as the basis for evaluation of the increased target throughput of 12Mtpa, superimposed on flowsheet development driven by the need to minimise the capital cost.

In addition to the usual envelope of plant feed types, represented in the case of Orapa 3 by the lower (10%) and upper (47%) limits of basalt breccia content of the ore feed, the proposed Orapa 3 flowsheet introduces an internal recirculation stream, where a portion of the 6 to 25mm

scrubber product normally routed directly to the DMS section, can be bypassed to the HPRC section. The purpose of this is to allow the process plant to maintain ROM throughput, particularly of high basalt content feed, under such circumstances as lower than planned DMS section availability, or alternatively to take advantage of planned available DMS capacity to increase ROM throughput. This feature, together with the variable mid-cut-off size and the option to route 4 to 6mm material to either the fines or coarse DMS sections, added additional dimensions to the mass balance modelling. The Prosim model was revised accordingly to reflect the range of scenarios being considered, so as to provide an understanding of the effectiveness of the proposed internal recirculation of 6 to 28mm material feed on decoupling the DMS feed arisings from the basalt content of the feed.

The mass balance summary outputs shown in Tables 3.1.1 and 3.1.2 illustrate the range of process plant section feed arisings for progressively finer mid-cut-off sizes of 10 mm, 8 mm and 6 mm, and the limits of the 6 to 28mm material bypassed to the HPRC section.

Table 3.1.1 – Mass Balance (dry t/h) for 0% bypass of 6 to 28 mm material to HPRC

	47% Basalt Breccia, 0% 6-28mm bypass					
	Recrush Size 6mm		Recrush Size 8mm		Recrush Size 10mm	
	4-6mm Middles		4-6mm Middles		4-6mm Middles	
Stream	Coarse DMS	Fines DMS	Coarse DMS	Fines DMS	Coarse DMS	Fines DMS
ROM Feed	1715	1715	1715	1715	1715	1715
Scrubbing Section Feed	4437	4228	3951	3927	3535	3532
HPRC Section Feed	2722	2513	2236	2212	1820	1817
Cone Crusher Feed	575	562	545	543	516	515
Coarse DMS Feed	1975	1589	1638	1443	1360	1212
Fines DMS Feed	281	495	254	426	226	369
Total DMS Feed	2256	2084	1891	1868	1586	1581

Table 3.1.2 – Mass Balance (dry t/h) for 50% bypass of 6 to 28mm material to HPRC

	47% Basalt Breccia, 50% 6-28mm bypass					
	Recrush Size 6mm		Recrush Size 8mm		Recrush Size 10mm	
	4-6mm Middles		4-6mm Middles		4-6mm Middles	
Stream	Coarse DMS	Fines DMS	Coarse DMS	Fines DMS	Coarse DMS	Fines DMS
ROM Feed	1715	1715	1715	1715	1715	1715
Scrubbing Section Feed	4511	4289	4020	4092	3629	3818
HPRC Section Feed	2796	2574	2305	2377	1914	2103
Cone Crusher Feed	579	566	549	554	523	536
Coarse DMS Feed	1156	805	1039	757	941	676
Fines DMS Feed	292	521	261	474	234	432
Total DMS Feed	1447	1326	1300	1231	1175	1109

As can be seen from comparison of the total DMS feed arisings in matching columns, the ability to bypass 50% of 6-28 mm scrubber product to the HPRC has a dramatic impact.

To narrow the mass balance and avoid costly over-design, a decision was taken by Debswana to set the mid-cut-off size (i.e. the recrush size) at 8 mm. During the process flowsheet and equipment selection exercise, it was also decided that the 4 to 6mm middlings fraction would be routed to treatment in DMS modules set up to optimise separation of the 1.6 to 6mm feed size range. The effect of a variable bypass ratio of 6 to 28mm material to HPRC on high basalt

breccia feed was modelled for these selections, and a benchmark added to represent low basalt breccia feed for comparison. This mass balance is shown in Table 2.1.3. Worst case arisings represented by this mass balance on a stream by stream basis have been used as the design criteria for equipment selection for the Orapa 3 process plant.

As discussed above, the predicted thickener feed arisings are considered too low, and a value of 750 dry t/h has been specified in the design criteria. Similarly, the recovery section design criteria feed rate has been based on worst case arisings of DMS concentrates rather than the nominal values given in Table 3.1.2.

Table 3.1.3 Mass Balance (dry t/h) for variable % bypass of 6 to 28mm material to HPRC

Basalt Breccia Content of ROM 6-28mm scrubber product to HPRC	47% 0%	47% 10%	47% 20%	47% 30%	47% 40%	47% 50%	10% 0%
Headfeed	1,715	1,715	1,715	1,715	1,715	1,715	1,715
Scrubber_Feed	3,927	3,955	3,985	4,018	4,053	4,092	3,261
HPRC_Feed	**2,212**	**2,240**	**2,270**	**2,303**	**2,338**	**2,377**	**1,546**
Cone Crusher Feed (+60mm)	543	545	547	549	552	554	422
Coarse DMS Feed	1,443	1,309	1,174	1,037	898	757	911
Desand Feed (-8mm)	1,507	1,521	1,535	1,551	1,568	1,586	1,569
Fines DMS Feed	426	434	443	452	463	474	405
TOTAL DMS	**1,868**	**1,743**	**1,617**	**1,489**	**1,361**	**1,231**	**1,316**
Degrit Feed	1,085	1,090	1,095	1,101	1,108	1,115	1,166
Thickener Feed	608	610	611	612	614	615	675
Tailings and Grits to Dump	1,100	1,099	1,098	1,097	1,096	1,094	1,035
Combine Concentrate_to_CARP	2.90	3.00	3.00	3.00	3.00	3.00	2.40
6-28mm scrubber product to HPRC	0	145.5	293.5	444.4	598.7	756.8	0

Carats							
Headfeed	1413.2	1413.2	1413.2	1413.2	1413.2	1413.2	1920.8
Combined DMS Concentrate	947.1	947	946.8	946.6	946.3	946	1283.8

It can be concluded from the tables above that the ability to bypass 6 to 28 mm scrubber product to the HPRC section, within acceptable limits, can be used to eliminate the variation of scrubber feed, HPRC section feed and DMS section feed arisings relative to basalt breccia content of the plant feed. At least as important, is the fact that 1.6-28 mm carat content of DMS concentrate from high basalt breccia feed is unaffected by bypassing 6 to 28mm scrubber product to the HPRC, up to the imposed 50% limit. Note the basalt breccia content is approximately 0.27 ct/t and kimberlite 0.8 ct/t. The headfeed carats are for the total content curve, from which carats <1.65 mm are not recovered into DMS concentrate.

The wider process design implications of this feature are discussed in section 3.0 below.

