APPLICATION OF UNI-DELAY SHOCK TUBES IN DEVELOPMENT IN UNDERGROUND MINES

FJ Fourie
General Manager, AnglogoldAshanti Kopanang Mine

T Zaniewski
Explosives Engineer, AnglogoldAshanti Kopanang Mine

M Cross
Mining Engineer, African Explosives Limited

SYNOPSIS

This paper describes the concept and development of the use of a uni-delay shock tube system in the timing and initiation of the development rounds, specifically in flat development. It was extended from stoping and now constitutes the only initiation system in use at Kopanang mine.

The two explosives initiation systems in general use in underground mines are the conventional fuse-igniter cord system, and the more modern Long Period Delay shock tube system, better known as the numbered LP system. Both are well accepted but have many drawbacks which can result in poor breaking and substantial wastage of the blasting material. Both of these deficiencies cause an increase in the cost of a blast.

Hitherto, the limited number of delays available has complicated the use of shock tubes in development blasting. Over eighteen month period to the end of 2007, a project team comprising members from Kopanang Mine and AEL developed a method for the use of a uni-delay shock tubes to time any development round. These uni-delay shock tubes are better known as Reef Masters® or EZ-Stopers® depending on the supplier, and the system has particular application in flat development. During the project, two new shock tube system components were designed, tested and manufactured; namely Splitters and Starter Packs.

The system has been successfully tested and implemented in both on-reef and off-reef development ends. At Kopanang, it has now been rolled out across the entire mine. Other AnglogoldAshanti mines are conducting trials and implementations into production sections. Initial results indicate improvements in the ground conditions and excavation profiles. The cost of blasting is showing a downward trend.

The authors consider that the system is a tool for use in further blast optimization and will contribute to rationalization of the explosives commodities basket on mines.
1. AIM OF THE PROJECT

Primarily the project was an attempt to provide an explosive initiation system which would be more reliable than conventional fuse-igniter cord (FIC) systems. Additional aims were to reduce the number of alternative items required to be held in stock, and to improve blasting effectiveness, both of which had potential cost-reduction benefits. The aim was to find a simple and effective product that could be adapted or developed for use in both narrow-reef stoping and in development ends. Safety aspects were also considered. Shock tubes produce less harmful gas than FIC systems, and had also shown the potential for more effective breaking when used in stoping. Thus the shock tube used in stoping seemed to be a promising starting point. No specific quantitative success criteria were specified at this stage.

The two systems were compared as shown in the table below.

Table 1: Comparison of FIC and shock tube initiation systems in development blasting

<table>
<thead>
<tr>
<th>Historical performance of FIC systems</th>
<th>Expected (required) performance of shock tube initiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>• Simple system</td>
<td>• Reduced exposure to hazards (i.e. noxious gas, smoke, fire)</td>
</tr>
<tr>
<td>• Easy to connect up</td>
<td>• Improved ground conditions</td>
</tr>
<tr>
<td>• Low cost per unit</td>
<td>• Reduced wastage of explosives</td>
</tr>
<tr>
<td>• User-friendly</td>
<td>• Water resistant</td>
</tr>
<tr>
<td>• Widely available on the mine</td>
<td>• Sequential firing</td>
</tr>
<tr>
<td>• Robust in handling</td>
<td>• Greater reliability and controllability of the blast (millisecond delay)</td>
</tr>
<tr>
<td>• Easy to train people on it</td>
<td>• Controlled throw rock profile</td>
</tr>
<tr>
<td></td>
<td>• 8D cap sensitivity to obviate the need for a primer or booster</td>
</tr>
<tr>
<td></td>
<td>• Improved productivity as measured by breaking efficiency</td>
</tr>
<tr>
<td></td>
<td>• Cost per blast to be comparable with FIC systems</td>
</tr>
</tbody>
</table>

2. RISK ASSESSMENT
A formal risk assessment process was applied to identify issues which would have to be addressed in any planned implementation of a shock tube initiation system. An issue-based assessment document was prepared, from which failure modes were identified and in which corrective actions were specified. The risks so identified fell into the categories of “undesirable” and “acceptable”. In other words, the risks could be countered by training and practicable actions like the application of procedures. The following issues were identified as requiring attention:

- Face examination after a blast and before any other work begins is needed to prevent the possibility of an explosion from cut-offs or loose connector blocks which may contain a mini detonator. This is especially important when development crews are first exposed to this technology.
- A high standard of marking-off and drilling is required.
- Training in connecting-up with splitters is required.
- Shock tubes are more expensive than FIC systems.
- The additional element, that is the Splitter, makes connecting-up more complicated than FIC systems.
- Very little smell and almost no smoke is emitted during the ignition phase.
- Resistance to change has to be addressed.

