Safety in Mines Research Advisory Committee

FINAL REPORT

Develop a quiet non-atmosphere polluting blast hole drilling system

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Executive Summary

Past research has shown that to a large extent, specific noise sources within blast-hole drilling systems can be individually addressed but, in general, such solutions have been found to be impracticable for underground application. In reviewing past work in this area a novel concept was identified which would enable the practical application of previously identified noise reduction methods and technologies. The basis of the concept was to integrate the rockdrill and the thrust leg into one device, i.e. the drill becomes a piston within an enlarged thrust leg. This configuration not only provided an effective method of applying identified noise reduction methods, but also afforded several advantages in the operation and handling of the drilling system. The noise level of a commonly used pneumatic rock drill was reduced from 111 decibels on an A-weighted scale (dBA) to 87 dBA while running in over travel and from 115 dB to 92-93 dB during drilling. However, subsequent evaluation of the system identified several limitations in the area of dynamic seals particularly those involved in the provision of the thrust force. These limitations were of a magnitude that prohibited the development of a viable blast hole drilling system based on such a thrust arrangement. However, in recognising that the concept is the only one identified to date that permits the effective application of existing noise reduction methods, it is strongly recommended that further efforts be applied in the development of improved thrust systems within this original concept.

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1 Introduction

Drilling and blasting remains as the primary method of rock breaking used within South African gold and platinum mines and requires the use of approximately 20 000 pneumatically driven rockdrills daily from a total rockdrill population of approximately 50 000 machines. The majority of the pneumatic rockdrills used in South Africa are not generally fitted with any means of noise reduction with the consequence that operators, assistants and the majority of stoping personnel are regularly exposed to the high levels of noise produced by these machines. Such exposure presents a significant occupational health hazard of noise induced hearing impairment: a painless progression of irreversible damage which is not apparent in the early stages and only becomes so when speech communication is affected. Given the number of rockdrills in daily use it is estimated that more than 40 000 employees are adversely affected by such exposure. In addition to the longer term effect of the noise exposure the prevailing noise level at the work place severely limits verbal communication between workers. Communication is further inhibited by the reduced visibility in the work place which results from the atmospheric fogging produced by the discharge of the cold exhaust air into the generally warm and humid atmosphere of the work place.

It is a generally accepted fact that noise emissions from unsilenced pneumatic rockdrills subject operatives to equivalent noise exposure levels in excess of the South African Statutory limit of 85 dB even when good hearing protection devices are worn. Many research/development organizations and drill manufacturers have investigated the noise sources of pneumatic drills and, to a lesser degree, the emissions from drill steels and have developed methods for quietening them. In parallel, hydraulic rockdrills that have inherently lower noise emissions than pneumatic machines have been developed

The exhaust noise of pneumatic drills has been identified as the predominant source, accounting as it does for approximately 90 per cent of the noise power emitted from a drill/drill steel combination when drilling into hard rock. Noise emissions from the drill steel and mechanical parts of the drill are of approximately equal intensity and are significantly lower than the exhaust noise.

Techniques have been identified for reducing all three sources, generally with only a minimal loss of drilling performance, in one surface drilling test the noise emission was reduced from 115 dBA to 97 dBA. However, in a mining situation and particularly in stoping, many of the proposals have not proven to be practical

In discussion with three major South African pneumatic drill manufacturers it was disclosed that they had addressed the problem of noise emission from their drills in the 1970s/80s. Their findings indicated that fitting exhaust silencers is effective and claim that noise reductions of up to 10 dBA are possible with the modified production drills. However, it is accepted that even using these 'quiet' drills and wearing good hearing protection devices operatives will still be exposed to effective equivalent noise levels (the noise actually reaching the ear) where they could suffer hearing related damage after a number of years.

These manufacturers have evaluated their silenced drills in stopes and development ends in South African mines with little or no success. It was generally the operators perception that these drills were not performing correctly because they were quiet: as a result, they either punctured the mufflers or sent them out for repair.

Being a mechanical reciprocating device a rockdrill requires continuous lubrication for its continued operation and the prevention of excessive wear and is generally achieved by the installation of 'in-line' lubricators containing grease. The lubricators introduce approximately 1 gm of grease into the air supply for each metre of drilling and therefore it may be determined that at a drilling rate of approximately 600 000 metres per day, within the gold and platinum mines, 0.6 tonne of grease is consumed each day. A significant proportion of this grease is passes immediately through the machine and is discharged directly into the atmosphere either as a mist or in globular form. There is little published work regarding the determination of any potential health risk regarding this element of rockdrill operation.

The industry has over the past decade dedicated considerable resources to research, development and establishment of hearing conservation programmes on mines. While this approach has afforded significant improvement in the protection of the workforce it has unfortunately redirected efforts away from the reduction of noise levels at source. According to research conducted by COMRO [Van Rensburg, A. J.,1990], long term objectives when dealing with drill noise problems should be directed toward noise reduction at source rather than on personal protection and administrative control.

Experience elsewhere does suggest the if noise reduction techniques are considered at the design and construction stage of plants and machinery, considerable benefit could be reaped. Most industrial noise has its origins from inappropriate design and application of the equipment.

Legislation relating to noise control and hearing conservation was promulgated on 02 June 1989 in "Regulations 4.17.1-4, Mines and Works Act". In this Government Gazette an amendment to the Regulations of Mines and Works Act was introduced which stipulates that wherever the equivalent noise exposure in the work place exceeds 85 dB(A), 'the manager shall take the necessary steps to reduce the noise below this level'.

Maximum permissible sound level in any working environment in South Africa is specified indirectly, that is, operator equivalent noise exposure (Neq) must not exceed 85 dB irrespective of the prevailing sound pressure level. For every increase of 3 dB above the given level employee exposure time is halved. The relationship between noise level and exposure time is demonstrated Table 1.

Table 1.1 Relationship between noise level and exposure time for the South African noise equivalent (Neq) of 85 dB(A)

Noise Level dB (A)	Exposure Time	Noise Equivalent dB(A)
85	8h	85
88	4h	85
91	2h	85
94	1h	85
97	30min	85
100	15min	85
103	7.5 min	85
106	3.75min	85
109	112 s	85
112	56 s	85
115	28 s	85

2 Literature search/survey/evaluation

Since rockdrill noise has been recognised as a significant issue for many years there has been a large prolonged effort on the part of the mining industry, research organizations and rockdrill manufacturers targeted at resolving the problem resulting in a large volume of published information. In reviewing this information a distinction has been made between work carried out to identify and characterise the primary noise sources and investigations into methods for the quietening of pneumatic rockdrills and drill steels and the results of underground evaluations conducted in South Africa on modified pneumatic rockdrills.

2.1 Noise sources of rockdrills and drill steels

A significant number of investigations have been carried out to determine the main noise sources of pneumatic rockdrills and drill steels, (Becker 1965, Beiers 1966, Miller 1963, Summers 1975 and Visnapuu 1975). In this work three areas were identified as major sources of noise from a drill and steel, and while there was consensus about the predominant one (namely drill exhaust), there was disagreement regarding the ranking of the other two areas (namely mechanical noise from the drill and impact/ringing from the drill steel). The major noise sources are as listed below:

Exhaust noise:

- spent air passing from the exhaust ports at high velocity and mixing with relatively still atmospheric air. In this action vortices are generated at random and move and are dissipated in an equally random manner giving rise to wide band random noise,
- twice during each cycle air is exhausted from the drill housing. This gives rise to narrow band noise at a frequency twice that of the drill's operating frequency.
- the exhaust air itself acts as a medium of propagation for mechanical noise from within the drill (eg valve, rifle bar, ratchet assembly)

Mechanical drill noise from:

- attachment between drill and thrusting/mounting mechanism.
- rattle of drill steel in chuck.

- rattle of drill steel retainer,
- movement of ratchet over pawls and their impact at the end of motion before reversing.
- impact of rifle bar against back head and piston flutes. and mechanical impacts of valve.

Drill steel noise:

- impact noise between the drill piston and drill steel. This generates a narrow band emission at the same frequency as the drill operating frequency,
- impact of the drill bit against the rock. The observed level at the operatives positions is highest when a drill is collaring and decreases as the drill steel penetrates the rock, and
- ringing of the drill steel due to transverse and longitudinal vibrations set up by the piston/steel and steel/rock impacts.

In the case of mechanical noise emission from the drill, the noise level depends very much on the design and state of repair of the equipment while in the case of the steel, it depends on the type and length of drill steel in use and its depth of penetration into the rock.

2.2 Reducing pneumatic rockdrill and drill steel noise emissions

2.2.1 Transvaal and Orange Free State Chamber of Mines Research organisation

In this investigation (Beck 1965), ten different light-weight rockdrills from four manufacturers were evaluated. The preliminary measurements indicated that the noise emission characteristics for all the drills was very similar and as a consequence all subsequent detailed work to determine relevant noise sources was carried out on one representative drill.

The results ranked the noise sources as follows:

- exhaust.
- drill steel,
- mechanical noise from the drill

A detailed analysis indicated that drill steel noise level exceeded mechanical noise from the drill by 10 to 20 dB. It was argued that, since nothing practical could be done to reduce drill steel emissions, any attempt to reduce the level of mechanical emission from the drill would be superfluous and thus only the exhaust emission should be addressed.

A range of mufflers was evaluated with varying results from:

- designs with complex internal constructions in which icing occurred, to
- units that gave greater attenuation than was really required, but restricted the airflow and consequently reduced the drill's output power. to
- mufflers with insufficient attenuation. and finally to
- a muffler of simple construction (a number of "half or five-eights baffles in a steel pipe) that effectively reduced exhaust noise level to below that of the combined drill steel and mechanical drill noise and could therefore be considered acceptable.

The investigation concluded that effective, simple mufflers could be produced such that the noise due to the exhaust air was reduced to levels lower than emissions from the drill steel and drill housing. Also, since there was no effective way of reducing the noise emission from the drill steel, no significant benefit would be derived from silencing the housing and mechanical noise produced by the drill mechanism.

2.2.2 Department of Mining and Metallurgy. University of Queensland Australia

The investigation (Beiers 1966) of noise sources concluded that exhaust noise was predominant followed by a number of discrete sources from the drill and drill steel. By addressing the individual areas the researcher was able to reduce the overall noise level from 117 to 98,5dB at a position equivalent to the operators ears but with an attendant reduction in drill output power of 45 per cent.

Exhaust muffling was achieved using a variety of small commercial units, each of which reduced the noise level measured at the operators ear by about 3 dB. However, in each case there was a reduction in the drill operating frequency due, it is assumed, to the increase of exhaust back pressure. While the overall noise level was reduced, the higher frequencies of the exhaust that were previously masked became more noticeable and, though of lower power, were a greater irritation to the operator.

The effect of surrounding the drill with a jacket to reduce noise emission was also evaluated. In one design, in which a jacket of heavy drill material (packed with two half inch thickness of linoleum underfelt) was wound round the drill and the exhaust was piped away to a muffler, a reduction of 12,5 DB was measured at the position of the operator's ear without loss of efficiency. However, no comment was made on the additional mass or practicality of using this concept.

A further reduction in the noise emission from the drill was achieved by replacing some of the metal parts that contributed significantly to mechanical noise, valve and pawls being the notable ones, with plastic components. In this instance, though emissions were reduced, it was not considered a practical proposition because within 30 minutes the plastic components were showing signs of significant wear.

Another conclusion of this work was that for minimum noise to be generated by the drill steel for a given blow energy, the drill piston and steel should be of approximately the same mass.

2.2.3 US Bureau of Mines

Over a number of years several investigations (Miller 1963, Summers 1975, Visnapuu 1975, Chester 1964 and De Woody 1964) were conducted to reduce the noise emission from a variety of pneumatically powered machines, including stoping and development end drills. The work was based on their earlier observations and ranking of the various sources, namely:

- exhaust noise. (accounting for about 90 per cent of the total noise energy)
- piston to drill steel impact,
- transverse drill steel vibration. and
- drill steel to rock impact.

Four basic methods for reducing noise emissions such as those produced by pneumatic rockdrill exhaust are possible, though not necessarily practical, namely:

- dissipative mufflers: sound energy is absorbed in some medium,
- reactive mufflers: sound energy is dissipated through repeated reflections.
- exhaust hose; the noise is piped away from the operator. and
- noise cancelling devices: using electronic means the noise to be silenced is reproduced such that it is 180 degrees out of phase with the original and at the same energy level, the two are then added together and cancel each other out.

In the context of stope drills. the most practical approach was thought to be the reactive muffler. Using this approach the unit could be small and light, offer little resistance to air flow and therefore have minimal effect on the back pressure, and should be easily adapted to the drill, even with the possibility of making it a part of the body. Two designs of reactive muffler were produced and evaluated, one of which was quite successful: the other failed because the air exhausting from the muffler had an exit velocity in the region of 400 m/s and was consequently noisy in itself. However, the muffler that was successful from an acoustic point of view was large and heavy

Further designs based on the same concept were produced. The results of this work showed that the shape of the muffler cavity was not critical to its performance and this allowed a design to be produced that shaped the muffler to the drill body. By going one step further and making the muffler an integral part of the body it was felt that the modified drill would be more acceptable to the operators. In these evaluations it was again observed that the exhaust port design was a major factor that influenced the effectiveness of the muffler.

A final evaluation was carried out to compare the effectiveness of the reactive muffler developed previously with an expansion muffler that was also configured to the drill shape. The results of the laboratory tests, carried out on an Atlas Copco BBC-I 17 drill. indicated the noise level was 110 dBA with no muffler, 99 dBA with the expansion muffler and 95 dBA with the reactive unit. In these tests it was noted that no icing occurred in the mufflers to restrict the air flow.

It was concluded that further noise attenuation should be possible with a "muffler cover' completely surrounding the drill. This unit, which had to be a good barrier to sound transmission, mine worthy and conformable, was designed to absorb drill housing noise and maximize the exhaust muffler volume. With the cover fitted. and carrying out comparative free running tests, the noise level of the BBC-1 17 was reduced from 109 dBA to 92 dBA

In addition to the work on reducing exhaust noise effort was directed to attenuating the noise emitted by the drill steel. An effective method of achieving this reduction in surface tests was by the addition of a "constrained layer damping" system. This comprised a thin walled steel tube surrounding the drill steel near the collar filled with a viscoelastic material. For optimum attenuation. the length of the damping system was found to be dependent on the drill steel length. for example, with a 1.2 m steel the damping system should be about 150 mm long. (During the tests it was observed that little benefit was to be derived from fully encasing the steel since a partially constrained-layer damped steel was found to be only 2 to 3dB noisier than a fully covered steel.)

It was also noted. in one particular set of tests, that when using a standard rope thread steel with a detachable bit in place of a one piece drill steel the noise level was reduced by 6 dB.

Some work was also undertaken to evaluate the effect of replacing various steel drill parts with parts made from energy absorbing alloys. In some instances, however, because of the high rate of thermal expansion of the alloys, operational difficulties were encountered. To overcome this problem, some parts were made with increased clearances but this usually resulted in a lower drill efficiency. However, by choice of the suitable component/material/part combinations some success was achieved.

Final laboratory tests were conducted drilling on surface with the BBC-1 17 drill with various combinations of the above noise reducing features installed. Using the best of these combinations the noise level was reduced from 115 dBA in the standard build to 97 dBA in the optimum build when operating at 620 kPa. In this condition it was observed that the penetration rate for a 1.2 m drill steel was reduced by about 10 per cent though with long heavy steels the loss was insignificant.

2.2.4 MESA (Mechanical Enforcement and Safety Administration of the USA Department of the Interior)

The work at MESA (Muldoon 1975) was a continuation of that reported by the US Bureau of Mines and applied the techniques of quietening the exhaust and drill steel discussed in Section 2.2.3 above to a range or pneumatic machines (jackleg drills, stoper drills, vertical carriage mounted drills, jackhammers, drifters, column mounted surface drills and a diamond core drill). Depending on the application, either wrap around or remote cylindrical mufflers were used on the drills and a constrained elastomer damping arrangement on the drill steel.

Of particular interest for the South African gold mines were the results obtained during drilling tests on the jackleg and stoper drills where wrap around mufflers were applied. In these cases the noise reductions measured were:

- for mufflers alone from 3 dBA (112 to 109 dBA) to 8 dBA (119 to 111 dBA). and
- for combined drill and steel silencing. from 6 dBA (112 to 106 dBA) to 13 dBA (119 to 1O6dBA).