3.2 Recovery Section Mass Balance

Mass and particle size distribution envelopes were generated based on production data for Orapa 1 and 2 over several years. This generated a 10.4 t/h peak tonnage based on a DMS yield equivalent to 0.61% of ROM at a ROM feed rate of 12 Mtpa and a plant utilisation of 83%. Particle size distributions from fine to coarse of:

- 50%-27% +1.6 mm-3 mm
- 35%-30% +3 mm-8 mm
- 15%-43% +8 mm-32 mm

The plant design allows for the presence of -1.6 mm grit in the feed to the recovery as well as grit developed in the recovery process but no reduction is applied to the recovery processing in the X-Ray streams.

The material mass distribution is divided equally amongst the various available streams and is recombined at reconstituting points such as the scrubber feed and tailings.

X-ray yields are based on luminescent material present but with allowable factors for the presence of non diamond luminescent material. The factors used can indicate the maximum presence of non diamond material based on the flow sheet without overloading the re-concentrate circuit.

The water balance for the plant allows for a constant inflow of potable (desalinated) water to the X-ray circuits but with raw water make up for level control and tapping of process water from the DMS concentrate delivery. The grease process water circuits utilise recycled process water to keep process water inside the temperature control envelope. The water balance makes use of considerable recycled process water in transfer and spray systems with dirty (grits) process watering being bled from the system via the scrubber product and safety screen.

Diamond size distributions were generated by Debswana operations and an additional 10% allowance in total carats was made based on the extra liberation expected from the plant front end. This equated to a head feed grade of 77 CPHT.

Metallurgical testwork on magnetic separation application to Orapa concentrates indicated that there is potential for magnetic separation to achieve a significant reduction in X-ray sorter feed arisings of a minimum 40% in all the size ranges, with no loss of magnetic diamonds (mainly boart) from Orapa concentrates.

4.0 FLOW SHEET DEVELOPMENT

4.1 Baseline Flowsheet at commencement of Feasibility Study

The conceptual flowsheet developed during the PFS by Debswana adopted features that more recently have become accepted within the De Beers group. In addition, lessons learned from the operation of the Orapa 2 plant proved a valuable guide in flowsheet development. At a conceptual level, these can be summarised as follows:

- Flexibility to manage changes in ore characteristics with minimal impact on ROM capability and without excessive over-design.
- Advance HPRC to a combined tertiary/recrushing role, to reduce both the overall DMS feed arisings and the impact of variations in ore competency thereon, and to liberate diamonds as soon as possible.
- Combined primary and secondary scrubbing duties.

- General elimination of standby equipment and streams unless "mission-critical".
- Minimising the number of drives required to function in a particular sequence, by use of surge points and passive standby.
- Inclusion of a degritting section to protect the thickeners from fast settling solids that require no thickening, and to reduce overall water consumption.

4.2 Hooks and the Core Plant

Advancing from the general flowsheet concepts, the concept of the "Core Plant" was partially considered at PFS stage. The "Core Plant" principle involves matching the priority of stream processing to the value of the stream. This means that the flowsheet and associated layout should allow for low value streams to be selectively either temporarily stored or discarded where ROM throughput is threatened. The principle examples of such streams are those containing:

- Small diamonds, in the case of Orapa <1.6 mm, which are relatively abundant but which vary in value significantly with trends in the global diamond market.
- Large diamonds, in the case of Orapa >28 mm, which are very rare and extremely variable in value.
- Locked diamonds in the coarse DMS floats stream.
- Easily identifiable coarse waste that can be cost-effectively removed to reduce downstream processing of essentially barren material.

In each of the above, the contribution of the diamonds to overall revenue is relatively low, often unpredictable, and the capital and operating cost associated with recovering the diamonds is relatively high

With the exception of the coarse DMS floats stream, which was included in effect as a core stream, the other low value streams were excluded from the intended Orapa 3 design. In each case, consideration was given to the manner in which such streams could be generated at some future point with minimal disruption to ongoing core operations. Whether this will eventuate is not possible to predict. However, in each case the relevant additions and modifications will only be made if a business case can be proven. Since these streams will always remain relatively low value streams compared to ROM ore, implementation should be such that bypassing such sections can be easily accomplished if equipment failure etc threatens ROM throughput targets.

4.3 Capex Reduction - Prefeasibility Study

A Capex reduction initiative (Orapa 3 – Lean Option) carried out by Debswana during the concluding period of the PFS evaluated a variety of potential options for simplifying the process flowsheet and plant layout.

An additional series of value engineering studies was undertaken by Fluor during a basis of design review at the beginning of the feasibility study stage. Alternatives were considered, including those proposed in the Orapa 3 – Lean Option, and recommendations presented to Debswana for approval.

Changes identified in the Orapa 3 – Lean Option which were adopted in the feasibility study flowsheet following Debswana approval included:

- Reduce scrubber retention time to two minutes.
- Install a single stream comminution circuit. This referred to the elimination of the previously proposed dual stream secondary crushing section, combining the secondary crushing duty into a single unit, fed by >60 mm material from the scrubbing section and discharging <60 mm crushed product onto the HPRC feed conveyor.
- Single HPRC feed bin. The feed from all sources to the HPRC section is combined in a single bin, from which the two HPRC units are fed by variable speed belt feeders.
- Pump fed DMS cyclones instead of gravity fed DMS cyclones.
- Replacement of paste thickening with high-density thickening.
- Eliminate emergency DMS tailings node.
- Changes identified in the Orapa 3 – Lean Option which were not adopted in the proposed flowsheet:
- Perform Desand screening in the scrubber section. This was not adopted because of the inability of the proposed screens to achieve the process duty, and hence the proposed concept was considered unworkable as presented. In addition, a philosophy was adopted that critical screening duties should be upper-deck duties, promoting operator vigilance and relatively simple maintenance. The duty proposed in the PFS was a bottom deck duty on a double-deck screen.
- Scrubber feed stockpile simplification. This was partially adopted in that the slewing/luffing stacker conveyor was eliminated. However, largely as a result of the impact of dust control measures required to prevent the inundation of Orapa 2 with dust generated on the Orapa 3 stockpile, a 12,000 tonne concrete silo was adopted, similar to the existing silo servicing Orapa 1 and Orapa 2 (and in future, also Orapa 3)

Changes identified in the Orapa 3 – Lean Option which were not applicable to the Fluor proposed flowsheet:

- Eliminate one series of DMS feed storage silos feed conveyor systems
- Reduction of DMS feed storage silo capacity
- Eliminate the individual DMS feed conveyors

The above were rendered obsolete as a result of the decision to adopt a split DMS arrangement, with separate coarse and fines DMS modules.

4.4 Feasibility Study Flowsheet

The flowsheet adopted as the basis of design for the Orapa 3 process plant differs in several aspects from the flowsheet proposed at pre-feasibility study stage.