These factors were incorporated into the modus operandi of the project, and where applicable, into training courses and material.

3. SHOCK TUBE CONCEPT AND DESIGN

A shock tube consists of a small diameter plastic tube which has been internally coated with layers of explosive material, as depicted in Figure 1. In this case, the material consists of a mixture of HMX (Octagen) and fine Aluminium powder applied at a rate of 20g/m. It has a velocity of detonation of approximately 2000 m/s. This small amount of explosives is insufficient to cause the tube to rupture as the detonation shock passes through it, and has no effect on surrounding explosives. There are two types of the shock tube assemblies namely:

- Long or short period delays shock tubes assemblies; in this type the tube is heat sealed and has a clip on one end and detonator with the delay element on other.
- Uni – delay shock tube where one end has a connecting block containing a mini detonator representing the inter-hole delay i.e. 200 ms, and on the other end has a detonator with down-the-hole delay i.e. 4000 ms. All assemblies have the same set of inter-hole and down-the-hole delays.

They are shown diagrammatically in Figure 2. The principle of use is shown in Figure 3.
Following initiation, a low energy shock wave is transmitted at a speed of approximately 2000 m/s in both directions to the detonator and next connecting block.

**Figure 1: Cross-sectional schematic of a shock tube**

**Figure 2: Types of shock tube assemblies**

**Figure 3: Principle of use of an uni – delay shock tube system**
The out-of-hole detonator delay is the first number in a shock tube designation, and the
down-the-hole delay is the second number. Thus a shock tube designated 200/4000 has
an out-of-hole delay of 200ms which represents igniter cord and a down-the-hole delay of
4000ms which represents fuse itself. Blast design involves the selection and combination
of these parameters in shock tube components to obtain an optimal burning front. The
combination of delays can be varied depending on the timing and rock breaking
requirements.

4. DEVELOPMENT OF THE CONNECTING METHOD FOR DEVELOPMENT

In the case of a 200/4000 shock tube, only 20 delays are available. So having 46 holes to
be blasted sequentially in a flat development end, it was necessary to find a new way of
connecting-up the round to ensure sequential firing of all holes. Merely copying the
method used in stoping would result in a number of cut-offs and possibly also misfires
due to the restricted space in a development end.

Some work on utilising Reef Master® technology (RM) in development applications had
been conducted about ten years previously, but without success. In a trackless mining
environment utilising emulsion explosives in large diameter holes success has been
achieved, albeit with specially trained supplier staff to perform the complicated task of
connecting-up the blasts. Such an approach is not feasible for conventional development
in narrow-reef mining applications.

Management of Kopanang mine identified a number of reasons for wanting to replace the
use of FIC and Tunnel Master® technology (TM) in conventional development. These
included safety, cost and efficiency issues. If the process could be simplified, it would
make training easier, reduce the stockholding requirement, enhance the consistency of
results for blasting and reduce costs. The main disadvantage of the TM system is that the
detonating set is “round-specific” and requires use of the detonating cord. Given that
development layouts include cubbies, breakaways both flat and inclined, as well as other
dimension changes, wastage of TM sets resulted. Kopanang was looking for a standard
product which could be applied to all excavation sizes and which would impose no
additional cost burden. In conjunction with LAKHO Mining, a BEE company and
supplier of initiating systems, trials were performed using standard 200/4000 in
conventional haulage and crosscut developments on Kopanang Mine and on Platinum
Mines with some success. However, the complicated connecting-up method resulted in
the trial being suspended; the inadequate burning front created by this shortcoming
resulted in peripheral holes being cut off. It was recognised that this might have been
overcome had a 100/4000 RM been available. When LAKHO was unable to provide the
item on time, AEL was asked to become involved.

At about the same time, early in 2006, AEL and Kopanang Mine were jointly
investigating the possible use of the 200/4000 RM in development applications; it had
already been identified as the standard replacement product for FIC in stoping for both
gold and platinum mining. Rather than follow the path of developing a 100/4000 RM,
alternative connecting-up configurations were investigated; in this way overcoming the need for an additional stock item.