The results of penetration tests comparing unsilenced and silenced drills and steels indicated that performance losses, on one particular drill, were in the order of 2.6 per cent only.

The additional weight due to the wrap around muffler on the drills was less than 2 kg and this cost approximately US $35 in 1975 values.

2.2.5 CompAir

In the late 1980's CompAir (Findlay 1992) announced that "silenced" versions of two of their commercial range of drills were available, these were the "CompAir Dart" (a stoping drill) and "Holman Rocket" (a development end drill). Silencing was achieved by the addition of a "three chamber baffle/expansion" type muffler. Little or no weight was added to the machines when making this modification because "large" sections of the drill housing (principally the exhaust port cowl) were removed in order to accommodate the muffler.

CompAir claimed that the overall noise level from the drills was reduced by about 10.5 dB. (from about 125 down to 115 dB) Measurements by the SABS, in an open field, taken 1 m from the drill at a number of positions while drilling into a Norite block, indicated that the maximum overall reductions were 5.7 dBA for the Dart and 9,7 dBA for the Rocket The muffler in both cases was most effective in reducing noise emissions in the 63 Hz to 1 kHz frequency range. (No measurements were reported from an underground situation.)

A series of tests was conducted by CompAir at an underground production site to determine the drilling performance of the silenced drills and their acceptability to operators. During these tests it was noted that the penetration rate was approximately 10 per cent lower with the silenced drills than with the equivalent unsilenced ones, though whether or not this would be noticeable to the operator is questionable. However, because of the degree of noise reduction, an operator would suffer less hearing damage when using the silenced drill than he would with the unsilenced version if he drilled the same number of holes, even though it took him slightly longer, An additional benefit that was observed underground from the addition of the muffler was an absence of fogging while drilling.

A number of the silenced drills was purchased by one particular mine with the objective of evaluating them in specific panels. The trial started successfully in this manner but as time went by the drills became ineffective because:

- operators perceived the quieter drills to be "sick" because of their quieter operation, and not performing as they should: in many cases the operator punctured the muffler so that the drill "sounded right". and
- the silenced drills became distributed in among the standard machines and the beneficial effect of silencing was lost in the general noise of the louder machines.

It was concluded by CompAir that, though benefits can be derived from the introduction of mufflers on stope and development end drills, until there is a change in the attitude of the operators there is nothing to be gained from their introduction.

2.2.6 The Steel Engineering Co. Limited (SECO)

In 1978/79 SECO investigated mufflers for their stoping and development end pneumatic drills for the South African market (Hunt 1992). Emphasis was placed on reducing the exhaust noise and to this end expansion type mufflers were welded to the drill housing as an integral part. The effect on the drill mass of adding the muffler, a 'sturdy metal device' was offset to a large degree by machining off the exhaust port cowls.

The reduction in overall noise level emitted by the drill was in the order of 6 dBA. 115 down to 109 dBA. Comparative penetration rate tests between unsilenced and silenced drills in the laboratory at optimum thrust indicated a loss of some 5 per cent only in performance. It was the opinion of the engineers that this would not be discernible in an underground situation because drills were rarely used at optimum thrust or in the "as new" condition.

Though muffled drills were produced on a commercial basis, very few of them were sold to local mines. The main reason given for not purchasing them was that because the drills were quiet and operators did not like them as "their performance was poor". Relatively few of these drills are sold today.

In the meantime, the company has been active in reducing the noise emission from their overseas drills and other pneumatic equipment. Some of this work includes the use of wrap around mufflers of the type developed by the US Bureau of Mines (Summers 1973) and MESA (Muldoon 1975). It appears that with the materials used, good reductions in noise emission are obtained and the mufflers have a good service life, though no definitive results on the latter point are available.

Another area in which the company has some experience is in the damping of impact tools to reduce noise emission. Tools are available commercially for paving breakers with a constrained layer damping system fitted. these are reported to significantly reduce the overall noise emission from paving breakers fitted with wrap around mufflers.

If the demand for quieter drills becomes a reality, new drills are readily available and replacement housings for existing drills could be supplied as stock for repair workshops; However, it was concluded that there has to be a change in attitude in the South African mines before any progress can be made in the application of silenced drills.

Finally, two points were noted by SECO from their dealings with overseas customers: firstly, that in some countries the use of hearing protection is becoming mandatory in designated "Noisy" areas and secondly. that some overseas hearing protection devices are now claimed to have attenuation properties of up to 30 dB.

2.2.7 Delfos & Atlas Copco (Pty Limited)

Some years ago, Delfos & Atlas Copco undertook a programme of work to quieten their pneumatically powered equipment (Van Der Heyde 1992). For the South African mining market they developed silencers for their range of stoping and development end drills and produced them commercially. These silencers were welded onto the drill housing and added approximately one kilogram to the drill's mass.

It was claimed that during surface tests to compare the various drills. the noise level of the standard unit was found to be 110 dBA while the "quiet" drill was about 8 dBA lower. Also, when drilling with new machines on surface at optimum thrust, the penetration rate of silenced drills was only about six per cent lower than unsilenced units.

In discussion it was felt that the loss of power noted during these tests, and the extra mass, would not be readily discernible to the operators. whereas the noise reductions would be. This was borne out in underground trials of the silenced drills where operators said the drills did not "sound right" and therefore hey could not be "drilling right". However, no comment was made on the additional mass or actual measured or noted reductions in drilling rates.

An approach was adopted to make the quiet drills more acceptable to the operator by making them "sound right". This was achieved by modifying the silencer exhaust ports to make the drill's tone similar to the unsilenced versions, but with lower noise levels: this appeared to have success in some quarters.

Though a number of the local silenced drills was purchased by some mines, their use has not been widespread because of operator resistance. On one particular occasion where a mine purchased a large number of silenced drills, the machines were returned to the supplier in exchange for standard drills because of operator resistance. However, at a new mine, where it is claimed that only the silenced versions of the drills are purchased, operators are quite happy with the drill's performance in all respects.

Based on the underground experience, it was felt that until there is a change in attitude of the operators and an understanding of the problem, there is little to be gained from an ad hoc partial introduction of silenced drills. The changes in attitude will only come about through training and understanding, and the implementation will only succeed with the full and clear backing of all mine management.

If required, silenced drills can readily be supplied when new drills are ordered. However, because of the number of standard units already in service. "silenced" drill housings will be available for mine workshop stock to replace standard ones during service or repair. Also, if the condition warrants it, old housings could be sent back to the factory for silencers to be welded on and then returned to service.

In their overseas markets, Delfos & Atlas Copco have silenced pneumatic drills that incorporate a valveless cycle and a wrap around muffler. (An additional benefit noted with the use of these drills is the reported complete absence of fogging). Based on the results discussed in Section 2, these drills should have a lower noise emission level than the current units and the South African company are investigating the design with a view to possible local production and supply.

2.2.8 Hydraulic rockdrills- The quieter alternative

Following the development of the high water based emulsion powered rockdrill, the equivalent noise exposure of the drill's crew was determined in narrow. 1,2 m, and wide, 2.0 m, stopes and compared with that of pneumatic drill operatives in similar situations Van Rensberg 1989). Standard un-muffled leg mounted drills were used in conjunction with normal 25 A/F unclad mine drill steel having a nominal bit diameter of 42 mm. (In the case of the pneumatic machine, both stope and development end drills were evaluated, in each case in the stope.)

The average calculated "equivalent noise exposure" (Neq) determined for the drill operatives was as listed below, the ranges given account for the different exposure levels for operators and assistants:

- hydraulic drill. 105.0 to 107,8dB,
- pneumatic stope drill. 112.8 to 113.1 dB. and
- pneumatic development end drill. 112,510 113.5 dB.

From the results it was also possible to determine the "effective equivalent noise exposure level" (ENeq) to which the various operatives would be subjected should they be wearing good and effective hearing protection devices. namely:

- hydraulic drill crews: 80.0 to 83.6 dB with ear muffs and 87.3 to 89.3 dB with ear plugs.
- pneumatic stope drill crews; 90.2 to 90.6 dB with ear muffs and 96.6 to 97.4 dB with ear plugs, and
- pneumatic development end drill crews: 90,8 to 92.3 DB with ear muffs and

95,6 to 96,3 DB with ear plugs.

It should be noted that:

- because of the frequency spectrum of the various drills differs significantly the hearing protection devices are more effective against the noise from a hydraulic drill than a pneumatic machine, and
- the assumed noise attenuation is derived from laboratory tests and the effective figure may be less in a working environment.

During these evaluations, the penetration rates and drilling cycle times of all the drills were also determined. Using this information in combination with the exposure levels it was possible to calculate the equivalent noise exposure as a function of the number of holes drilled by each type of drill. From these results it was concluded, assuming a normal production rate for the hydraulic drill of 80 1.2 m holes per shift, that:

- in a shift the hydraulic drill operator would experience an equivalent noise exposure of about 105 dB while for the pneumatic drill operator drilling the same number of holes it would be about 116 dB. and
- if the pneumatic drill operator were to be exposed to the same 105DB equivalent exposure level as the hydraulic drill operator then he would be able to drill only 5 or 6 holes

2.3 Evaluation

From the literature survey and the above discussions it is evident that several effective methods have been successfully developed for the reduction of noise emissions of pneumatic blast hole drilling systems. However, it is equally apparent that few of these methods have been successfully introduced into a mining environment without the assistance of legislation (eg the European legislation on the wearing of hearing protection in noisy areas). A common factor cited in the failure of the successful introduction of 'silenced' rockdrills is a lack of operator acceptance and the perception, by the operators, that any machine which 'sounds different' or quieter must per force have a lower performance. While this is generally true of the configurations generally used on South African mines it should be recognised that at the noise levels being considered it is unlikely that an operator would be able to distinguish the difference in noise levels without a reference source ie an un-silenced machine for comparison purposes. Similarly, at the penetration rates generally encountered in South African deep level mines, where the compressed air supply pressure is frequently less than 400 kPa , it is also unlikely that the operators would recognise a reduction in performance of 2.5 to 10 per cent. However, the above comments not withstanding it would appear that a pre-requisite of successful application of a 'quiet' blast hole drilling system is that it should offer significant and easily recognisable direct benefits to the operator in addition to reduced noise exposure levels.

3 Research methodology and process

From the overview of noise reduction approaches for pneumatic rockdrills (Visnapuu , 1975) it was concluded that "*these modifications have left the basic drill configuration, air-hose requirements, controls, and operating methods of the drill unchanged, and it appears that any further noise reduction would require enclosing the complete drill and steel in an air bag or similar device*". The premise was adopted that this conclusion is, in general, correct but that additional features would have to be incorporated and changes made to the operational method if such an approach was to find general acceptance in the mining industry. In particular there should be no perceivable reduction in the performance of the machine and the overall operator effort during drilling should be reduced.

3.1 Identification of concepts

Based on the findings of the literature review it is evident that effective methods have been developed and evaluated for the reduction of the noise emission sources of exhaust air, drill steel and to a lesser extent internal components by the application of pi-reactive mufflers, constrained layer damping and material substitution respectively. However, each of these approaches has significant disadvantages which inhibited their general acceptance in production environments and included, but were not limited to, reduced drilling performance, wear of the constrained layer damping material, and limited life of substitute materials. It was necessary therefore that such disadvantages be addressed during the identification of potential concepts and either negated or reduced to acceptable levels. It was decided that the approaches of pi-reactive mufflers and constrained layer damping of the drill steel would be included in the initial concepts and that methods for reducing mechanical noise would be considered subsequently. Furthermore, since the United States Bureau of Mines had already developed and evaluated a machine incorporating each of these approaches it was evident that any initial concepts would have to reflect a more comprehensive approach to noise reduction and therefore it was decided to pursue the possibility of enclosing the drill and drill steel in some form of enclosure.

From the general geometry of a common rock drill (eg a SECO 215) and drill steel it appears obvious than an enclosure which does not significantly change the overall shape and dimensions is that of a long cylinder.

If the drill and drill steel are to be enclosed in a cylinder of some form then the next question to be addressed is that of how the required rock drill thrust will be applied.

3.1.1 Thrust Methods

Since the only power sources readily available to a rock drill in production are compressed air and flushing water the concepts considered for the provision of thrust were perforce limited to pneumatic and hydraulic devices.

A mathematical analysis (Hustralid 1971:247) indicates that for a pneumatic machine the minimum thrust force required to ensure that the bit and rock are in contact when the impact wave arrives can be determined from the following relationship.

$$F_t = \frac{\bar{f}}{30}(1+\beta)\int_0^{\tau} \sigma_i dt \qquad (3.1)$$

where σ_i = incident stress (longitudinal wave) as a function of time (KPa)

τ	=	duration of incident wave (sec)
β	=	coefficient of momentum transfer from drill steel to piston, normally $0 \le \beta \le 0.2$
F_t	=	minimum required thrust (N)
f	=	actual blow frequency (Hz)

It is important to note that the thrust required for optimum drilling depends on the particular drill and is essentially independent of rock type and bit diameter. Furthermore the method used by Hustralid is limited to the determination of the thrust required to restore bit/rock contact and does not include any allowance for the fact that in rockdrills such as the SECO 215 the percussion and rotation are mechanically linked causing the drill to stall if excessive thrust is applied. In recognition of this it was decided that the thrust requirements be determined by experimental drilling in Norite. The relationship between thrust and drill penetration rate for a percussive rock drill is shown in Figure 3.1.1.a

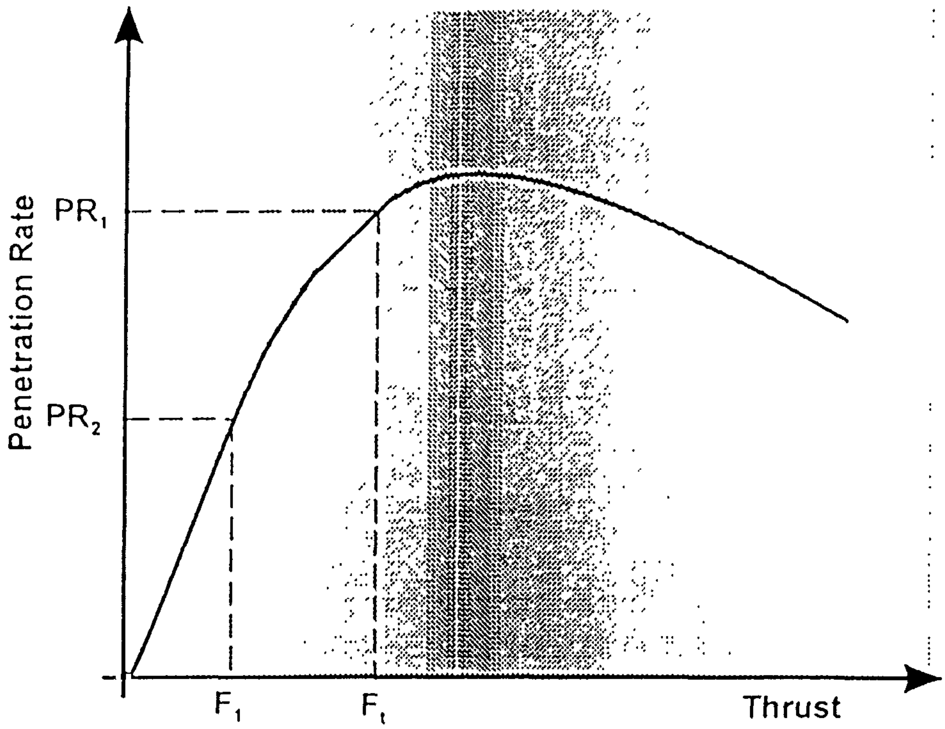

Figure 3.1.1.a A typical thrust-penetration rate curve for a percussive rock drill

When a piston impacts the end of a drill steel an incident wave having a certain amplitude travels towards the bit-rock interface. The shape and amplitude of the wave that is reflected back down the drill steel (away from the interface) depends on the conditions pertaining at the interface. If the bit and rock are not in intimate contact, as may occur under conditions of under thrust, a free end reflection will result Successive incident and reflected waves will continue to be of approximately the same amplitude as the initial incident wave and decreasing only as a result of hysteresis losses and dispersion until bit-rock contact is re-established. On re-establishment of the bit-rock contact a rapid decrease in amplitude will occur as a result of energy transfer to the rock. If the bit and rock are in contact when the first incident wave arrives the amplitude of the reflected wave will be much smaller than that of the incident wave again as a result of energy transfer to the rock. Because fatigue life decreases exponentially with increasing peak-to peak stress amplitude it is important to keep the number of high-level stress reversals as low as possible. This minimum occurs when the the bit and rock are in contact each time a new stress wave arrives at their interface. The thrust force F_t required to achieve this condition is determined from the relationship of equation 3.1. A typical curve for penetration rate as a function of thrust at a given air supply pressure is shown in Figure 3.1.1.a.