- Provision of the ability to bypass a portion of the scrubber product in the 6-28 mm size range to the HPRC section. The reason for this is to trade-off, if necessary, a minimal risk of damage to liberated diamonds against the ability to maintain ROM throughput with

reduced DMS section availability. Alternatively, this feature can be utilised to increase ROM throughput capability, assuming DMS availability is as planned, up to the limit of the capacity of the HPRC section. This is a somewhat more controversial application, as it could be construed as over-design. A more rational evaluation would be to consider the bypass facility as allowing the available capacity of the key plant sections to be balanced to permit the maximum ROM treatment possible under any particular set of circumstances.

- The DMS section has been configured with five coarse modules (6-28 mm), two fines modules (1.6-6 mm) and two swing modules. The swing modules can be used for either coarse or fines feed streams, but are configured as fines modules with regard to cyclone operating parameters.
- The envisaged scenario, with respect to the capabilities provided in the flowsheet, is potentially as follows:
- Worst case ROM type (47% ROM) at 1,715 dry t/h with no bypass of 6-28 mm scrubber product can be accommodated using all five coarse modules, two fines modules and one swing module operating on coarse feed. One DMS module (which would have to be module 7, 8 or 9) is available for maintenance etc.
- If a second DMS module becomes unavailable, bypassing 20% of the 6-28 mm scrubber product allows the ROM feedrate to be maintained at 1,715 dry t/h. The second unavailable module can be any module.
- If a third DMS module becomes unavailable, bypassing 30% of the 6-28 mm scrubber product allows the ROM feedrate to be maintained at 1,715 dry t/h. In this case, of the remaining six modules, three out of modules six to nine must be available, or ROM throughput will fall towards 1,500 dry t/h to avoid compromising fines DMS medium: ore ratio (or this could be temporarily compromised, which in practice is probably the logical selection).
- The ultimate selection of 50% bypass of 6-28 mm scrubber product to HPRC potentially allows 1,715 dry t/h of 47% basalt breccia feed to be accommodated in only five modules, although if only two of these are available for fines treatment (i.e. only two of modules six to nine), then a similar effect on fines DMS medium: ore ratio would be encountered

As can be seen, the bypass facility affects almost exclusively the arisings to the coarse DMS, and will ultimately allow full ROM capacity to be accommodated in only three coarse DMS modules (i.e. three out of modules one to seven). Beyond the 50% allowable bypass of 6-28 mm material to HPRC, maintaining ROM capacity can then only be achieved by selectively discarding coarse DMS floats to rejects which is provided for on a module by module basis. This impacts largely the fines DMS arisings, thus balancing the required fines modules versus available fines modules six to nine. It is only at this point that revenue is potentially at risk, although ROM revenue contribution is much greater than that from coarse DMS floats.

4.5 Recovery Section

The flow sheet was developed following the basic unit process requirements as stipulated by Debswana:

4.5.1 Sizing and Storage:

The concentrate from the DMS requires sizing into fractions suitable for further processing and surge is required for both decoupling the recovery from the DMS as well as providing holding for batch processing.

4.5.2 Transfer to further treatment

This is achieved using jet pump/booster pump hybrid systems due to the heights required, to avoid excess tip speeds in the centrifugal pumps and to ensure reliable delivery from the bottom of gravel filled bins. Slurry streams are dewatered prior to processing and weighing for accounting purposes.

4.5.3 Bulk Magnetic Reduction:

BaFe and NdFeB magnetic separation units will be included in the flow sheet post the successful bulk reduction testwork done on Orapa material.

4.5.4 Wet Primary X-ray systems:

X-ray sorters are per Debswana's requirement for wet and dry CWX118CD and CDX118CD (ModRUP) sorters from Debtech. The X-ray sorters will be supplied with desalinated water to avoid problems associated with dissolved salts crystallising on the sorter widows.

Wet X-ray treatment, in rougher/scavenger configured sorters, is split into a dedicated fines stream, and batch middles/coarse streams.

X-ray tailings report to grease scavenging while the concentrates are re-concentrated to meet the at least 50% diamond by weight (DBW) required for shipment.

4.5.5 Dry Re-concentration X-ray:

Dry re-concentration X-ray sorting was selected primarily as, unlike wet re-concentration, the dry route was capable of achieving the required 50% DBW and hence eliminated the need for further retreatment in a dry single-particle X-ray sorter.

This required drying and cooling step between the wet primary and dry re-concentration stages was provided by vibrating pan infra-red driers with post-drier-cooling air to reduce the concentrates temperature sufficiently to preserve diamond X-ray fluorescence response.

4.5.6 Weighing and packaging of X-ray concentrates

The X-ray concentrates will be collected and shipped to the Jwaneng Fully Integrated Sort House (FISH) for final recovery. To fit the current system this will be by means of Debtech dock locks and a system for optimally and reliably filling these is currently being developed.

4.5.7 Grease Scavenging of X-ray Tails

Grease scavenging of X-ray fine tails is included, to increase overall diamond recovery and as an auditing function on X-ray sorter performance.

Effective grease recovery of diamonds requires a light attritioning step to prepare the surface of the diamonds for grease recovery. This is accomplished by using a conventional wet rotary scrubber. The scrubbed product is scalped at 12mm, with the -12mm stream screened into two size-fractions, which are fed separately to the grease belt to ensure acceptable material flow control. Material larger than 12mm is returned to the HPRC section in the main plant both to liberate any additional diamond revenue and, in the rare event that any large diamonds are lost to X-ray rejects, to ensure that these are locked into the circuit.

Final degreasing of diamond-bearing grease concentrates will be either internal to the grease belt unit or manually accomplished as an external operation. An internal automated inspection and cleaning system is preferable to satisfy security protocols and is currently under development.

4.5.8 Material Transport and Transfer

Gravity will be used for the most part to transport material from unit process to unit process with exceptions for entering feed into the plant for the first time and introducing material back to the grease circuit. All attempts were made to reduce impact velocities in gravity transport by reducing drop heights by either height reduction and/or cascade chutes.

Jet pump systems are used either by themselves or as part of hybrid systems for transfer of material from loaded bins with little vertical height required under the bin and a reduced chance of blockage.

Vacuum systems will be used for the return of re-concentration tails and spillage but not the transfer of first stage X-ray concentrates due to the difficulty of controlling particle velocity across the duty envelope and hence potential for unacceptable diamond damage.

4.5.9 Accounting

Mass accounting of material in the recovery will be achieved by either batch weighing systems of variable accuracy depending on the stream to be weighed. Belt scales will be used for interim accounting and process control and final tailings accounting.

Mass accounting in individual process streams for process control is achieved by monitoring the throughputs of the volume feeders though these generate implied rates rather than rates determined from feedback.

Accounting of grease concentrates and to a lower degree X-ray concentrates will be handled by the SCADA system. SADAS was omitted due to the functionality required not being that of a full sort house.

4.5.10 Process stream requirements were based on the following:

The total tonnage to the plant with the supplied particle size distribution envelope and utilisation of 81%. In addition to other details this limited the top particle size of 35 mm eliminating the need for oversize scalping in the recovery.