Flat development ends at Kopanang are 3,0m wide by 3,8m high and are drilled using 2,3m steel. The round consists of six columns and seven rows of holes drilled on a grid with a five-hole cut drilled between the grid holes. Of the forty-seven holes, one is left uncharged. The geometry of holes and the connecting-up using FIC is shown in figure 4. It consists of linking all the holes in each column and linking them with a horizontal cord; the starter being placed at the first hole to be initiated. The time interval between consecutive shots when 3,0m capped fuse is used with Duraline is approximately 4 - 30 seconds.

Figure 4: Conventional FIC connection

As an ideal, the method in use for FIC was adopted for shock tubes. To cater for this specific requirement AEL developed Reef Master® a tie-up shown in the sketch below.
Figure 5: Initial Reef Master® connection (Tree branches)

Two trial blasts were conducted. Neither produced an advance comparable with that achieved using FIC. Connecting-up proved to be difficult, requiring stretching the shock tube leading to possible breaks in the delicate explosives lining inside of the tube what could result in the stoppage of the detonating front; it was also difficult to check that connections were correct. A burning front of 10 was created in the first blast, implying that the round was detonated within two seconds, but it produced an advance of only 1.5m with long overburdened sockets in the lower half of the face. This could be result of the out-of-sequence firing. The thrown rock profile extended for 20m which was also an unacceptable outcome, potentially creating problems with cleaning and equipping. The second blast was cut off at the cut. It was observed that concussion produced by the blasts was excessive. Blasting trials were suspended while an improvement was investigated for the tying-up process.

If the FIC method was to be emulated, a means of overcoming the need to stretch the shock tubes was required and a method of initiating both upwards and downwards from a horizontal input had to be created. This led to the innovation known as the “splitter”. It consists of a 1.5m length of shock tube equipped initially with 200ms and later 100 ms minidets in a connector block at both ends. Its function is to receive a single signal and transmit it in two different directions. It is also used to simplify the tie-up at the cut. The Splitter has been patented in two of the three southern hemisphere continents, Australia being the exception. It should be noted that the out-of-hole delay can be varied according to requirements.
The first connecting-up using Splitters is shown in the sketch below. This method was referred to as Vertical Splitter for ease of reference and to distinguish it from later methods which also utilised Splitters. One horizontal splitter is shown linking two holes in the grid above the cut without any stretching of the shock tube. After the vertical splitters receive the signal from the horizontal feed it is split upwards and downwards.

**Picture 1: Splitter**

The first connecting-up using Splitters is shown in the sketch below. This method was referred to as Vertical Splitter for ease of reference and to distinguish it from later methods which also utilised Splitters. One horizontal splitter is shown linking two holes in the grid above the cut without any stretching of the shock tube. After the vertical splitters receive the signal from the horizontal feed it is split upwards and downwards.

**Figure 6: Reef Master® connecting-up utilising Splitters**
The work had taken the project into the third quarter of 2006 when the first test blast using Splitters was conducted. Connecting-up was much simplified, but the advance achieved for the 2,1m drilled round was only 1,9m. Rock was thrown 14m back from the face and concussion was again observed to be excessive.

Based on the promise of the approach, the mine developed a different connecting-up method in an attempt to achieve further cost and component reductions. This took the form a chevron above and below the cut. Given that the number of single connections exceeded twenty in this design, a 100/4000 RM was provided by AEL for the purpose. It is shown below in diagrammatic form below.

![Diagrammatic Reefmaster Chevron tie-up](image)

**Figure 7: Diagram of Reef Master® connection in ½ spiral – chevron format**

In practice this arrangement proved to be difficult to connect up and to check. The advance achieved by the blast was approximately 1,7m. Although the cut broke well, long sockets were observed on one sidewall. Some reduction in the distance of thrown rock was achieved.

The 100/4000 RM was also used in an experimental spiral connecting-up for a blast in a return airway. This method is in commonly use in Canada with good results because advance is not totally dependant on sequential firing. The outcome was exciting in that an advance of 2,3m was achieved with no sockets and thrown rock accumulated within 5m of the face. Being the best achievement so far, it was agreed that this should be set as the criterion against which all future methods of connecting-up the blast would be measured.
5. BLAST SIMULATION AND TIMING EVALUATION

Further discussions with mine management resulted in the creation of a project team to evaluate different timings. Splitters with different delays and Reef Masters with 200/4000 ms delays would be used, but the chevron format would not be utilised due to its agreed impracticality. Quantitative objectives were also set at this point. They were:

- advance per blast must be at least as good as that achieved with FIC
- excavation profile must be at least as precise as that achieved with FIC
- concussion (as measured by displaced equipment such ventilation columns) must be reduced