If the applied thrust is F_1 rather than F_t the penetration rate is approximately half that at optimum thrust. However, the machine continues to provide the same energy to the drill steel irrespective of thrust. The energy not absorbed by rock penetration must therefore be dissipated as hysteresis heating within the drill steel which requires a large number of cycles of stress reversal. Assuming that these cycles are high level stress reversals then the fatigue life of the drill steel will be severely reduced. Typically, the reduction in fatigue life may be by a factor of 3 when operating at half the optimum thrust. This reduction is in addition to the fatigue limitations of the drill steel incurred as a result of bending loads resulting from the non-axial thrust produced by a conventional thrust leg arrangement. As a result of these factors and following several drilling test using a drilling test rig an optimum thrust force for a SECO 215 machine was determined to be 1000 N.

Given this requirement several concepts for the provision of the thrust were developed five of which were selected for further consideration. A schematic of each is shown in Figures 3.1.1.b-f. Each of the concepts for the thrusting of the rock drill shown have the following generic advantages:

- The thrust is generated in line with the direction of drilling which according to Hustralid 1971:268 can provide an improvement in performance of up to 100 per cent over a conventionally thrusted machine. This increase should be more than sufficient to compensate for the 10-15 per cent reduction generally produced by the application of noise suppression to the exhaust system of pneumatic rock drills.
- In line thrusting reduces the bending moment applied to the drill steel and therefore provides for longer drill steel life and a reduction in the wear rates of both the drill chuck bush and the drill steel shanks.
- Reduced wear of the chuck bush and drill steel shank affords the potential for increased usage of the drill-steel before replacement and may therefore negate any difficulties with drill steel retention within the enclosure.
- In line thrusting provides improved accuracy of drilling by minimising the deviations in drilling direction.
- Each of the arrangements facilitate the inclusion of a front guide or bearing for the drill steel which simplifies collaring and avoids the need for an assistant during collaring.
- Each of the thrust arrangements can provide the necessary thrust over the full hole length required thus obviating the necessity for 're-stinging' as is the case with conventionally thrusted rock drills.

The specific advantages and disadvantages of each of the five concepts for thrusting are presented in the following sections.

Peristaltic drive

In this approach (Figure 3.1.1.b) the drill acts as a restriction within a flexible tube which is itself installed in the cylindrical enclosure. By introducing air between the flexible tube and the outer cylinder a thrust is produced as a result of the pressure acting on the annular area created between the tube and the cylinder. The annular area can be adjusted to be equivalent to that of a standard thrust leg piston so that the conventional thrust leg control mechanism can be used. While at first sight this appears as a simple elegant solution there are several drawbacks which precluded further consideration as follows:

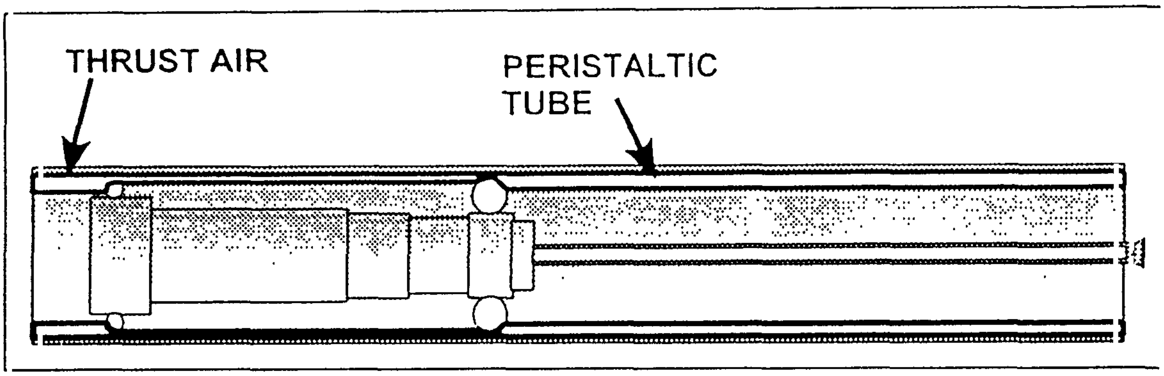

Figure 3.1.1.b A peristaltic drive

- The thrust must also allow for the forces required to expand the inner flexible tube.
- To prevent collapse of the inner tube the tube must be of circular cross-section which would not provide any reaction for the drill rotation.
- It was not possible to source a material for the inner tube which had the necessary flexibility for the rock drill to expand it to provide a seal against the outer tube whilst retaining sufficient rigidity to prevent collapse even at relatively low pressure differentials.

The potential advantages of such a design would have been its inherent simplicity and the fact that the air volume between the inner tube and outer cylinder would provide additional noise attenuation for the internal mechanical noise of the drill.

Air motor driven lead screw

In this approach (Figure 3.1.1.c) an air motor is used to provide the necessary thrust via a lead screw. The potential advantages of this are as follows:

- A simple bi directional positive drive utilising standard air motors via a lead screw.
- The presence of the lead screw would provide the necessary reaction for the drill steel rotation.
- Since the major loads would be carried by the lead screw the outer enclosure material can be selected simply on the basis of mass and noise attenuation and possibly even be considered as a consumable item.

- No modifications would be required to the rock drill.

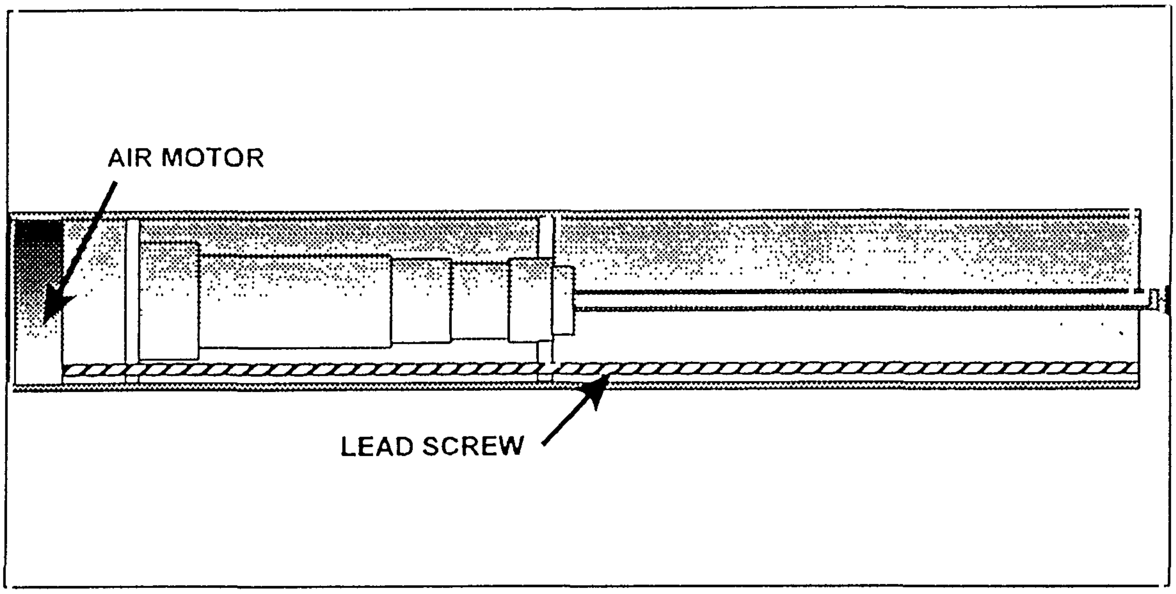

Figure 3.1.1.c Air motor driven lead screw

The disadvantages of the air motor driven lead screw approach to the thrusting of the machine are :

- The air motor itself is an additional noise source which would require a muffler device.
- The rigid nature of the attachment of the drill to the drive mechanism would introduce additional mechanical noise and vibration and potential high dynamic loads within the lead screw and its attachments.
- The positive nature of the drive would possibly require a torque limiting device to prevent stalling of the drill and this would also be an additional noise source.
- The additional mass of an air motor and a 1.2 metre lead screw and attachments would potentially inhibit operator acceptance.

Air motor driven lead screw and rotation

A further development of the lead screw approach (Figure 3.1.1.d) would be to utilise an air motor such as that used in the SECO Nova 70 machine which in addition to providing a thrust would also provide the drill steel rotation which would enable the removal of the rotation related components of the rock drill such as the ratchet, pawls, rifle bar and rifle nut. This apart the concept would have the same advantages and disadvantages as the air motor driven lead screw described above except that an air motor rotation, being continuous, is expected to have a lower noise level than the standard ratchet and pawl mechanism.

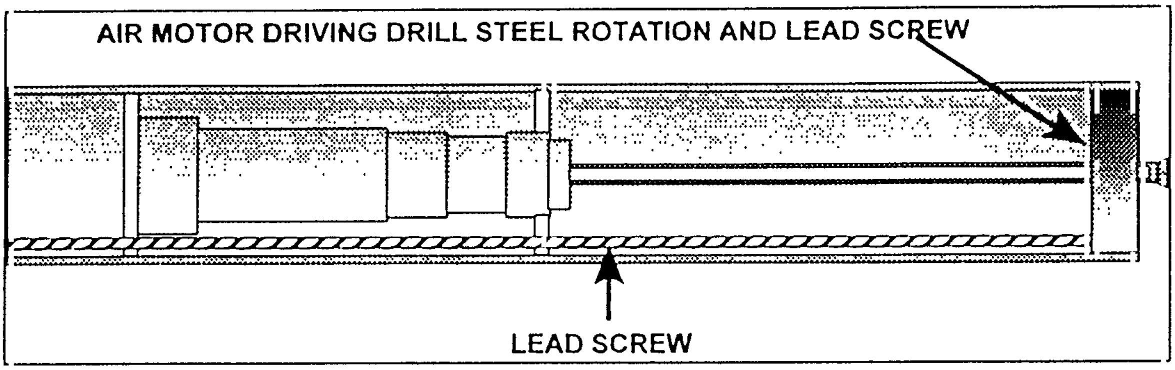

Figure 3.1.1.d Air motor driven lead screw and rotation

Air driven piston

In this approach (Figure 3.1.1.e) the drill is modified by the addition of discs at the back head and percussion/rotation interface in order that it may act as a piston within the enclosure. The thrust is provided by the introduction of air behind the rock drill and would require very low pressures for the necessary thrust as a result of the large cross-sectional area of the drill The potential advantages of such an arrangement are :

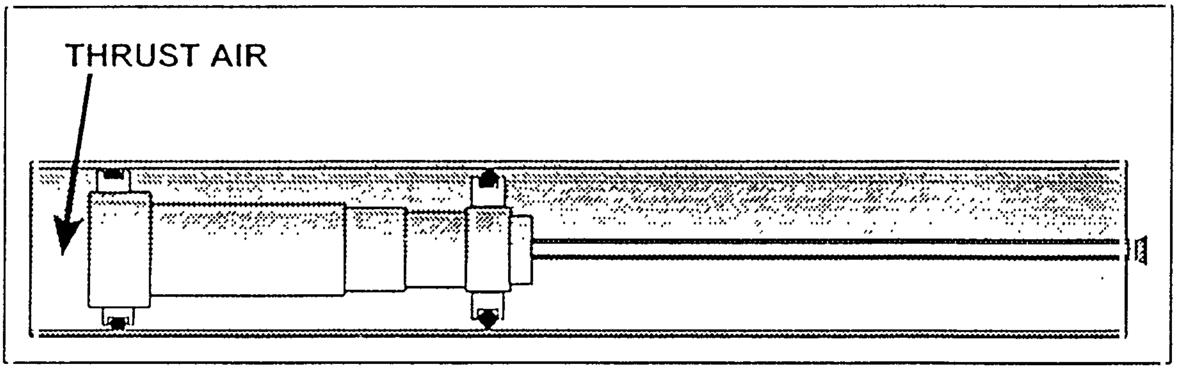

Figure 3.1.1.e Air driven piston

- A simple effect approach requiring minimal modifications to a standard rockdrill.
- Potentially compact design with a generally smooth external surface.
- The approach can accommodate additional half or five eights baffles for additional attenuation of exhaust noise should this be required.

- Mass should be equivalent to a convention machine and thrust leg.
- The use of a prismatic cross-section permits reaction of the drill rotation torque.
- Since there will be no direct mechanical connection between the drill and the thrust mechanism no additional damping is envisaged.

The potential disadvantages include the following:

- Since the system must be sealed provision must be made to deal with extraneous flushing water issuing from the chuck bush and the provision of the main air supply to the drill.
- The large cross-sectional area will require a fine control of the thrust pressure to ensure a controllable thrust force.
- The large diameter of the tube may produce insufficient damping.

Rod -less cylinder approach

This approach is similar in many respects to the air motor driven lead screw method but with the thrust being provided by a pneumatic in line rod less cylinder. This approach provides for all the advantages enumerated above regarding in line thrusting but with a cylinder which is typically only 50 to 60 per cent of the length of a conventional cylinder. A particular disadvantage of this approach is the cost of the cylinder which is typically R 4 000 to R 5 000 for a one metre stroke.

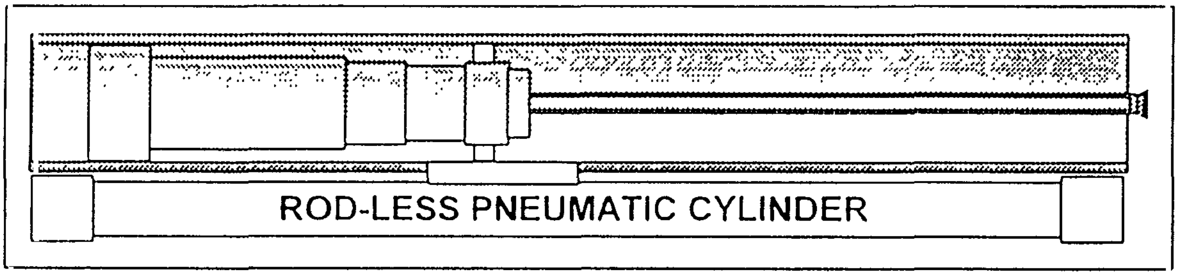

Figure 3.1.1.f Rod-less cylinder approach

3.1.2 Stinging and support

To enhance operator acceptance of a quiet machine an objective of the current work was that the overall operator effort required for drilling should be reduced. This aspect is addressed within the concepts discussed above via the elimination of the requirement for re-stinging since each of the concepts provides for the drilling of a hole in one continuous operation However, this is but one element of the operator input during drilling and therefore does not address issues such as the required downward force to balance the upward component of the conventional thrust leg, the effort required to prevent the drill from falling over and the ongoing adjustment of the thrust pressure To minimise these operator inputs a stable self supporting drilling system is required.