The feeding arrangement of a hybrid batch approach with a series of streams being allocated to fines only while middles and coarse shared a series of streams.

The diamond size, frequency distribution and grade which were used to determine yields and load on final re-concentration sorters. Factors were applied to this based on sorter supplier information and additional luminescent material and fines.
Vendor supplied throughput data based on general throughputs achievable for the various unit processes but without the benefit of specific material test work. An exception to this is the bulk magnetic reduction test work which has just been completed and whose outcome will be used in the detailed design phase.

5.0 BOTTLENECK ANALYSIS

Detailed bottleneck analysis for the Orapa 3 process plant awaits the planned dynamic simulation exercise. However, a preliminary conceptual bottleneck analysis was undertaken to indicate the achievable overall plant throughput as constrained by various sections of the process plant. The key impacts on plant throughput are associated with the availability of DMS treatment capacity, the extent to which the plant feed is infested with low grade, but hard, basalt breccia, and the use made of the ability to bypass DMS feed to the HPRC section. The generalised bottlenecks are shown in Table 4.1 – Orapa 3 General Plant Capacity Constraints and the extended DMS specific bottlenecks in Table 4.2 – Orapa 3 DMS Specific Plant Capacity Constraints.

Table 4.1 – Orapa 3 - General Plant Capacity Constraints

Stream	47 % BB, 0% bleed of 6-28mm to HPRC					47 % BB, 50% bleed of 6-28mm to HPRC					10 % BB, 0% bleed to HPRC				
	Arisings	Section Capacity		Ajusted Orapa 3 Plant Capacity		Arisings	Section Capacity		Ajusted Orapa 3 Plant Capacity		Arisings	Section Capacity		Ajusted Orapa 3 Plant Capacity	
	Design dtph	Maximum dtph	%	Per Section dtph	At First Bottleneck dtph	Design dtph	Maximum dtph	%	Per Section dtph	At First Bottleneck dtph	Design dtph	Maximum dtph	%	Per Section dtph	At First Bottleneck dtph
Headfeed	1715				1716	1715				1715	1715				2152
Scrubber_Feed	3927	4092	104%	1787		4092	4092	100%	1715		3261	4092	125%	2152	
Scrubber Screening	3384	3540	105%	1794		3538	3540	100%	1716		2480	3540	143%	2448	
HPRC_Feed	2212	3000	136%	2326		2377	3000	126%	2165		1546	3000	194%	3328	
Cone Crusher Feed (+60mm)	543	700	129%	2209		554	700	126%	2167		422	700	166%	2846	
Coarse DMS Feed	1443	1500	104%	1783		757	1500	198%	3399		911	1500	165%	2825	
Desand Feed (-6mm)	1507	2220	147%	2526		1586	2220	140%	2400		1569	2220	141%	2427	
Fines DMS Feed	426	426	100%	1716		474	639	135%	2312		405	639	158%	2706	
TOTAL DMS	1868	1926	103%	1768		1231	2139	174%	2980		1316	2139	163%	2788	
DEGRIT FEED	1086	1656	153%	2619		1115	1656	149%	2547		1166	1656	142%	2436	
THICKENER FEED	608	960	158%	2706		616	960	156%	2674		675	960	142%	2438	
Combine Concentrate_to_CARP	3	10.4	359%	6150		3	10.4	347%	5945		2	10.4	433%	7432	

Notes: Above capacities assume all available process streams are operational, with any one DMS module on maintenance
Recovery section capacity defined by value of 0.61% of Orapa 2 headfeed, per production records

Table 4.2 – Orapa 3 – DMS Specific Plant Capacity Constraints

DMS Availability						Orapa 3 Plant Capacity, dtph		
Coarse Modules		Fines Modules		Total DMS		47% BB	47% BB	10% BB
No	Capacity	No	Capacity	No	Capacity	0% 6-28mm Bleed	50% 6-28mm Bleed	0% 6-28mm Bleed
2	500	1	213	3	713	594	771	902
2	500	2	426	4	926	594	1133	942
3	750	2	426	5	1176	892	1541	1412
3	750	3	639	6	1389	892	1700	1412
4	1000	2	426	6	1426	1189	1541	1804
4	1000	3	639	7	1639	1189	2266	1883
5	1250	2	426	7	1676	1486	1541	1804
5	1250	3	639	8	1889	1486	2312	2354
6	1500	2	426	8	1926	1716	1541	1804

The baseline design case assumes that a feed of 47% basalt breccia will be treated with no use of the facility to divert the 6-28 mm portion of the DMS feed to the HPRC section. This has driven the selection of nine DMS modules, of which any one is assumed to be unavailable at all times. As can be seen from Table 8.5.1, the plant design is otherwise aligned quite well with the required capacity, noting that in the desanding section particularly the spare capacity is expected to be employed to allow individual screens to be stopped for regular inspection on a regular basis.

Table 4.2 shows that, by employing the DMS feed diversion facility, it is possible to achieve the design plant throughput even on ores with high basalt breccia content with as few as seven modules. Following the dynamic simulation exercise this will be evaluated more thoroughly and the number of DMS modules to be installed confirmed.

6.0 PROCESS DESIGN FEATURES OF THE ORAPA 3 PLANT

6.1 Scrubbing and Screening

The Orapa 3 scrubbing and screening section has been designed to incorporate the advantages of parallel primary scrubbing with those of split primary/secondary scrubbing. Together with the ability to divert 6-28 mm scrubber product to the HPRC circuit, this configuration provides a highly flexible means of responding to changes in ore type and downstream equipment availability.

Conventional scrubbing section arrangements in use in large diamond recovery plants follow one of the following configurations (although there are variations in detail if not in concept):

6.2 Complex scrubbing, high DMS feed arisings, high scrubbing capacity required

All ROM ore is fed to primary scrubber(s). Washed ore in the size range for diamond recovery is routed to the DMS circuit. Oversize from the primary scrubbers and coarse floats from the DMS circuit are crushed in a combination of cone and HPRC crushers and the crushed products re-scrubbed in separate secondary scrubbers. In this configuration, the primary scrubbers are open-circuit and the secondary scrubbers in closed-circuit. Typical examples are Orapa 2, Venetia, and Diavik.

6.3 Simple Scrubbing, high DMS feed arisings, low scrubbing capacity required

All scrubbing duties are combined in a single scrubbing circuit, with crushed oversize and recrushed HPRC product returning to join ROM ore. Washed ore in the size range for diamond recovery is routed to the DMS circuit and coarse DMS floats reporting to the HPRC circuit. The scrubbing section is in closed-circuit. A typical example is Kimberley CTP.

6.4 Complex scrubbing, low DMS feed arisings, high scrubbing capacity required

ROM/Secondary crushed ore is fed to primary scrubbing with oversize routed to HPRC. Washed ore in the size range for diamond recovery is also routed to HPRC and the HPRC product reports to secondary scrubbing. Only washed ore in the size range for diamond recovery from the

secondary scrubbing circuit reports to the DMS circuit. Coarse DMS floats are returned to the HPRC. In this configuration, primary scrubbing is in open circuit, secondary scrubbing in closed-circuit. The principle current example is Ekati.