To establish absolute data for FIC blasting against which the project results would be compared, a series of parameters were collected from specific FIC blast events conducted for the purpose. Measurements and photographs were used to also establish the spread of thrown rock and the range of fragmentation achieved with FIC. A number of tests were conducted to establish the average time between consecutive shots which would produce:

- full advance
- correct thrown rock profile
- minimal concussion
Electronic blasts were conducted using four different delay intervals of 3m Smartdets™ for the blastholes excluding the cut, namely 50ms, 75ms and 100ms. In all cases, cut holes were provided with 200ms delays, and the rest of the round was set to the stated delay. In all cases sockets observed were minimal, and faces were blasted solid and square with no misfires or cut-offs.

**Diagrammatic Smartdet timing (7 rows, 6 columns) 50ms between shots**

Cut low down between grid lines to the right

![Diagram of Smartdet timing](image)

Figure 9: Diagram of Smartdet™ timing
Table 2: Parameter-setting Smartdet\textsuperscript{TM} blast results

<table>
<thead>
<tr>
<th>Delay period</th>
<th>Time for shots to go off</th>
<th>Average advance</th>
<th>Rock throw</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>50ms</td>
<td>2800ms</td>
<td>2.0m</td>
<td>14.1m</td>
<td>Compressed air supply problem resulted in some holes drilled short and some omitted, only 44 holes blasted</td>
</tr>
<tr>
<td>75ms</td>
<td>3950ms</td>
<td>2.21m</td>
<td>14m</td>
<td>Most thrown rock within 8m</td>
</tr>
<tr>
<td>100ms</td>
<td>5000ms</td>
<td>2.4m</td>
<td>9m</td>
<td>Most thrown rock within 4m with good fragmentation</td>
</tr>
</tbody>
</table>

It was concluded that an interhole delay period of at least 75ms was necessary for the achievement of the required advance and thrown rock profile.

The target for quantitative parameters of success having been achieved with 100/4000 RM, i.e., a different item than that specified for the standard, it was necessary to develop a working system using 200/4000 RM. The spiral connecting-up also presented potential difficulties for training of mine personnel. The connecting-up was redesigned by AEL/Kopanang team to simulate the effect of the spiral, but using the 200/4000 RM. This gave rise to the so-called “quarter spiral” or “spider cut”, a nickname given by development crews, and shown in the diagram below. Connections for the cut and splitters showing the links between quadrants can be seen also in the diagram and photograph below.
Figure 10: Diagram of Reef Master connection in quarter spiral format

![Diagram of Reef Master connection](image)

A single connector block to the first four holes of the cut is attached to Splitters (shown in red in the diagram). This method was applied in both Kopanang and Tau Lekoa mines at a variety of sites over a period towards the end of 2006. Average advance exceeded 2,0m however, the thrown rock pile profile was not ideal. Attempts to improve it
involved the use of a 100ms Splitter for the top two grid holes with a 200ms Splitter for
the bottom two grid holes to achieve an offset between the top and bottom of the round.
Results from the few trials so far have been rated as subjectively better but insufficient
data exists to draw a definitive conclusion.
For better coordination of project activities, a specific area at Kopanang mine was
allocated for test purposes. Four ends were being developed in an area isolated from other
workings. Results achieved in these ends when utilising FIC encompassed the full
spectrum of quality. Beginning in January 2007, blasting using the quarter spiral tie-up of
200/4000 RM commenced. Initial results were disappointing, due at least in part to poor
drilling discipline. Further blasting for which greater attention was paid to drilling
accuracy and in which the top two grid holes were connected with a 100ms Splitter while
the bottom two grid holes were connected with a 200ms Splitter produced an acceptable
result. On occasion, cut-offs were encountered, and sometimes misfires resulted from the
possibly over-enthusiastic participation of the developer. After trying a number of
variations, it was found that consistent results were obtained if the top and bottom of the
face were offset by 100ms, with the 100ms Splitter being connected to the bottom two
grid holes. At this point, the team was confident that the 200/4000 RM could be utilised
in development. A number of additional questions now arose. These were
- whether locating the cut on the grid lines would improve results
- how practical were the tie-up formats, especially with respect to training of
  mine employees
- whether Splitters were required at all, or if so, whether both 100ms and 200ms
  Splitters were needed
- what length of the splitter is needed
6. VALIDATION OF THE BLAST DESIGN

For the purposes of conducting trials on timing, a test rig was constructed from two sheets of expanded metal mounted 2m apart in a development end.