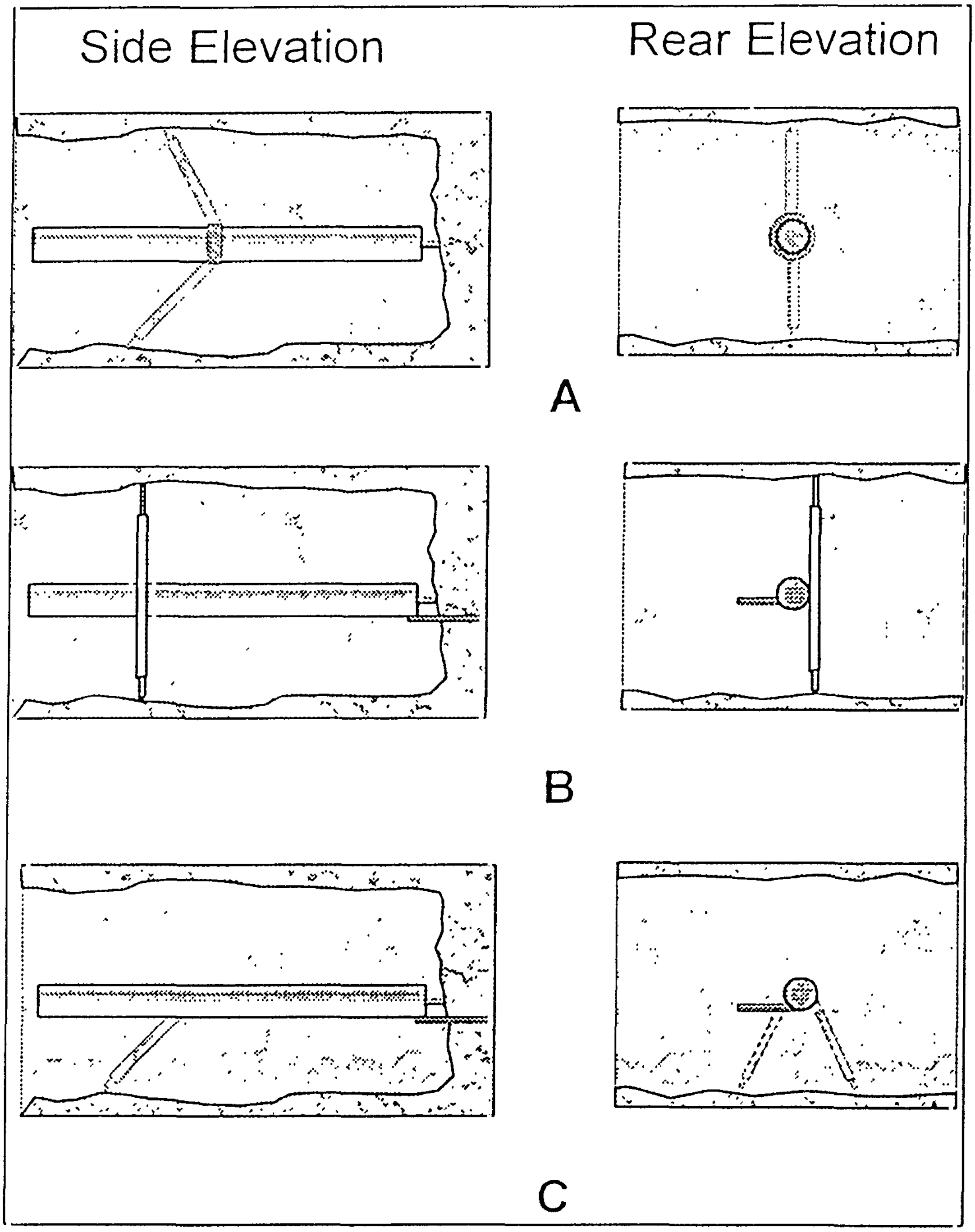

Figure 3.1.2.a Alternative stinging arrangements

To achieve such a system requires a minimum of three reaction point which will include one at the face and either two on the foot wall or one on the foot wall and one at the hanging. The thrust force of the machine may be reacted either at the face or at the reaction points at both foot wall and hanging. Furthermore, the selected arrangement must be able to provide the necessary reaction to the rotation torque which in the case of a typical pneumatic rock drill is approximately 10 Nm .

In arrangement 'A' of Figure 3.1.2.a the system is supported by three reaction points at the face, foot wall and hanging. In this concept the foot wall and hanging reactions are carried by two spring loaded legs of disparate lengths and the face reaction is accommodated by a spring loaded single point stinger. The envisaged method of operation would be to place the front stinger at a point below the required position of the blast hole and push the whole drill system forward against the spring. The two legs would then be released allowing the spring loading to open the legs to provide engagement against the foot wall and the hanging. A release by the operator would permit the spring of the front stinger to move the system away from the face until the legs engaged fully at the foot wall and hanging.

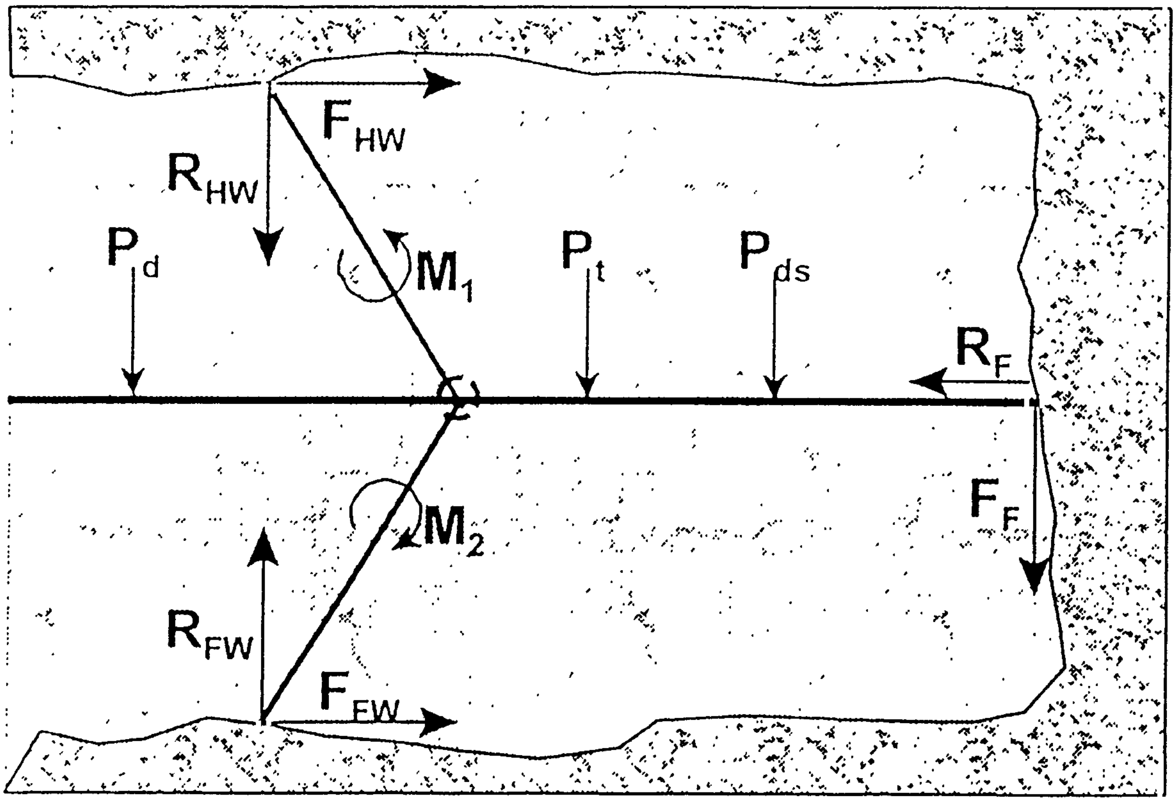

Figure 3.1.2.b Model of stinging arrangement for analysis

Where: P_d P_t,P_{ds} are the masses of the drill, enclosing tube and drill steel respectively.

R represents the reactions

F represents the friction forces and

$_{F, HW, FW}$ refer to the face, hanging wall and foot wall respectively.

This system was modelled as shown in Figure 3.1.2.b and analysed to determine the required reaction force at the face to provide stability. It was assumed that the additional reaction force at the face provided by the drill thrust would be fully reacted by the legs.

The analysis indicates that a face reaction (R_F) of 15 Kgf would be sufficient to provide stability for any position of the rockdrill.

Arrangement B of Figure 3.1.2.a uses a simple pneumatic or mechanical jack arrangement to provide both support of the system and reaction of the drill thrust force. With point stingers at each end of the jack the required loads to resist the thrust force are of the order of 200 kg, a value which can readily be achieved with mechanical systems.

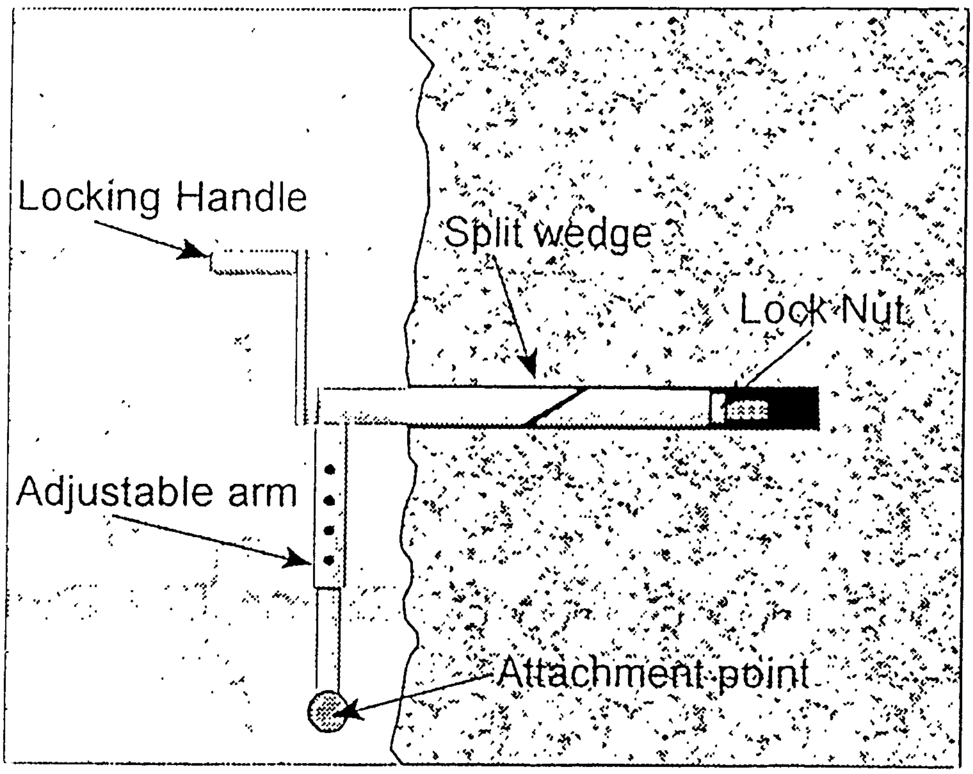

Figure 3.1.2.c Face locking device

The arrangement C of Figure 3.1.2.a is significantly different in that the thrust force is reacted via a device installed in the previously drilled hole while the legs simply provide support and stability.

The device used to react the thrust is based on a previous development to improve drilling accuracy and is based on a mechanically operated wedge locking system as shown in Figure 3.1.2.c.

3.2 Development of concepts

Following the initial identification of concepts and a comparative analysis of their relative advantages and disadvantages and an assessment of available materials and technologies the decision was taken to manufacture a pre-prototype based around pneumatic thrusting (Figure 3.1.1.5).

3.2.1 Exhaust noise

According to the USBM (De Woody RT. 1964), exhaust noise can be reduced by using dissipative mufflers, reactive mufflers, or noise cancelling techniques. Dissipative mufflers attenuate sound by absorption whereas reactive mufflers attenuate sound by reflection. Noise cancelling techniques involves using electronic means to reproduce the noise at the same energy level but exactly out of phase with the original such that on combination the two noise sources cancel each other. In the investigations carried out by the USBM (De Woody RT. 1964), reactive exhaust mufflers were demonstrated to be the most effective for the attenuation of rock drill noise. However, for a muffler to be considered acceptable in the mining industry, the following minimum requirements must be met:

- Mufflers should be small and light weight.
- Back-pressure should be as low as possible.
- Muffler should be adaptable for attachment to a rockdrill or be suitable for incorporation into the shell of the drill itself.

In the design of reactive mufflers it was demonstrated by the USBM (De Woody RT. 1964), that the reactive muffler amenable to analysis by electrical analogy thereby providing a method for preliminary design of physical systems without time-consuming and expensive mechanical trial construction.

The basis of the analogy derives from the fact that both acoustical and its electrical equivalent are both based on the same basic laws of conservation of energy. According to electrical and acoustical analogies, a tube with a diameter that is small in comparison to its length has the properties of series resistance and inductance, and the impedance of a small diameter tube is given by the following equation (Olsen HF 1957: 56-123):

$$Z_A = \frac{8\mu l}{\pi R^4} + j\omega \frac{4\rho l}{3\pi R^2} \qquad (3.2)$$

Where R = Radius of the tube in 'cm'.
μ = Viscosity coefficient ($1.86.10^{-4}$ for Air).
ω = $2\pi f_A$ where f_A = frequency in Hz.
ρ = Air density ($1.2.10^{-3}$ g/cm3 at 20°C.)
l = Tube length, in 'cm'.
j = Square root of minus one.

This relationship is used to determine the physical dimensions of elements of the muffler from its electrical analogue.

The input parameters to the design methodology are the drill frequency, the cross-sectional area of the drill exhaust port and the selected filter cut-off frequency. The parameters selected by De Woody et al (5 cm^2 exhaust port area, drill frequency of 30 Hz and a cut off frequency of 100 Hz) were sufficiently close to those of the SECO 215 rockdrill (4.8 cm^2 exhaust port area, drill frequency of 28 Hz and a cut off frequency of 100 Hz) to warrant using the same design parameters for the initial prototype. This was considered appropriate considering that the analysis assumed a constant air density and therefore does not account for changes of pressure and/or temperature within the muffler. The design parameters of the pi-reactive muffler developed by the USBM are shown in Figure 3.2.1.a.

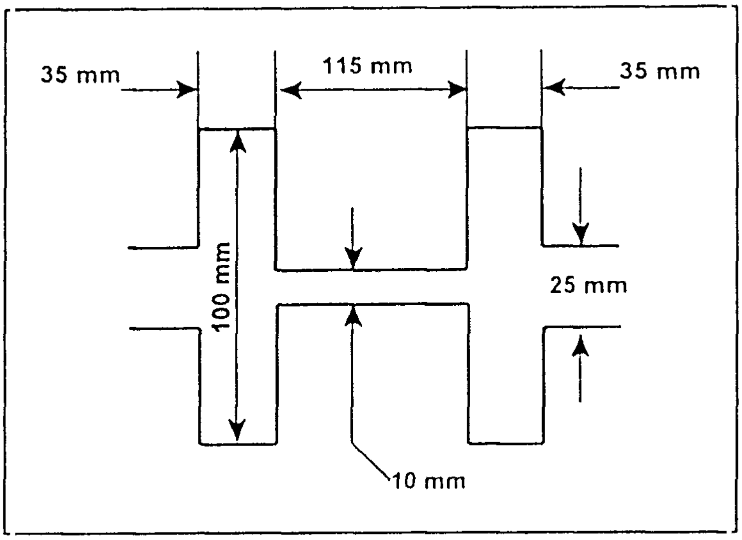

Figure 3.2.1.a. Pi-reactive muffler details (De Woody et al :1964)

A particular feature of the analysis of the pi-reactive muffler is that the geometry of the input and output volumes is not significant, provided that is, that their diameter to length ratio is sufficiently small to avoid acoustical resonance. With this feature it was possible to develop the requisite muffler geometry by cylindrical enclosures around the percussion and rotation sections of the drill with the lengths of each enclosure being modified to provide the required volume as shown in Figure 3.2.1.b.

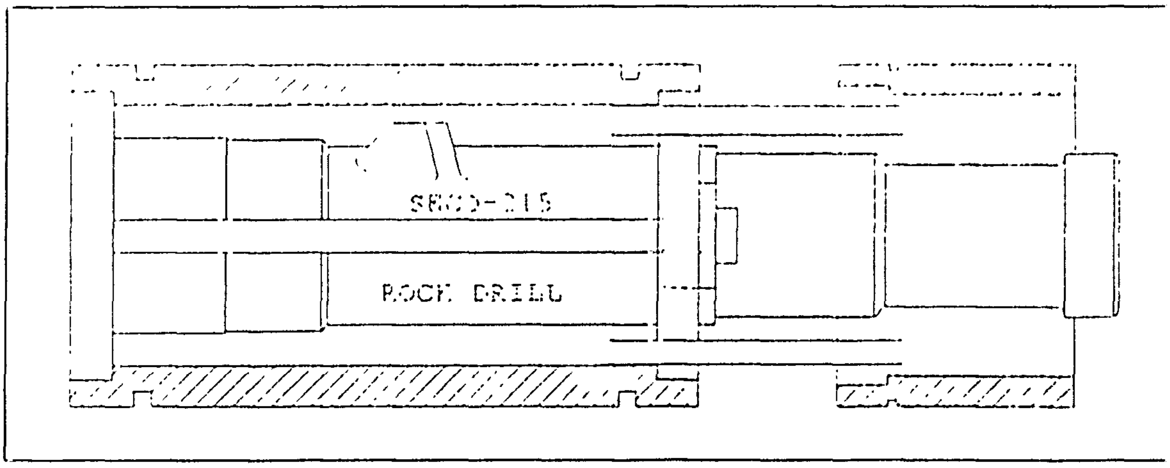

Figure 3.2.1.b Pi-reactive muffler arrangement on a SECO 215 drill

While the pi-reactive muffler arrangement was found to be the most effective method for the attenuation of exhaust noise it should be noted that if the exhaust air velocity is excessive the noise produced at the exit can nullify the benefits of the muffler.