The obvious configuration missing from the above is to combine simplified scrubbing with low DMS feed arisings. This is the configuration embodied in the Orapa 3 plant:

6.5 Simple Scrubbing, low DMS feed arisings, low scrubbing capacity required

All scrubbing duties are combined in the same two scrubbers. Washed ore in the size range for diamond recovery can be routed either to DMS or diverted to HPRC. DMS coarse floats are normally routed to HPRC but can also be discarded to tails.

ROM ore can be preferentially fed to one scrubber and HPRC product to the other scrubber. Any combination of ROM ore/HPRC product can be selected for feed to one scrubber, with the other scrubber by default receiving the remainder. Therefore the scrubber receiving preferentially ROM ore (pseudo-primary scrubbing) can be selected to deliver washed ore in the size range for diamond recovery to HPRC, whilst the scrubber receiving preferentially HPRC product (pseudo-secondary scrubbing) delivers washed ore in the size range for diamond recovery to the DMS circuit. Either scrubber can assume either role, or the balance of HPRC product relative to ROM ore can be assigned between scrubbers on the basis of maximising scrubbing efficiency.

The flexibility provided by the combination of asymmetric scrubbing feed and diversion of some 6-28 mm material to HPRC pre-DMS is shown in Table 6.1.1 – Effects of Asymmetric Scrubbing and Bypass on 6-28 mm Ore to HPRC. The salient features are:

- 8.4% increase in scrubber feed (pseudo-secondary only)
- 7.5% increase in HPRC feed
- 34% reduction in feed to DMS

The appropriate capacity allowances are within the design safety margins for scrubbing and HPRC. The ability to reduce DMS feed by 34% on the worst case ore type (47% basalt breccia) whilst maintaining ROM ore throughput is key to delivering consistent plant performance in periods of challenging DMS operation.

Table 6.1.1 – Effects of Asymmetric Scrubbing and Bypass of 6-28mm Ore to HPRC

ROM Feed	DMS Feed	Scrubbing Feed	Scrubber 1					HPRC	Scrubber 2				
47% BB			Total Feed	ROM Feed		HPRC Product Feed	Divert 6-28mm	Product	Total Feed	ROM Feed		HPRC Product Feed	Divert 6-28mm
dtph	dtph	dtph	dtph	% of total	dtph	dtph	% to HPRC	dtph	dtph	% of total	dtph	dtph	% to HPRC
1715	1868	3927	1964	50	858	1106	0	2212	1964	50	858	1106	0
1715	1868	3927	1964	60	1029	935	0	2212	1964	40	686	1278	0
1715	1868	3927	1964	70	1201	763	0	2212	1964	30	515	1449	0
1715	1743	3955	1964	50	858	1106	10	2240	1992	50	858	1134	0
1715	1743	3955	1964	60	1029	935	10	2240	1992	40	686	1306	0
1715	1743	3955	1964	70	1201	763	10	2240	1992	30	515	1477	0
1715	1617	3985	1964	50	858	1106	20	2270	2022	50	858	1164	0
1715	1617	3985	1964	60	1029	935	20	2270	2022	40	686	1336	0
1715	1617	3985	1964	70	1201	763	20	2270	2022	30	515	1507	0
1715	1489	4018	1964	50	858	1106	30	2303	2055	50	858	1197	0
1715	1489	4018	1964	60	1029	935	30	2303	2055	40	686	1369	0
1715	1489	4018	1964	70	1201	763	30	2303	2055	30	515	1540	0
1715	1361	4053	1964	50	858	1106	40	2338	2090	50	858	1232	0
1715	1361	4053	1964	60	1029	935	40	2338	2090	40	686	1404	0
1715	1361	4053	1964	70	1201	763	40	2338	2090	30	515	1575	0
1715	1231	4092	1964	50	858	1106	50	2377	2129	50	858	1271	0
1715	1231	4092	1964	60	1029	935	50	2377	2129	40	686	1443	0
1715	1231	4092	1964	70	1201	763	50	2377	2129	30	515	1614	0

Scrubber 1 feedrate maintained constant, Scrubber 2 feedrate allowed to vary.
Total scrubbing section feedrate variation 165dtph: HPRC feedrate variation 165 dry t/h; DMS feedrate variation 637dry t/h

6.6 Secondary Cone Crusher

At Orapa 3, HPRC has been promoted to the combined role of tertiary and recrush crushing. HPRC delivers a much greater size reduction ratio than cone crushing, at an operating gap that all but eliminates the risk of damage to diamonds present in the feed to the rolls. However, the maximum feed particle size to the rolls must be restricted to avoid damage to the studded surfaces and to reduce wear on the studs as a result of the inability of the rolls to draw in large particles efficiently. For this reason a single cone crusher has been selected to generate a product with a 60 mm nominal top-size. Feed to the cone crusher is >60 mm washed scrubber product. The cone crusher is in open-circuit, with the product joining <60 mm washed scrubber product and reporting to the HPRC section.

Although it is inevitable that >60 mm particles will occasionally be present in the cone crusher product as a result of tramp bypass events etc., the small quantity reporting to the HPRC poses very limited risk of meaningful stud damage and will have negligible impact on HPRC throughput or product quality. The cost and complexity of closed circuiting the cone crusher is therefore avoided.

Of importance, given only a single unit will be installed, is that the cone crusher product quality is of little interest relative to the ability of the crusher to withstand a feed of up to 100% basalt breccia without failing either mechanically or electrically, and the ability to accept a large feed size on occasions. This means that the crusher can be over-designed with wear parts selected for long life rather than to generate a product focused on a high "set-under" value. Complexities such as grooved mantle and liner configurations etc. are less attractive than a short crushing path and a coarse liner configuration. The preliminary selection of a Metso HP800 with extra coarse cavity will accept feed particles up to 350 mm, which would be a rare occurrence.

6.7 Studded Roll HPRC

The use of studded roll HPRC units has become common in diamond recovery operations. Continual development of the studded surfaces, and more importantly protection of the roll edges has resulted in units that have a significantly higher availability than was previously the case with profiled rolls. More recently, the availability of studded roll HPRC units, which inherently deliver higher specific throughput than non-studded rolls and are also more tolerant of feed moisture, has allowed HPRC technology to be applied in a combined tertiary and recrush crushing role. The combination of a large working gap (thus protecting diamonds from potential damage) and large feed size capability relative to roll diameter ideally suits this duty. Unique at the present time within Debswana (and De Beers), the Orapa 3 HPRC circuit is designed to be also fed with liberated diamonds contained within material of a size range that is conventionally routed to the DMS section for diamond recovery. Previously (with the exception of Ekati in terms of major diamond operations) introducing liberated diamonds into an HPRC was considered high risk. Whilst studies undertaken by a number of operations had concluded that damage to diamonds less than approximately 80% of the working gap was economically insignificant, the application of HPRC was still restricted to feed stock containing locked diamonds. Thus the ability to greatly reduce the DMS feed arisings by crushing and then re-screening the DMS feed was excluded. However, simple consideration of the mechanics of the roll crushing process leads to the conclusion that, even

if a diamond is locked within a piece of kimberlite when fed into the roll gap, it is not effectively liberated at the instant of exit from the rolls, but at some point between entering and leaving the roll gap. At that point it becomes identical in circumstance to a free diamond of the same size fed into the roll along with kimberlite particles to which it is not related. Hence, if the risk to the formerly locked diamond is economically insignificant as long as it is less than 80% of the roll gap in size, then the risk to the formerly free diamond of the same size is logically also economically insignificant.