Picture 3: Photograph of Reef Master Connection in 1/4spiral – chevron format

Shock tubes are suspended between them and tied up according to the pattern to be tested. A number of blasts were conducted using various combinations of 200ms and 100ms Splitters in conjunction with an 8D detonator to evaluate sequence of the blast and the potential for cut-offs caused by shrapnel. Nine occurred in the three test blasts. Timing looked and sounded correct, and photographs showed the expected sequential
burning geometry. High-speed photography proved to be impossible due to inadequate lighting and the lack of a remotely operated trigger. However, the test blasts were successfully videotaped with a commercial camera. The recordings were later used for the training of the development crews.

![Photo of the shock tube blast in progress on the test rig](image)

**Picture 5: Photo of the shock tube blast in progress on the test rig**

Having shown that the system worked in flat ends, wider application into other types of development was pursued. The test rig was utilised to develop and design rounds for other types of development end. Rounds were designed for a drag round in flat development, burn cuts in raise/winze development, travelling ways, boxholes and boxhole connections. The results of this work are shown in the diagrams in Appendix A.

**8. QUANTIFYING RESULTS**

During the trial, 76 blasts were evaluated. The following blast parameters were measured:

- drilling geometry
- explosives use and consumption
- advance per blast
- end geometry before and after the blast.
- thrown rock profile
- fragmentation
Blasting efficiency

Blasting efficiency was calculated by dividing the advance achieved by the 2.3m drilled length of the round.

Table 3: Summary of trial blast results

<table>
<thead>
<tr>
<th>System</th>
<th>Number of blasts</th>
<th>Average advance per blast (m)</th>
<th>Blasting efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIC</td>
<td>37</td>
<td>2.02</td>
<td>88</td>
</tr>
<tr>
<td>Reef Master</td>
<td>39</td>
<td>2.09</td>
<td>91</td>
</tr>
</tbody>
</table>

Advance per blast

The combined results indicate that advance per blast obtained with Reef Master Shock Tubes is better than when FIC is used. An average of 2.09 m versus 2.02 m translates into a 3.0 % improvement. This shows the effect of perfect sequential firing, no cut-offs and better accuracy of timing. Greater consistency of results was achieved using RM as shown in the graph below, figure 16.

Figure 16: Comparison of the advance per blast between FIC and Shock Tube technologies

Face geometry after the blast

Full advance and sidewall control are shown to have been successfully achieved in the following photographs. Concomitant benefits arising from the precision of the timing are that fracturing is more precise and less barring is required.
Containment of the thrown rock pile close to the face facilitates cleaning and minimises damage to equipment. Results of blasts with RM are shown in the following illustrations.
Fragmentation
During the trial, photographs were taken of the fragmented rock and they visually analysed. Using a tennis ball for reference, it was clear that shock tubes yielded coarser and more uniform fragmentation than blasting with FIC. This can be attributed to the more accurate timing and sequential firing of the shot holes.
9. DEVELOPMENT OF EXPLOSIVES ACCESSORIES
Referring to the initial aim of the project, one desired outcome was a reduction in the number and variety of items required to be held in stock by the mine. Starter packs were introduced to minimise wastage, and because only one starter pack is required for each blast. The packs consist of one Master Starter, one extender and a one metre length of igniter cord. Following their introduction, Master Starters and extenders could no longer be ordered as separate items.
Reef Master starter pack consisting of extender, Master Starter and igniter cord

200ms and 100ms Splitters

200 ms – orange,

Starter pack in the box

Boxed 3.0m Reef Master shock tubes

Picture 11: Photographs of Kopanang development explosives accessories.

The number of items required to be supplied and stored as blasting accessories has been reduced from fourteen to six, with concomitant savings in holding costs and space requirements. In the table below, both quantities and costs for 2008 and year-to-date for 2008 are shown.

Table 4: Tabulation of consumption of blasting accessory stock items
### As can be seen from table below some saving will be possible from the rationalisation of the explosives initiation system components, items as Duracord and Durafuse are taken of from the standard explosives list on Kopanang Mine.

This initiative will help save approximately ± R 264 000 per annum.