Consequently, the design was modified slightly by increasing the cross-sectional area of the exit from the second muffler volume to ensure that the exhaust air velocity was sub-sonic. While in practice this modification was found to be superfluous since sufficient attenuation was provided by the enclosure cylinder it was noted that if the cross-sectional area of the air outlet of the enclosure cylinder itself was insufficient additional noise could be produced.

3.2.2 Drill steel noise

The approach adopted to address the noise produced by 'ringing' of the drill steel was that of constrained layer damping as identified and developed by Visnapuu and Jensen (1975). In this approach the drill steel stem is surrounded by a viscoelastic material to provide damping with a further thin metal sheath to protect the viscoelastic material from abrasive wear during drilling. For a constrained-layer system, the bonding material should be strong enough to withstand the violent vibrations during drilling while sufficiently compliant to absorb the drill steel vibrations without transmitting them to outer cover. The USBM prepared constrained-layer damped steels by slipping the metal tube over the drill steel, centring the steel in the tube, and then filling the space between the tube and steel with liquid viscoelastic filler.

In an attempt to reproduce the work by the USBM a standard 22 mm AF divided-bit drill steel was damped in the same fashion using 80 Devcon Flexane as a filler. Noise emission tests of damped and undamped 1.2 m long 22mm AF drill steels were conducted in an open environment with the drill steels freely suspended and struck with a seismic hammer in the same manner and direction as would occur by the rockdrill piston during drilling . The results of the tests were that the noise level of (plain) undamped drill steel was reduced from 108 dBA to 95 dBA peak values for a single blow when measured at a position 0.5m away from the centre and perpendicular to the drill steel as shown in Figure 3.2.2a.

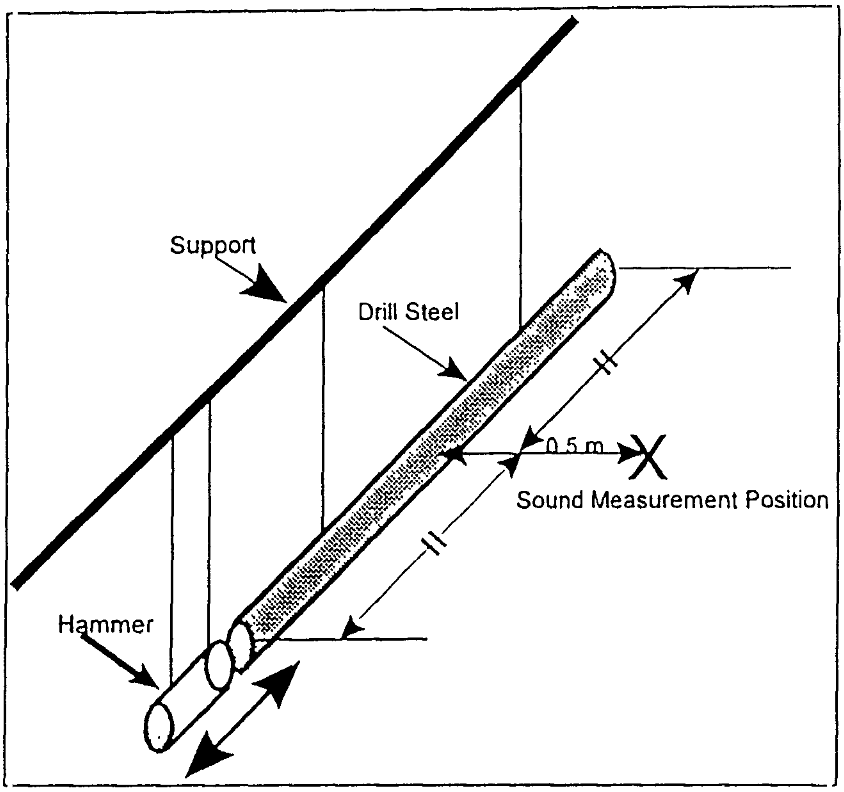

Figure 3.2.2.a Damped drill steel test arrangement

While the sound damping is demonstrably effective, 80 Devcon Flexane filler material proved to be too expensive (approximately R76 per drill steel) and therefore alternate methods of constrained layer damping were sought. In considering potential alternatives the following factors were taken into consideration:

- Increasing the mass of the drill steel has an adverse effect on the drilling rate in that penetration rate is inversely proportional to the drill steel mass.
- In the envisaged drill configuration with its 'in-line' thrust the bending loads on the drill steel should be minimal particularly in comparison to a conventionally thrust rock drill.
- The additional cost to the drill steel must be minimal

3.2.3 Mechanical noise

No initial attempts were made to specifically reduce the noise produced from internal components of the drill since it was considered that the concept of enclosure would effectively deal with this issue based on the following points:

- The drill as a whole is enclosed by two polymeric tubes, the first being part of the muffler system and the second the outer enclosure tube, with an air gap in between to provide high attenuation of the noise. This arrangement effectively addresses the internal noise sources within the drill such as valves, pawls and rotation.
- The drill is supported within the enclosure tube by large elastomeric seals which additionally provide vibration damping to reduce noise transmission. This effectively addresses the noise normally produced by the attachment of the drill to the standard thrust leg.
- The drill steel noise, while primarily addressed via the constrained layer damping approach, is further attenuated by enclosure within the outer tube.
- Noise from the drill steel/chuck interface is attenuated by the outer closure but additional noise reduction may be possible via using closer tolerances on these components which becomes practicable when using in-line thrust methods. The use of vibration absorbing materials such as used by the USBM were not considered to be warranted at this stage.
- No concepts or developments thereof were identified at this stage to address the noise produced from the drill bit/rock interaction. However, it should be noted that based on the discussion on thrust requirements in section 3.1.1 above that correct thrusting should minimise the noise of the longitudinal compressive waves within the drill steel by providing effective energy transfer to the rock and reducing the magnitude of any reflected waves.

3.3 First prototype

Six off first prototypes were manufactured to the details of the drawings presented in Appendix A. This prototype included the following features :

- Simple pneumatic thrust with the thrust air being initially supplied by an independent pressure controlled air supply. (Refer to drawing RD-002 of Appendix A)
- The drill was converted to a simple piston via the addition of modified front and rear plates and a polymeric piston (Refer to drawings RD-016, RD-015 and RD-025 of Appendix A)
- Air to the drill was supplied via a telescopic arrangement (Refer to drawing RD-029 of Appendix A)
- The drill was placed in an H.D.P.E tube which was closed at each end with closures (Refer to drawings RD-037 and RD-031 of Appendix A)
- The thrust direction was controlled by two sleeve valves (Refer to drawing RD-030 of Appendix A)
- The sleeve valves were operated by push/tie rods and controlled by an external lever arrangement (Refer to drawing RD-034 and RD-032 of Appendix A).
- The push/tie rods also serve to retain the closures of the outer tube and provide the reaction required for the drill rotation.

The initial prototypes were not fitted with stinging arrangements being simply fitted to an existing drill rig for evaluation purposes.

3.3.1 Results

During initial testing a noise level of 87.5 dB was measured for the drill operating in over travel. During drilling this rose to 92-93 dB .

During the drilling trials it was noted that the drill flow rate (measured at 2.3 m^3/min) was substantially below the manufactures quoted typical flow rate of 3 m^3/min at 500 kPa supply pressure. This indicated that an excess back pressure was being applied to the machine resulting in the lower than expected penetration rates shown in Figure 3.3.1.a.

A subsequent analysis of the modifications to the drill showed that the modifications to the rear plate of the drill had not allowed sufficient cross-sectional area for the required air flow rate and was therefore modified to the detail shown in drawing RD-040 of Appendix B. Following this modification the penetration rates increased substantially reaching levels of 0.21 m/min as shown in Figure 3.3.1.a.

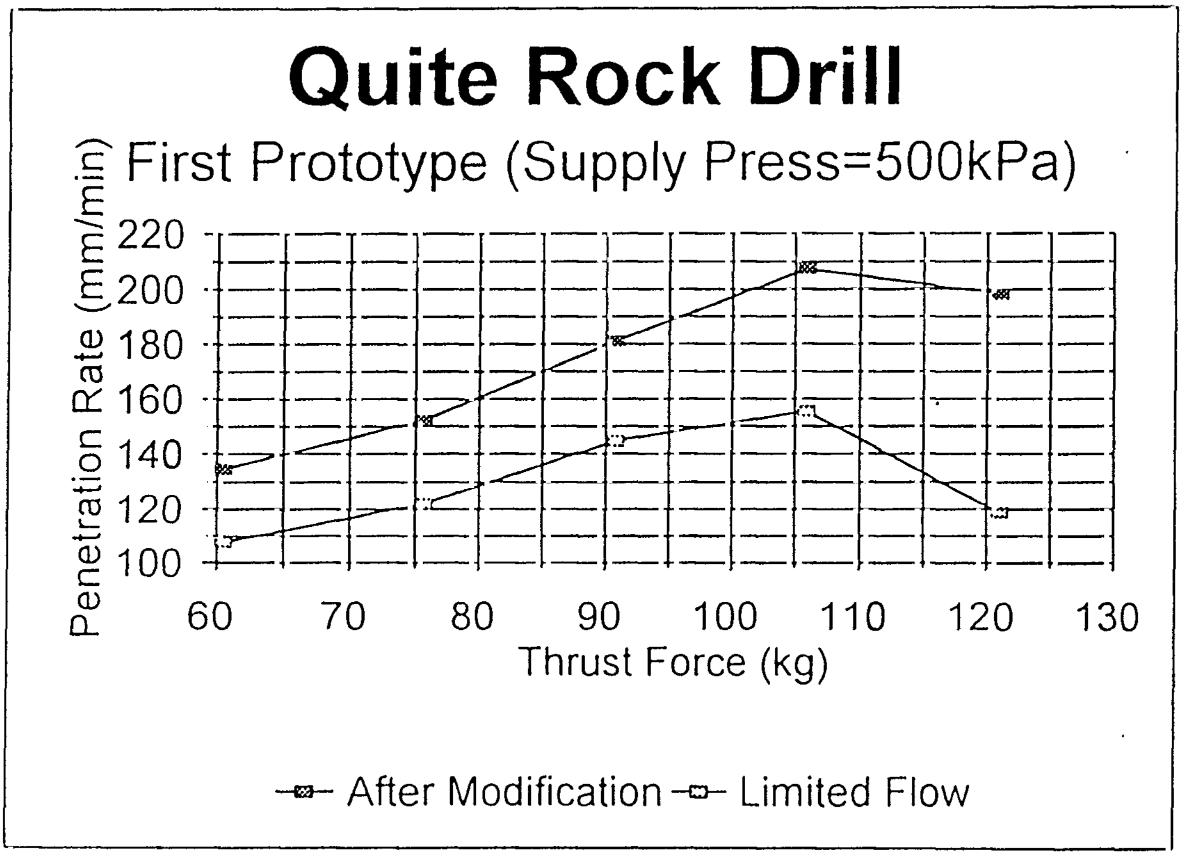

Figure 3.3.1.a Initial and subsequent penetration results of first prototype

Following tests to determine the noise levels during over-travel operation it was noted that the several of the drills were unable to be thrusted adequately. Subsequent examinations revealed that the seals between the drill and the outer housing and the seals around the tie rods had severely degraded as a result of hysteresis heating.

In general the large number of seals:

- Seals around the tie rods
- Seals in the telescopic air supply to the drill
- Seals around the drill

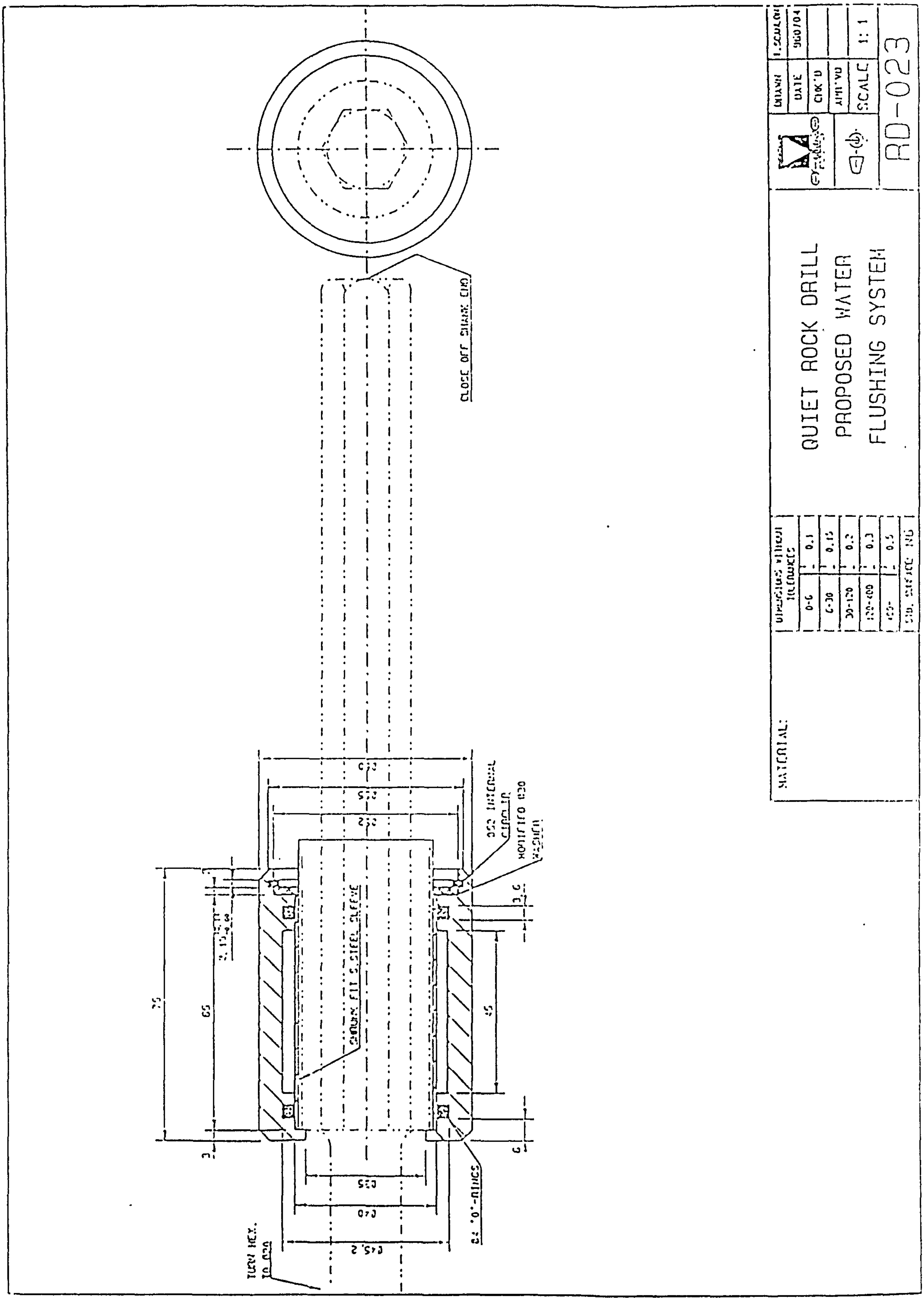

Figure 3.3.1.b Water flushing modifications

proved to problematic. A consequence of the large cross-sectional area of the outer tube is that the required air pressure for the optimum thrust is low and therefore any leakage either from the air supply to the drill or leakage of the exhaust air to the thrust side of the drill would compromise the thrust level. The nett result of the air leakage across the seals was that the thrust proved very difficult to control after even quite limited use of the drill.