The Orapa 3 flowsheet takes advantage of this conclusion in a very conservative way. That is, the installed DMS capacity is sufficient to permit the target ROM ore throughput to be attained with no diversion of DMS feed to the HPRC. However, given the challenges reported by Debswana in maintaining DMS module availability, particularly during periods of unstable power supply, the ability to reduce the volume of feed reporting to the DMS by up to 34% without reducing ROM ore throughput, represents a means of preserving operating revenue vastly greater than that at risk through any notion of HPRC damage to diamonds less than 80% of the rolls working gap. The bypass of DMS feed to the HPRC section in a sequential and controlled manner simply aims to match the available DMS capacity to the target ROM ore throughput rate on a continuous basis.

As discussed in Section 8.4 Process Design, the HPRC section product can be split between the two scrubbers to suit a range of operational requirements. Each HPRC is capable of a minimum of 133% of design capacity, and significantly more if the DMS section is at planned availability and hence no DMS feed is being bypassed to the HPRC section. The impact of temporary loss of one HPRC is therefore greatly reduced. Since the product from the two HPRCs is combined before being distributed to the scrubbers, individual HPRCs and scrubbers are isolated from each other.

6.8 Desanding

In the context of the Orapa 3 process plant, desanding applies to the process of removing from downstream diamond recovery stages the ore particles and accompanying diamonds that are smaller than the size range of diamonds to be recovered. From this point onwards, diamonds removed by the desanding section are essentially irretrievably lost. The desanding section is therefore one of the most critical sections of the process plant given the AK1 diamond content curve. Desanding is carried out on single-deck multislope screens, using low pressure wash sprays to increase screening efficiency. Holed, or excessively worn, screen panels will result in loss of economically recoverable diamonds to the tailings conveyors. It is very unlikely that these could be cost effectively salvaged at a later time. For this reason, the design philosophy for the Orapa 3 plant is aimed at facilitating operation and maintenance of the installed screens and screening surfaces. Of the four desanding screens installed, any three can be used to satisfy the design duty. When available, the fourth screen can be also utilised to enhance overall screening efficiency. At other times, the availability of an "installed spare" allows periodic inspection of all the screens, with time available to replace holed or worn panels without impacting on overall ROM throughput. Isolating the desanding duty from all other screening duties facilitates operational control as access to screen panels installed on a single deck screen is simple and quick, and there is no time lost to inspection of bottom-deck screen panels.

As each Desand screen underflow pump discharges to a dedicated degritting cyclone, inspection and maintenance of degritting cyclones should be synchronised with maintenance of the associated Desand screen or its underflow pump.

6.9 Degritting

Degritting, in the context of the Orapa 3 plant, refers to the removal of particles greater than nominally 300 μm from the feed to the thickening section. If fed to the thickening section, these fast-settling particles create potential instability in the thickeners, absorb flocculant unnecessarily, and increase overall water consumption. The degritting section consists of a cycloning section followed by dewatering screens. Each degrit cyclone is fed by a dedicated desand screen underflow pump. The cyclones are either rubber or ceramic lined for extended life, and will be inspected for spigot and internal wear to the same schedule as desanding screen panel inspections. As the degrit cyclone performance is not a critical process duty, cyclone replacement, when required, will be synchronised with desanding screen panel replacement.

The underflow from all operating degrit cyclones is combined before being distributed to the degrit screens. Similarly to the desand section, there are four degrit screens of which any three can be used to satisfy the design duty. This avoids the necessity to stop any of the desand screens to maintain one of the degrit screens (or associated underflow pump).
Degrit screens are not designed with the intention of achieving an efficient size separation. The purpose is rather to capture as many solids as possible into a deep bed, which is progressively dewatered as it climbs the inclined degrit screen in the direction of discharge. The screen panel aperture is somewhat larger than the nominal size cut of 300 μm, as finer particles are captured within the deep bed rather than on the screening surface itself. The screen discharge is conveyable and is co-disposed with the fines DMS floats material. Water and fine solids passing through the degrit screen are conventionally returned to the degrit cyclone feed which in the case of Orapa 3 would require returning this stream to the desanding section feed distributor. However, by delivering this stream to the thickener feed launder, the circuit is simplified. Small amounts of coarse material are not detrimental to the thickener performance. The installed spare degrit screen encourages operations personnel to maintain screening surface integrity without undue impact on ROM plant throughput. This is arguably a superior outcome to recycling degrit screen underflow, which has no economic value, and inherently assumes that operations personnel will act negligently.

6.10 High Density Thickeners

An evaluation of the advantages and disadvantages of the initially proposed paste thickening installation led to an interim selection of an alternative of using deep-bed compression thickeners of Ultrasep design. However, to achieve the process duty, at least 10 thickeners were required of the largest standard design available. The alternative of using modified conventional thickeners, with a higher wall height to increase underflow density, was adopted based on operational experience with the conventional thickeners at Orapa 1. Crucially, and as per the proposed Orapa 3 circuit, Orapa 1 has a degritting section to remove fast-settling grits from the thickener feed.

Basic design data derived from Orapa operating experience specified as follows:

Conventional thickener

Flux Rate	0.18 $t/m^2.h$
Rise Rate	2 m/h
Underflow Density	1.25 t/m^3
Flocculant Consumption	60g/tonne head feed

High Rate thickener

Flux Rate	0.2 $t/m^2.h$
Rise Rate	4 m/h
Underflow Density	1.3 t/m^3
Flocculant Consumption	60g/tonne head feed

Maximum thickener feed slimes arisings was estimated, based on modelling work, at 760 t/h. The flux rate and feed rate were used to calculate the thickener sizes and the actual rise rate checked from the overall process balance.

The merit of using high rate thickening is the higher underflow density. The water consumption of the plant is principally involved with the pumping of slimes to the dam and the water losses associated with deposition final moisture and net evaporation.

However, the relative disadvantage of the lower densities of conventional thickeners may be overcome by improving the design of sedimentation on the slimes dam to maximise water recovery from the dam.