### 10. DEVELOPMENT COST COMPARISON

Development blasting analysis shows that the use of uni-delay shock tubes does not result in costs higher than those for conventional FIC system initiation. Also, the trend in actual costs is positive. Comparative statistics are tabulated below. For each method of initiation, the following parameters were common:

- Total number of holes blasted per round = 45
- Included number of perimeter holes = 12
- Cost of primers = R36,72
- Cost of perimeter hole explosives = R85,80
- Cost of ANFEX = R143,59
- Assumed wastage of explosive = 5%
- Total cost per round of explosive = R279,41

### Table 5: Comparative analysis of development costs
<table>
<thead>
<tr>
<th></th>
<th>FIC</th>
<th>LP</th>
<th>Uni-delay shock tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance per blast</td>
<td>2.05m</td>
<td>2.15m</td>
<td>2.15m</td>
</tr>
<tr>
<td>Fuses</td>
<td>45</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Duraline (m)</td>
<td>23</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Number of shock tubes</td>
<td>N/A</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Explosives cost (R/m)</td>
<td>136.30</td>
<td>129.96</td>
<td>129.96</td>
</tr>
</tbody>
</table>

**Initiation system costs (R)**

<table>
<thead>
<tr>
<th></th>
<th>FIC</th>
<th>LP</th>
<th>Uni-delay shock tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuse</td>
<td>235.40</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Duraline</td>
<td>32.20</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Shock tube</td>
<td>N/A</td>
<td>257.40</td>
<td>283.50</td>
</tr>
<tr>
<td>Cordtex</td>
<td>N/A</td>
<td>35.88</td>
<td>N/A</td>
</tr>
<tr>
<td>Startup system per blast</td>
<td>4.98</td>
<td>4.04</td>
<td>4.04</td>
</tr>
<tr>
<td>Assumed wastage of initiation system items</td>
<td>10%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>Total initiation system</td>
<td>299.84</td>
<td>312.19</td>
<td>296.17</td>
</tr>
<tr>
<td>Total per blast</td>
<td>579.25</td>
<td>591.60</td>
<td>575.58</td>
</tr>
<tr>
<td>R/m blasted</td>
<td>282.56</td>
<td>275.16</td>
<td>267.71</td>
</tr>
</tbody>
</table>

**Note:** Double fuses are used in cut and lifter holes with FIC adding 10 fuses per blast.

This calculation is idealised as regards advance per blast. The year-to-date development explosives cost for Kopanang mine is R316/m and this includes the effects of inaccurate drilling, poor timing and other inadequacies. It also demonstrates that potential savings of the order of R46/m or about 14% are possible.
11. ENVIRONMENTAL IMPACT
Moving away from FIC towards RM initiation can have a dramatic impact on the volume of “greenhouse” gas created by blasting. A conservative estimation demonstrates that CO₂ and NO₂ emissions would be reduced from over 100tpa to below 2tpa on a mine the size of Kopanang.

12. TRAINING AND IMPLEMENTATION
Prior to mine-wide implementation, a three module training course was developed. In addition to simple and straightforward procedures for the use of Reef Masters in development, it also covered basic blasting theory as well as charging up procedures and disposal requirements for old explosives. All development crews were exposed to the programme. For completeness, those aspects of blasting practice which are common to all explosives were included. This served to reinforce the safety effort.

13. CONCLUSION
It remains true to say that the first requirement for explosives cost reduction and blasting effectiveness is for drilling accuracy. That said, any means to simplify the charging up and blasting process will also have a positive impact on these parameters. Many of the unsatisfactory results recorded during the early stages of the work were attributable to factors other than the products themselves. Resistance to change, rooted as it is locally in natural conservatism and actual fears for job security, is an ever-present factor when any attempt to improve efficiency and effectiveness is introduced. All innovation programmes ignore these factors to their potential detriment. The work described in this paper successfully met the aim of providing a new and reliable blast initiation system in development and improving the effectiveness of blasting as well as reducing the number of items required to be held in stock for this purpose. The idea of a single delay (200/4000ms) was not initially designed for the development ends. It in fact did meet and exceed the quantitative measures of success as determined from the results achieved using FIC. Product attributes have had the effect of reducing hazards in the working places underground through the reduced quantities of smoke and the reduction in the amount of combustible material. Improvements in ground conditions and significant cost reductions are yet to be seen, but the trends gleaned from available statistics are in the right direction.

ACKNOWLEDGEMENTS
Without the able assistance and keen interest of many people, the outcomes from this work would not have been as successful as they have, and the project would not be able
to continue. In the interests of length, this report does not include a lot of the apparently
insurmountable problems which arose.

The authors offer their thanks and appreciation to all the representatives in the following
organisations who have contributed to the results so far.

- AnglogoldAshanti
- Kopanang Mine team
- AEL

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