During drilling trials, and particularly when drilling the equivalent of 'top' holes the enclosure tube would fill with water and stall the drill. To overcome this problem the water flushing arrangement had to be redesigned and the drill steel modified (reference Figure 2.2.b). The drill steel collar is machined smooth and a stainless steel collar is shrunk on to it. A water banjo (rotating connection) is fitted on to this for the water connection via a plastic tube. The orifice at the rear of the drill steel is closed off and a radial hole is drilled through the wall of the collar breaking through into the cored hole of the drill steel allowing the water passage down to the bit without any leakage.

3.4 Second prototype

While the first prototype had proven the initial concept and demonstrated that high levels of noise reduction could be achieved there were many problems, particularly in the seals which required resolution.

In the second prototype the main concept of a rockdrill acting as a piston within a main enclosure tube was retained but with modifications to address the primary problems encountered with the first prototype. In particular the design was modified to use an aluminium tube of non-circular cross-section. It was anticipated that a metal tube of the section shown in Figure 3.4.1.a would first, provide reaction for the rock drill rotation thereby eliminating the need for tie rods and their associated seals and second provide the necessary heat dissipation to avoid hysteresis heating of the main seals during over travel operation.

Following discussions with a primary aluminium supplier it was agreed that a hollow section of the form shown in Figure 3.4.a could be produced relatively simply by the modification of the inner die only of an existing die-set thereby avoiding the major costs associated with a new die set The suppliers provided a sample which was used as a

]template for the design of the second prototype. Components necessary to the assembly of six second prototypes were manufactured before the aluminium supplier became aware that technical difficulties in the tube drawing prevented them supplying the required tubes within the existing budget and time constraints.

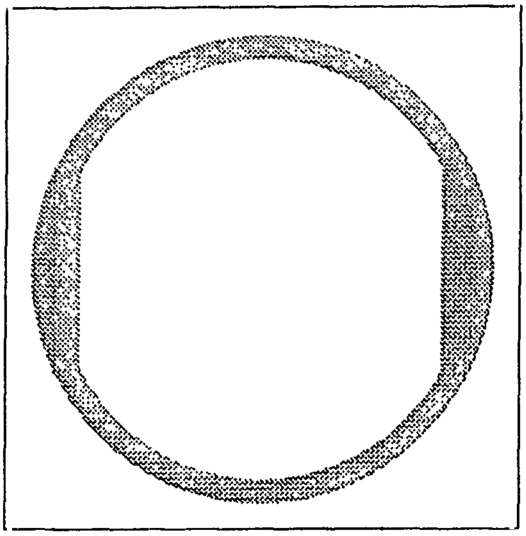

Figure 3.4.a Proposed aluminium tube section

3.4.1 Results

As a result of the non-availability of aluminium tubes of the section shown in Figure 3.4 a second prototypes could not be assembled for evaluation.

In an alternative approach the drills, as modified for the second prototype were mounted on a rod-less cylinder system as shown in the drawings included as Appendix D. In this configuration the drills were tested while drilling into Norite. While the penetration rates matched that achieved with the first prototype the noise levels did not. The noise levels were measured at 97.5 dB in overtravel and 102 dB during drilling. This increased noise level is ascribed to the internal noise (eg ratchet, pawls and valve), piston to drill steel impact, drill steel and attachment. The noise from these sources is more evident in the absence of the first prototype main tube which provided good attenuation of these sources in the previous tests.

It was concluded that, since this arrangement did not achieve the noise reduction levels of the first prototype, further work on this arrangement would be discontinued until such time as a concept for a fully enclosed system could be identified.

4 Discussion of results

The results of the drilling tests of the first prototype concept demonstrated that the arrangement has noise emission levels substantially lower than an identical rock drill while maintaining penetration rates equivalent or better than the same machine operating with a standard thrust leg.

Standard lubricators were used throughout all tests and there was no evidence of any grease issuing from the exhaust ports of the first prototype all the lubricant was in fact retained with the main enclosure tube. With prolonged use and increased accumulation of grease it is anticipated that his will eventually be discharged through the main axhaust parts as an emulsion and not an aerosol.

While the noise and drilling results were very encouraging it was evident that the thrusting arrangement of the first prototype was totally unsuitable for mine application for the several reasons outlined above.

In view of the severe impact of noise induced hearing loss on the mine work force and the consequences for the industry as a whole is entirely appropriate that efforts be continued to translate existing drill noise reduction strategies and approaches to a usable mine worthy system. The concept evaluated in this work effectively utilises the best noise reduction methods reported to date into a potentially viable system by enclosing both the drill and the drill steel in a tubular enclosure. It is suggested that this approach be continued with additional focus on the provision of a suitable thrusting mechanism, possibly by the further evaluation of the remaining concepts introduced in section 3.1.

5 Conclusions and recommendations

From results of the surface testing of the first prototype quiet blast hole drilling system it is evident that while there is a very positive indication that this type of arrangement can significantly reduce the noise emissions of pneumatic rock drills to levels which, at typical drilling shift times in South African mines, would permit compliance with the legislative requirements, significant further re-engineering will be required to develop an effective mining tool. The concept has resulted in the production of a device that can drill at rates better than conventionally thrust drills at significantly lower noise levels. Comparing the noise levels of a standard unmodified drill of 115dB against that of the prototypes at 92dB there is real cause for optimism regarding a major contribution to the reduction of noise induced hearing loss in the South African mining Industry.

However, it is very evident that the thrust method used in the first prototype is not acceptable for the following reasons:-

- Tie rods are required to react the rotation and add un-necessary mass to the device.
- A large number of low pressure seals are required which failed repeatedly as a result of hysteresis heating
- The low pressures required to provide the thrust were difficult to control when the seals leaked.
- The drill steel requires significant modification to provide a closed loop water flushing system.

In light of these problems an alternative method of providing the thrust should be sought as a matter of priority.

Previous attempts at noise reduction of pneumatic machines have met with significant operator resistance because of the reduced performance of these machines. The fact that the drills are self thrusting and could drill unmanned after being set up will significantly reduce operator input which, with the maintained performance levels, should provide for a high level of operator acceptance.

The reactive damping of drill steels is an effective method of noise reduction and while not applicable to conventional drilling should however, be given serious consideration for application with drilling rigs or any other system that provides for 'in-line' thrust.

In conclusion is strongly recommended that alternative methods of thrusting the rock drill be pursued via further development work

6 References

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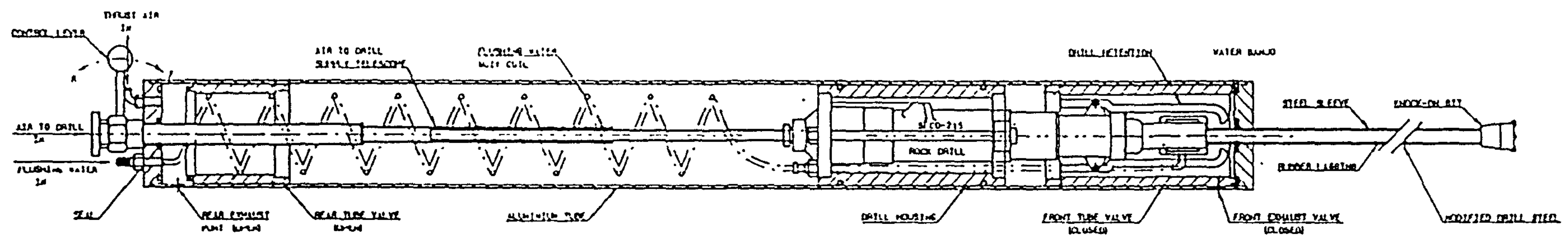
APPENDIX A - First prototype drawings

Table A-1 Drawing details in Appendix A

Drawing Number	Description
RD-002	Quiet Rockdrill air thrusted general arrangement
RD-025	Quiet Rockdrill drill piston detail
RD-015	Quiet Rockdrill rear piston plate detail
RD-016	Quiet Rockdrill front piston plate detail
RD-029	Quiet Rockdrill air telescope detail
RD-037	Quiet Rockdrill rear casing closure detail
RD-031	Quiet Rockdrill front casing closure detail
RD-030	Quiet Rockdrill tube valve detail
RD-034	Quiet Rockdrill push/tie rod detail
RD-032	Quiet Rockdrill control lever detail
RD-028	Quiet Rockdrill drill retention detail
RD-045	Quiet Rockdrill modified drill steel



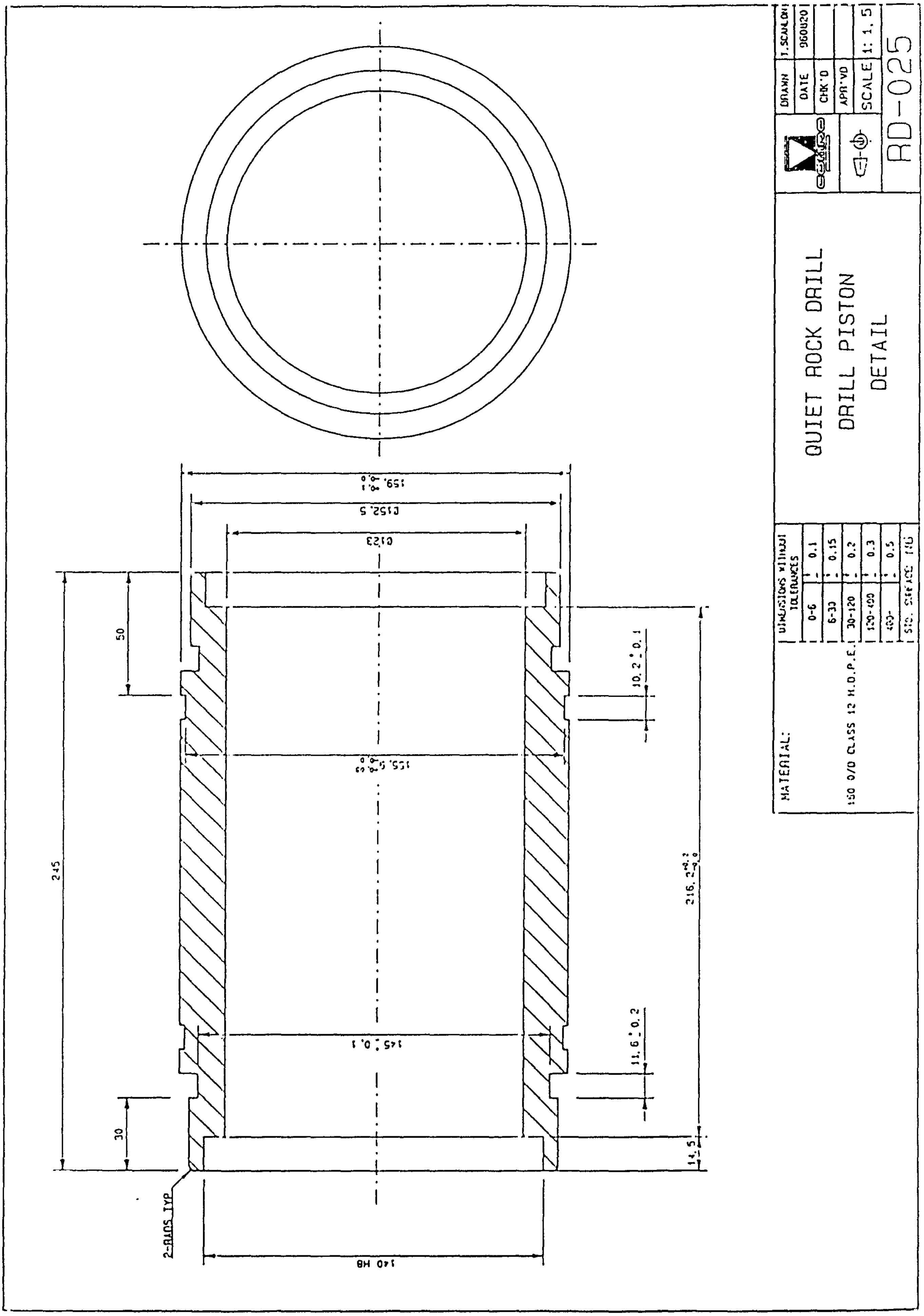
MATERIAL:

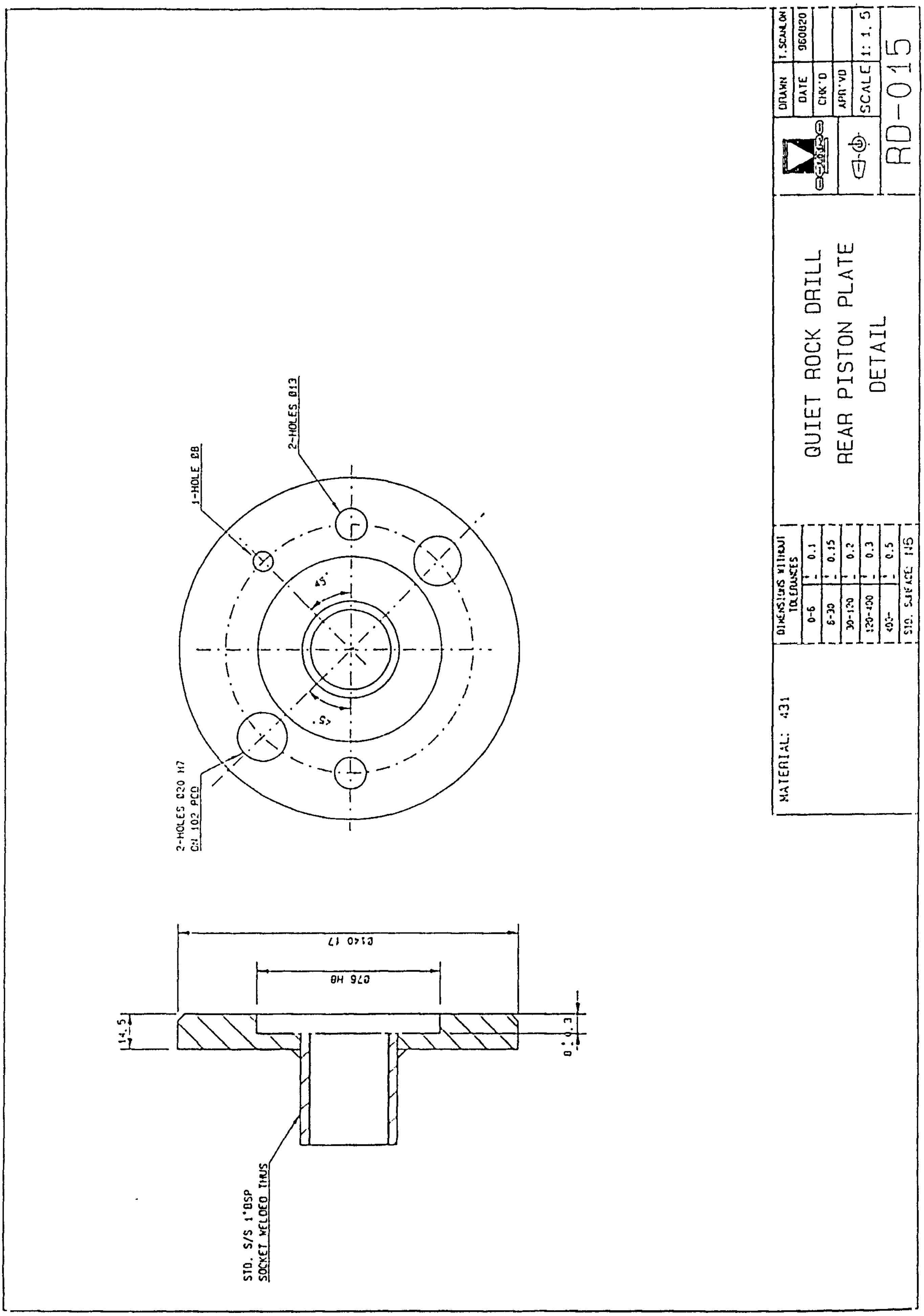
DIMENSIONS WITHOUT TOLERANCES	
0-6	± 0.1
6-30	± 0.15
30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD. SURFACE: N6	