A value-engineering study carried out during the feasibility study, inclusive of feedback from Orapa operations management, concluded that an installation consisting of three high-density thickeners of 45 metre diameter installed above ground would provide the best balance between performance and cost. High-density thickeners are simply thickeners of conventional design with an increased wall height to generate greater compression. Three thickeners were chosen instead of two, larger (60 metre diameter) thickeners for the following reasons:

The advantages were considered to be as follows:

- Able to operate at higher capacity when one thickener is on maintenance or underflow lines are blocked as there are more operational units.
- Smaller thickeners can be above ground steel tanks saving civil works.
- Good access to underflow valves, pipes and instruments for maintenance
- No issues for tunnel flooding
- These were considered to outweigh certain disadvantages, such as:
- The capital cost is higher than for above ground thickeners on concrete.
- Additional pumps, drives, valve work, instruments and pipe work to maintain.
- Additional height of feed distributor system and access to each thickener.
- Process Water System

The Orapa 3 plant process water distribution system is designed to reduce complexity. Internal recirculation of flows has been largely avoided, particularly the concept of recycling DMS effluent flows to the scrubbing and screening section. The reason for this is that the

DMS plant consists of nine modules, any of which may be operating, at any moment. This presents a potentially very wide variation in recirculated flows which must accordingly be accommodated in a parallel water supply system. In the past the driving factor has been the desire to maintain locked into circuit any potentially valuable diamond bearing material arising from worn screen panels etc in the DMS. The result has however been a complex water management system with a lot of additional instrumentation, adding to potential circuit instability and consequent process interruptions.

At Orapa 3, this has been avoided by routing all of the DMS effluent to a settling tank, with a bottom cone section. Whilst potentially containing misplaced diamond bearing material as discussed above, DMS effluent also contains grits (nom >0.3 mm) as a result of screening inefficiencies and in-circuit degradation. Such particles settle into the cone section and are continuously extracted along with approximately 10% of the incoming flow, which is then discharged to the desand feed distributor.

The slimes loading of the DMS effluent is usually very low. This means that the effluent water can be used without flocculation and thickening, and hence is normally routed directly to the process water tanks. For process upsets, and for periodic cleaning of the process water, the complete DMS effluent settler overflow can be routed to the thickener feed distributor. More usually, a small fraction only of the effluent flow would be routed to the thickeners for this purpose. This can also be isolated if required, since the settler underflow itself represents a bleed of water to the thickeners and hence will act as a continuous purge for cleaning purposes.

Two process water storage tanks have been provided, manifolded together. These are of the same, self-cleaning, design as those for Orapa 2.

Start-up after full plant shutdown always requires care in order to avoid water hammer. To assist with this, a small process water pump has been provided in parallel with the main process water supply pumps to serve the purpose of maintaining the system piping full of water during shutdown. This pump would also be used on initial plant start-up for the same purpose, with the first main supply pump being started once system pressure indicates the piping is full.

6.11 DMS Plant

6.11.1 Pump-Fed DMS Cyclones and Dilute Medium Densification

The use of pump-fed DMS cyclones versus gravity fed cyclones was the subject of much debate during each phase of the Orapa 3 plant evolution. The selection of pump-fed cyclones was driven by the reduced capital cost associated with lower plant height. Whilst the fact that the cyclones are the highest point of a pump-fed DMS plant whereas gravity fed cyclone configuration has an additional 10 metre structure above this point is an obvious driver of capital cost, there are other more subtle advantages that translate into capital cost advantage:

- Cyclone size and operating head are divorced from plant height.
- The same module design can be used for cyclones of a different size. This is important in the context of Orapa 3 as the 510 mm diameter cyclones may be changed for 420 mm diameter cyclones if the bottom size for diamond recovery is lowered significantly.
- The same cyclones can be used at different operating head.

- Therefore the same module design can be used for different duties.
- Different duties are interchangeable on-line in the same module design.

Other relative features of pump-fed versus gravity-fed cyclones are quite well known and can, depending on the relative importance assigned to each of these, be used to justify a selection either way.

The use of dilute medium densification is unusual in large plants. It has become more common to install densifiers fed with either circulating medium, or occasionally floats drain medium. However, once a decision has been made to adopt pump-fed dense medium separation cyclones, this requires an additional pump to provide sufficient pressure for the densifiers to function. The alternative, since the dilute medium is pumped to the magnetic separators, is to install the densifiers on this stream instead. This has the advantage of reducing the overall magnetics loading on the separators, leading to lower ferrosilicon losses. Adequate densification is maintained by diverting medium into the dilute medium circuit via a splitter on the underflow of the floats drain panel, and medium cleaning is ensured by diverting part of the densifiers underflow into the magnetic separator. At present this has been configured such that of the three densifiers installed, one is essentially a dummy unit, as both overflow and underflow products report to the magnetic separator. Further refinement is possible at the detailed design stage if considered justified.

6.11.2 DMS Capacity Configuration

The Orapa 3 DMS circuit is configured as a split coarse/fines circuit. Feed to the DMS (1.6-25 mm) is in two streams, 1.6-6 mm (fines DMS) and 6-25 mm (coarse DMS).

Since the design of the DMS modules for both fines and coarse fractions is identical, only the medium ore ratio differs, the cost impact of designing for separate size fractions is to reduce the overall capital cost. This is because modules designated as coarse modules have a nominal feedrate 25% higher than those designated as fines modules. If a single size range is treated, the module capacity is reduced to optimise performance on the fine end of the size range, since this is where the majority of the revenue occurs. The net result is that more modules are required for a particular feedrate if this is treated as a single stream.

Based on the mass balance, the maximum DMS feed arising is 1,868 t/h. This would require ten DMS modules if the throughput rate were limited to 200 t/h to satisfy the medium to ore ratio requirement of 7:1 for the finer feed fraction. If evenly fed, the ten modules would be fed at 187 t/h. At a reduced medium to ore ratio of 6.7:1, nine modules would be adequate, feeding at 208 t/h.

For a split DMS, the requirement is maximum nine modules. Of these, six are coarse modules operating at 241 t/h, and three are fines modules operating at only 142 t/h. At a slightly reduced medium to ore ratio of 6.5:1, only two fines modules would be required. Of nine installed modules, one module is therefore, at small risk, a spare module.

Of the nine modules installed, two modules can be fed with either fines or coarse feed size-ranges.

The DMS capacity can therefore be flexibly matched to the arisings in the coarse and fines size ranges by assigning several modules to address either duty. With the majority of Orapa

diamonds in the <6 mm size range, capacity dedicated to the 1.6-6 mm size range at enhanced medium: ore ratios would reduce the risk of diamond loss. The size split between fines and coarse can be optimised in the range 4-6 mm by changing screen panels in the scrubbing section, to maximise overall diamond revenue without impact on the overall DMS capacity required, as the swing modules will absorb the mass balance impact.

The swing modules (modules 6 and 7) are of the same design as all the other modules. Designation as a fines or coarse module simply implies that the feedrate is changed to suit the designation.