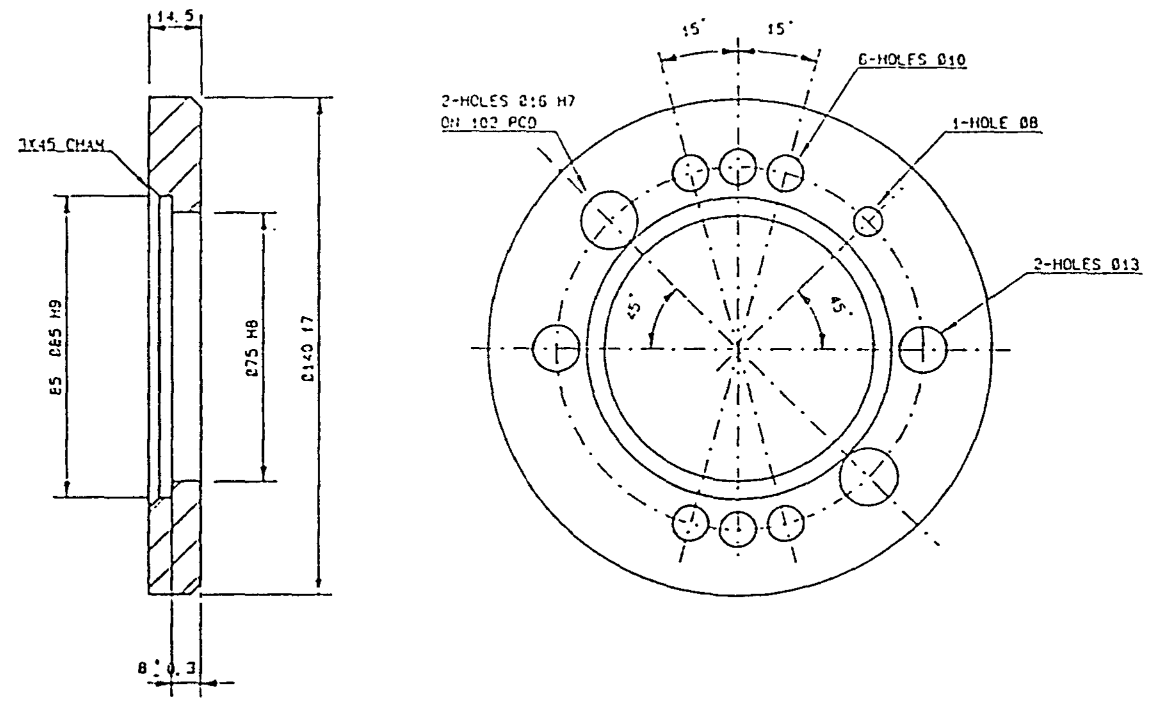
QUIET ROCK DRILL
AIR THRUSTED
GENERAL ARRANGEMENT

DRAWN	T.SCANLON
DATE	960110
CHK'D	
APR'VD	
SCALE	1: 7.5

RD-002


QUIET ROCK DRILL
DRILL PISTON
DETAIL
RD-025
DRAWN T.SCANLON
DATE 960820
CHK'D
APR'VD
SCALE 1:1.5
MATERIAL:
150 O/D CLASS 12 H.D.P.E.
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
Ø152.5
Ø123
245
50
30
14.5
10.2 ± 0.1
11.6 ± 0.2
145 ± 0.1
140 H8
2-RADS TYP


QUIET ROCK DRILL
REAR PISTON PLATE
DETAIL
RD-015
DRAWN T.SCANLON
DATE 960820
CHK'D
APR'VD
SCALE 1:1.5
MATERIAL: 431
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE
2-HOLES Ø13
1-HOLE Ø8
2-HOLES Ø20 H7
ON 102 PCD
45°
Ø140 f7
Ø76 H8
14.5
0 ± 0.3
STD. S/S 1"BSP
SOCKET WELDED THUS



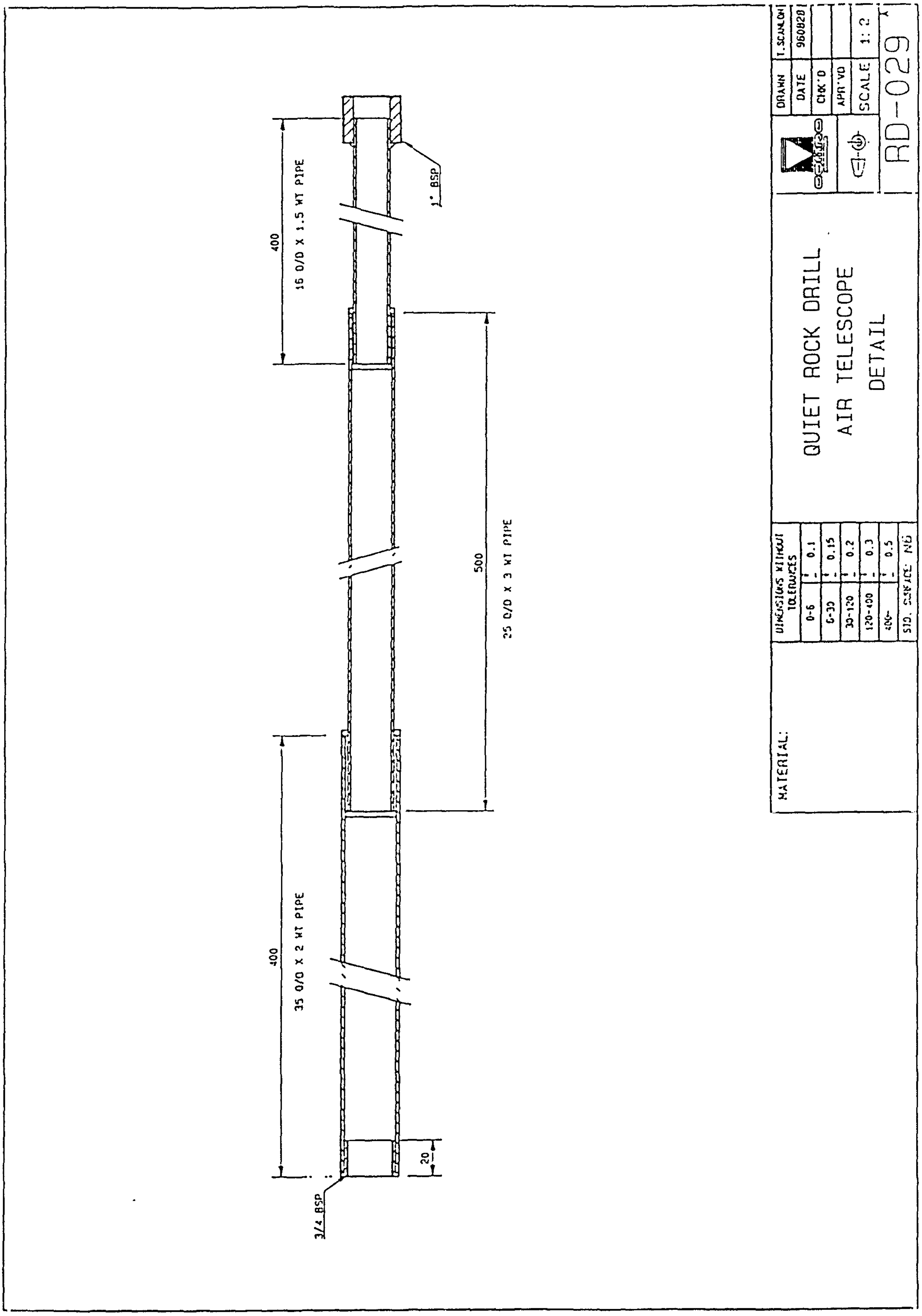
MATERIAL: 431

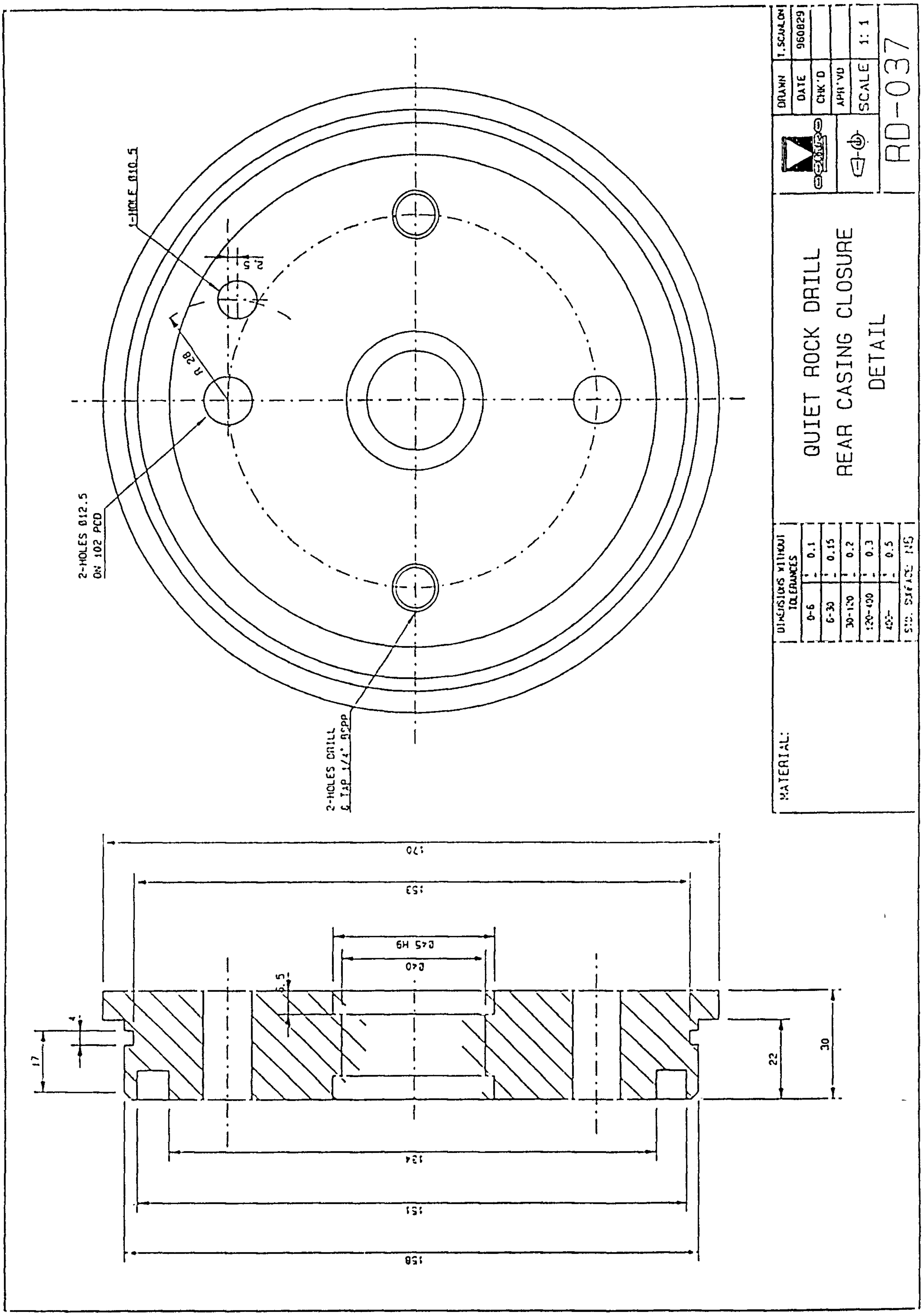
DIMENSIONS WITHOUT TOLERANCES	
0-6	± 0.1
6-30	± 0.15
30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD. SURFACE: N6	

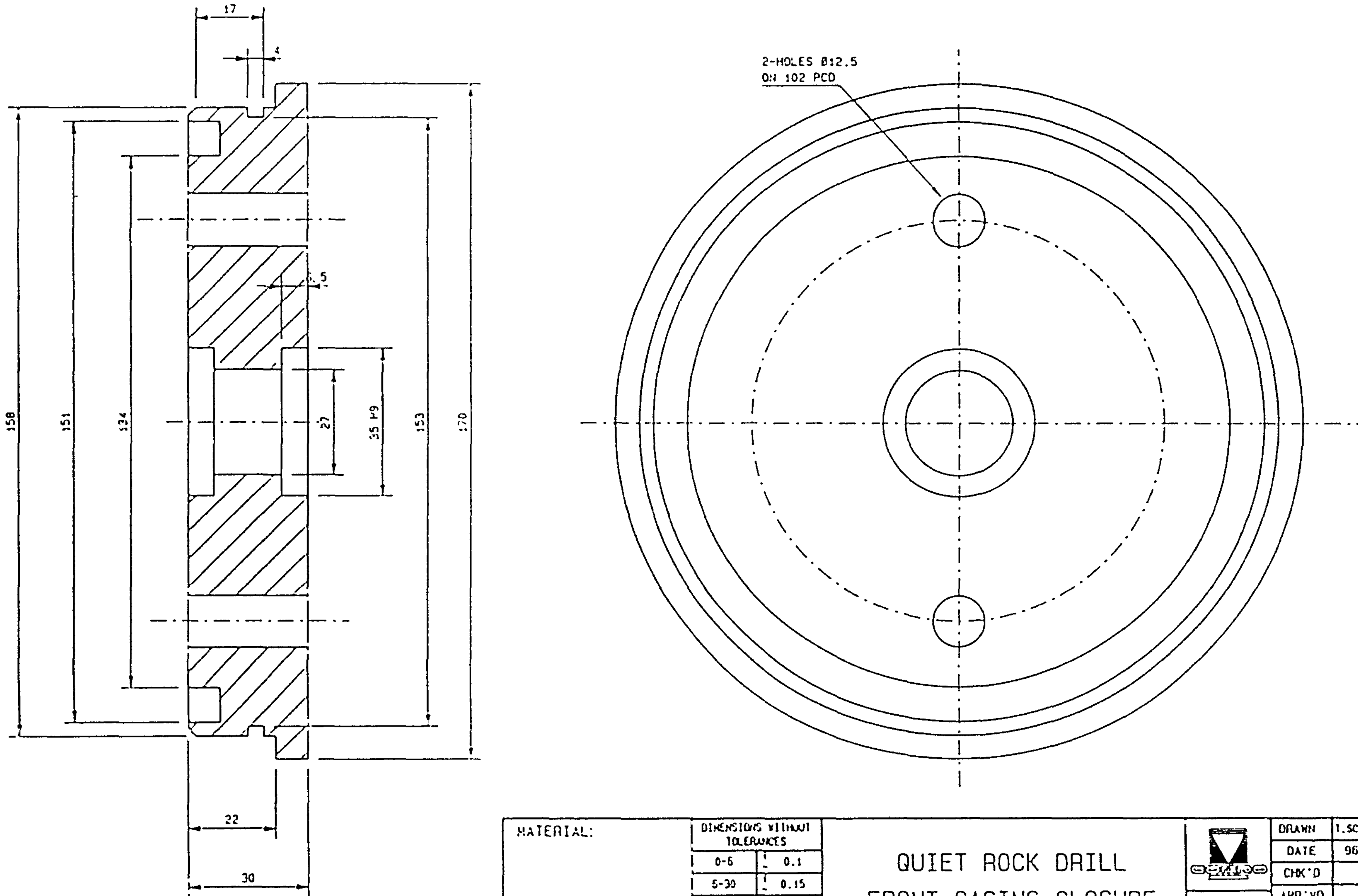
QUIET ROCK DRILL
FRONT PISTON PLATE
DETAIL

DRAWN	T.SCANLON
DATE	960820
CHK'D	
APP'VD	
SCALE	1: 1.5

RD-016


400
16 O/D X 1.5 WT PIPE
1" BSP
500
25 O/D X 3 WT PIPE
400
35 O/D X 2 WT PIPE
20
3/4 BSP
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE: N6
QUIET ROCK DRILL
AIR TELESCOPE
DETAIL
DRAWN T.SCANLON
DATE 960828
CHK'D
APP'VD
SCALE 1:2
RD-029


1-HOLE Ø10.5
2-HOLES Ø12.5
ON 102 PCD
2-HOLES DRILL
& TAP 1/4" BSPP
R 28
170
153
Ø45 H9
Ø40
5.5
4
17
22
30
134
151
158
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
QUIET ROCK DRILL
REAR CASING CLOSURE
DETAIL
DRAWN T.SCANLON
DATE 960829
CHK'D
APP'VD
SCALE 1:1
RD-037