6.11.3 Steady Water Head tank for Critical DMS Duties

Power failure has unpleasant consequences in a DMS plant. Mostly these cannot be easily avoided. Two duties which are important in facilitating restart are sinks screen spray water and medium pump flushing.

On general power failure in a pump-fed DMS module, the feed pressure to the DM cyclones is lost. The entire contents of the four cyclones are consequently discharged to the sinks screen, which ensures no loss of diamonds, whilst at the same time the sinks screen is stopping. Although the sinks screen is supplied by the emergency power circuit, this is unlikely to restart the sinks screen in time to be effective in restoring the screening performance within the critical time period. The drain section of the sinks screen will be less effective than normal in removing medium, which will report to the rinse section in greater quantity than normal, along with a much greater volume of un-separated gravel than is normally fed to the sinks screen. If the spray water has also ceased as a result of the general power failure, the net result is a large volume of settled medium and gravel sitting on the end third of the screen. When the screen restarts, even if the spray water has been restored, this material is discharged into the concentrates handling system, which is not equipped to efficiently handle this. Even if the transfer to emergency power is sufficiently rapid to maintain a reasonable screen performance, without wash sprays a large amount of ferrosilicon will still enter the concentrates handling system.

By providing a steady head tank to supply water to the sinks screen sprays for a period following failure of the process water pumps, washing of the combined ferrosilicon and gravel is maintained. This will minimise the amount of ferrosilicon reporting to the concentrates handling system.

The cyclone feed and circulating medium pumps stop on power failure and the drain valves open. Most ferrosilicon reports to the spillage containment area, along with gravel from the cyclone feed pump. Some ferrosilicon/gravel inevitably remains in the pumps, and standard practice is to flush the pumps with water after a time delay. Again however, if pressure has been lost in the process water system as a result of the power failure, this will be ineffective, although some water will be available at a steadily falling pressure as pipes higher in the building drain down to the pumps. By supplying flushing water to the circulating medium and cyclone feed pumps from the steady head tank, the water pressure is maintained for sufficient time to provide adequate flushing of the pump casings. This greatly assists with restarting the DMS module once power is restored.

6.12 Recovery Section

6.12.1 Wet Primary X-ray Sorting

For some considerable time, recovery sorter technology in De Beers family of companies has been based on dry sorting. A decision was taken in the early 1990's that development of wet X-ray sorters would be discontinued in favour of dry X-ray sorters. The implications of this were that the entire feed to the recovery plant had to be dried. Coupled with a philosophy of maximising gravity flow, this led to the extensive use of pneumodriers to dry and elevate the recovery plant feed simultaneously. The use of pneumodriers has however not been without controversy, from a cost perspective as well as through concerns as to risks of diamond damage and the generation of significant dust.

In parallel with the decision within De Beers to adopt a dry X-ray sorting route, elsewhere new diamond recovery operations, of a comparable sophistication to those of De Beers, were adopting wet X-ray sorting technology (Ekati, Diavik). The benefits of successful implementation of wet X-ray sorting, most particularly primary sorting, are obviously associated with the elimination of the bulk drying stage, with it's perceived disadvantages as noted above.

A new direction in sorter design development was taken more recently, with the evolution of new wet X-ray diamond sorters at Debtech. The current version, designated the Modular Recovery Unit Process (ModRUP), has been extensively tested in pilot plant operation against the only commercially available alternative, the DP6D supplied by Ultrasort Pty Ltd of Australia. Following a review of the results of this exercise, using a balanced scorecard approach to evaluation of the characteristics and performance of the two sorters, it was decided to select the ModRUP as the basis for design of the Orapa 3 recovery section.

The ModRUP unit can be configured as a dry sorter for reconcentration duties in a two-pass configuration. The design criteria for the recovery section calls for the product transferred to the FISH to be 70% diamond by weight (DBW) for the fines fraction and 50% DBW for the middles and coarse fractions. By using two-stage dry reconcentration, it was considered possible to eliminate the need for single-particle-sorting using De Beers Raven technology.

This confines the X-ray sorter technology to a single base model, with only minor differences between the wet and dry versions.

6.12.2 Grease Scavenging

Grease scavenging of X-ray rejects is not currently a feature of either of the CARP installations at Orapa or Jwaneng Mines. Historically, at least at Jwaneng, a fines grease plant was used for the primary recovery of diamonds smaller than 2mm, as the X-ray sorters available at the time were considered to perform poorly below this size, particularly wet X-ray sorters. A contemporary installation at Venetia used the same philosophy and in both operations the result of attempting to fully automate the diamond grease recovery process was expensive and operator/maintenance intensive. The advent of more advanced X-ray sorting technology resulted in later installations (viz the CARPs at Jwaneng, Orapa and CTP) becoming based on dry X-ray sorters, with no grease applied for any duty. More recently, a complete revision of the implementation of technology for grease recovery of diamonds, as well as a pragmatic response to the limitations of a single diamond recovery technology, in

this case XRF, has brought grease as a scavenging method back into vogue. This has accordingly been adopted for the Orapa 3 recovery plant flowsheet. Recovery plant rejects will therefore have been subjected to two stages of XRF, followed by attritioning and grease, prior to being deposited on the secure recovery rejects stockpile. The sequence of processing events is characteristic of an auditing process. Second-pass X-ray sorting ejection counts are an indication of first pass-X-ray sorter effectiveness, and the number of diamonds captured on the grease belts, batched by size fraction, is an indication of the overall X-ray sorting section efficiency.

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Graham has over 31 years experience in the design, operation and management of diamond, industrial minerals and base metals recovery plants. For the last 22 years, Graham has been involved in process design and project commissioning, focusing on diamonds particularly in Africa and Canada. Major assignments have been as lead process engineer for the 800tph De Beers Venetia Main Treatment plant, the Final Recovery Plant for Alexkor, and the 420tph Jwaneng Recrush DMS Plant for Debswana. Numerous more minor assignments have been completed in a variety of countries. Graham managed the process engineering, layout development and commissioning of the BHP Ekati diamond project in 1998 and since that time has been leading study work to define expansion strategies at Ekati, in addition performing a similar role for the Diavik diamond mine in 2004. Graham was process consultant and commissioning manager for the De Beers 1000tph CTP diamond recovery facility in Kimberley, South Africa. Recent assignments have been as study manager and process lead for the Diavik Small Diamonds Project (Rio Tinto), and Project Manager for the Ekati New Thickeners Project (BHP Billiton). Currently Graham is managing the Orapa Expansion Project FS (Debswana), being undertaken by Fluor in Melbourne. As one of only two independent consultants to the Debswana "Experienced Persons Group" throughout 2006, Graham was instrumental in the company undertaking a new direction in conceptual design, which is currently manifesting itself in the evolution of the 12Mtpa Orapa 3 plant in Botswana. Graham was appointed a Fluor Senior Fellow in 2009.