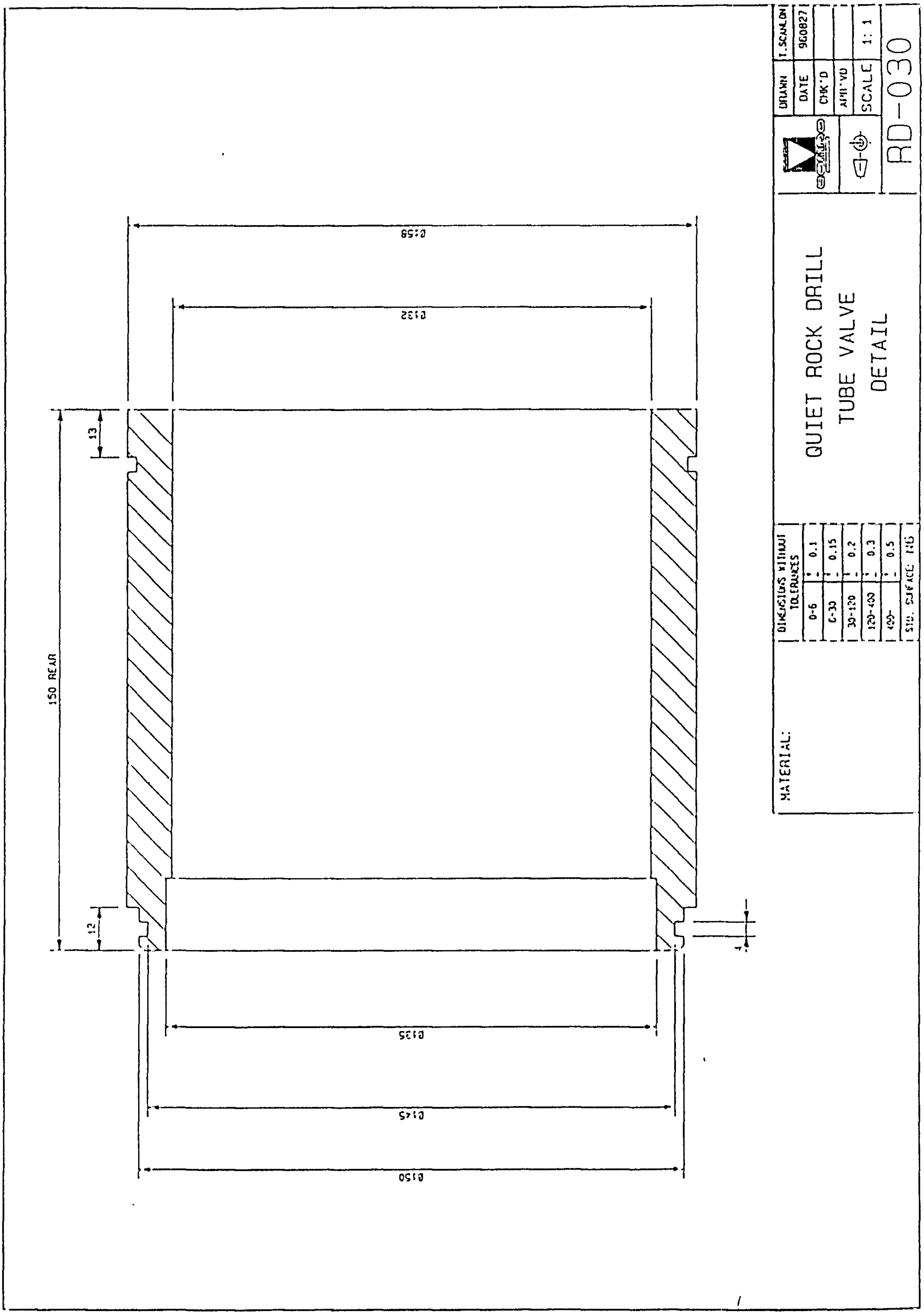
MATERIAL:

DIMENSIONS WITHOUT TOLERANCES	
0-6	± 0.1
6-30	± 0.15
30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD SURFACE: N6	

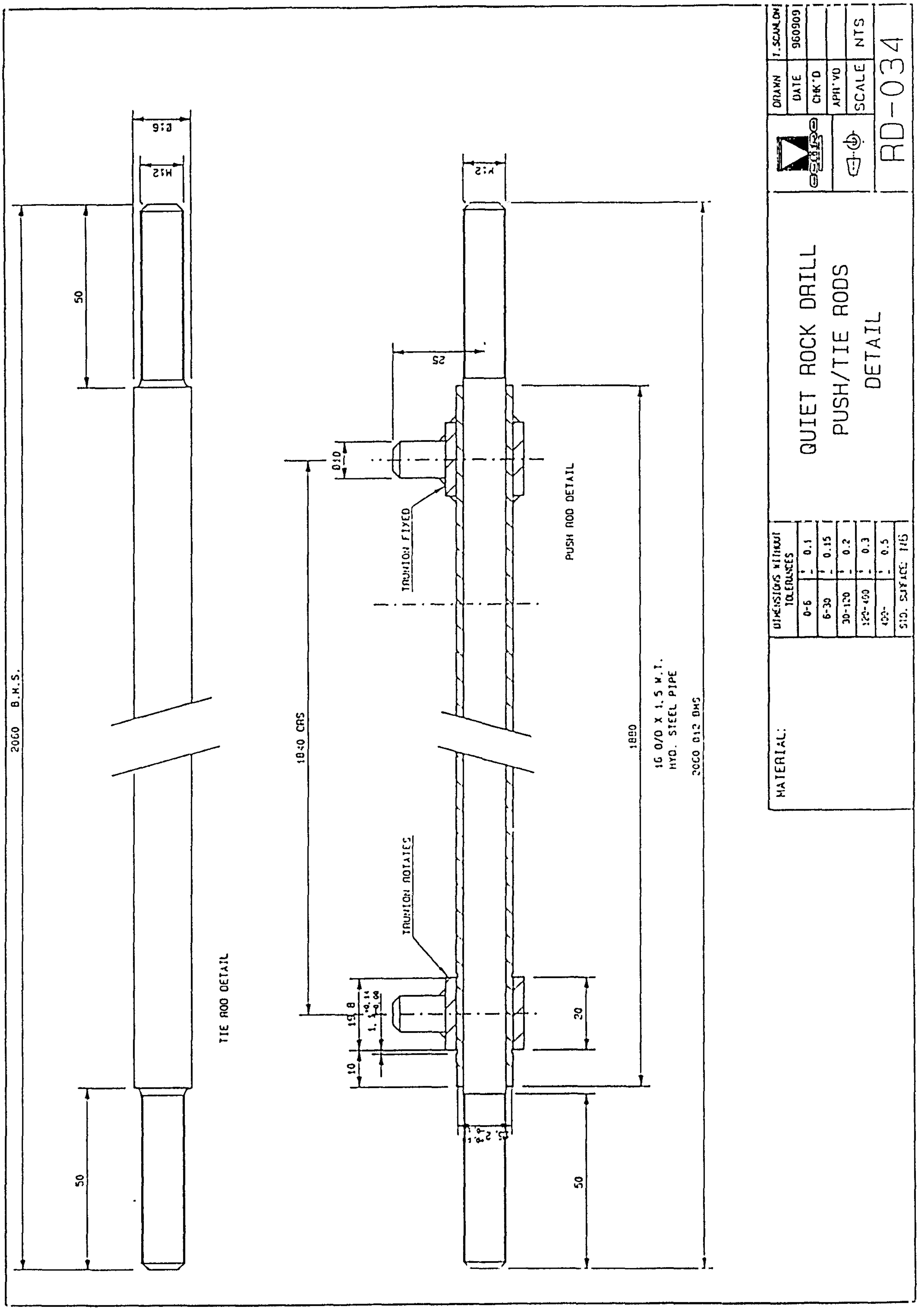
QUIET ROCK DRILL
FRONT CASING CLOSURE
DETAIL

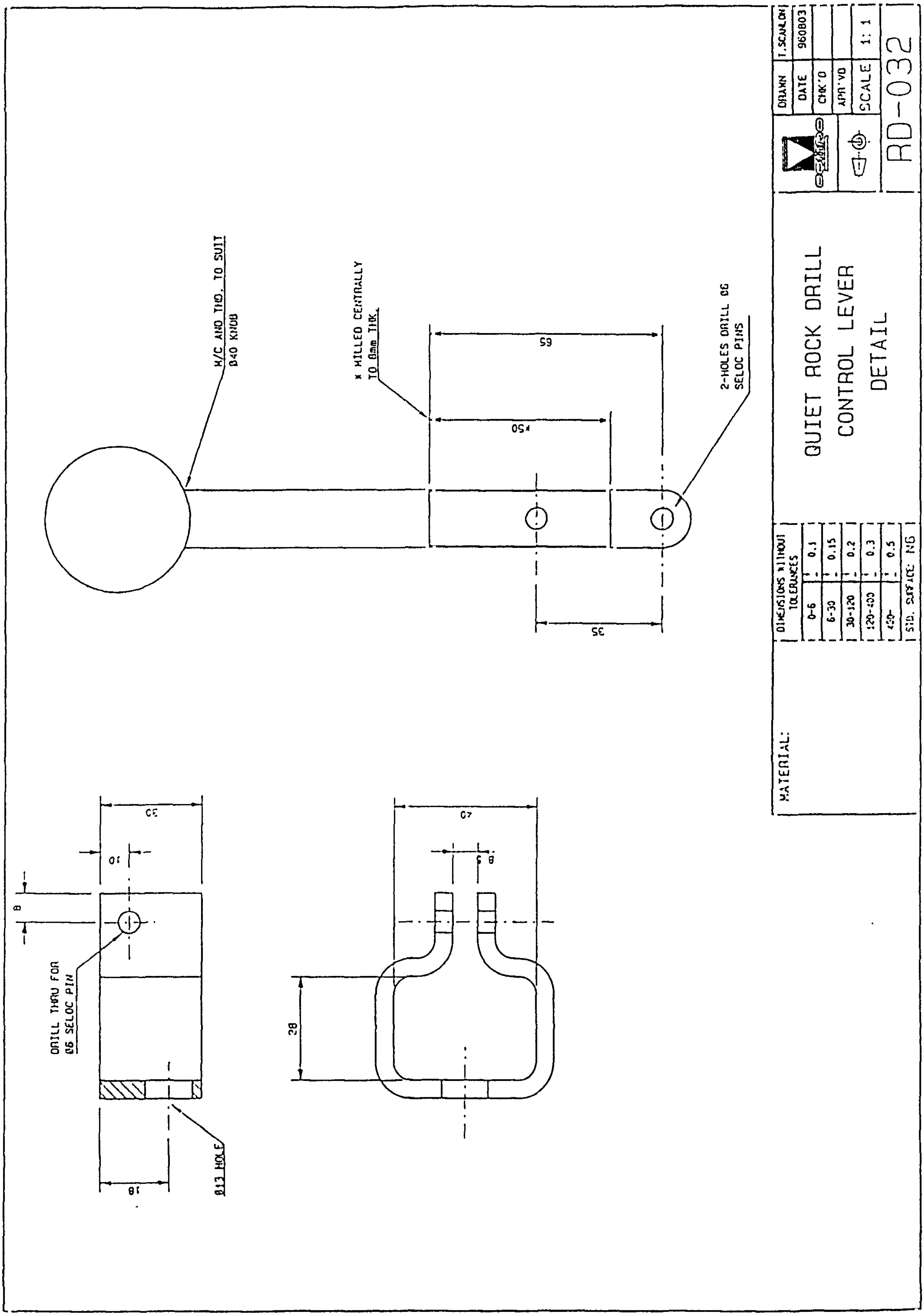
DRAWN	T.SCANLON
DATE	960829
CHK'D	
APR'VD	
SCALE	1: 1

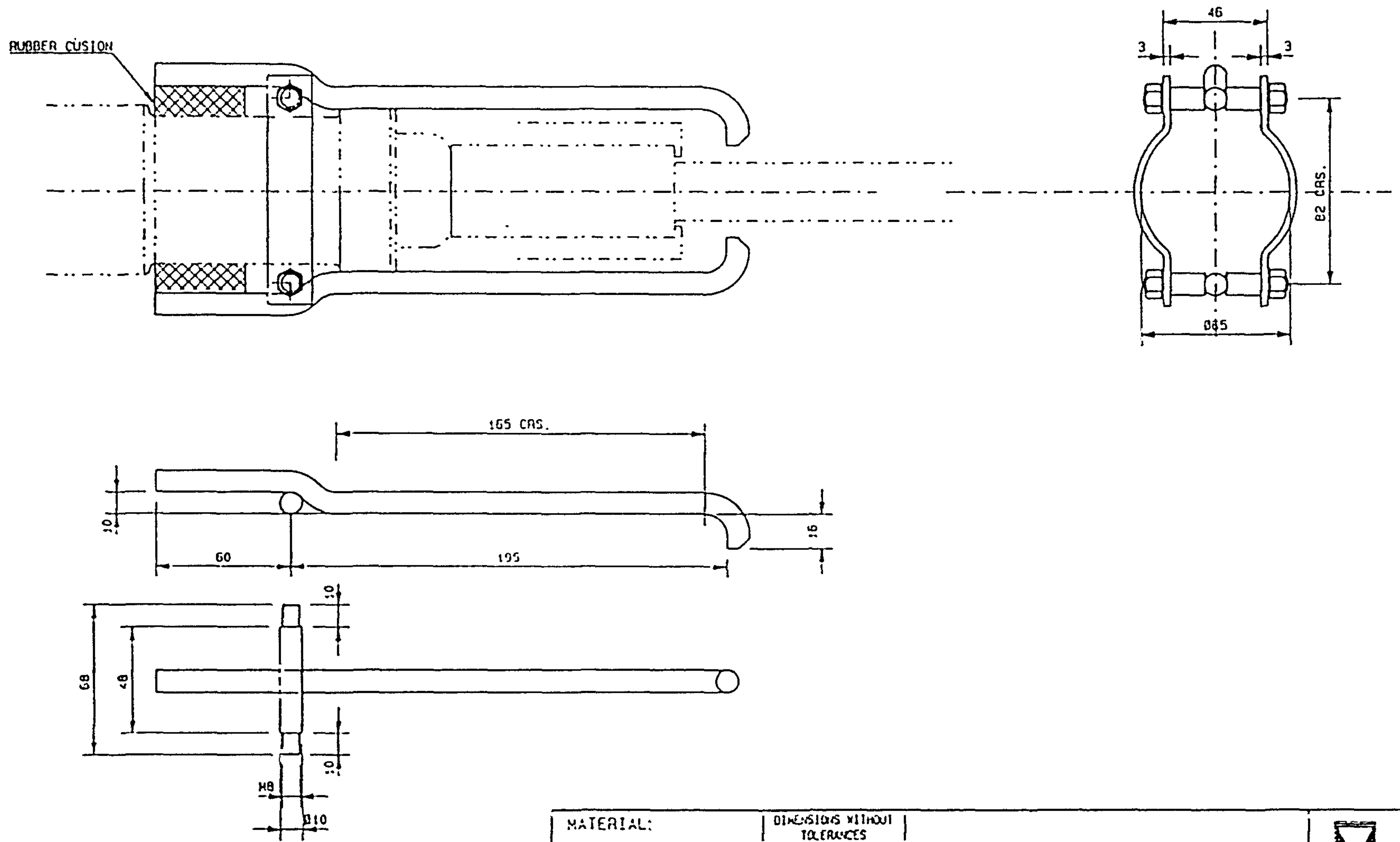
RD-031



Ø158
Ø132
13
150 REAR
12
4
Ø135
Ø145
Ø150
MATERIAL:
QUIET ROCK DRILL
TUBE VALVE
DETAIL
DRAWN
T.SCANLON
DATE
960827
CHK'D
SCALE
1:1
RD-030


QUIET ROCK DRILL
PUSH/TIE RODS
DETAIL
RD-034
DRAWN T.SCANLON
DATE 960909
CHK'D
APP'VD
SCALE NTS
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
TIE ROD DETAIL
PUSH ROD DETAIL
TRUNION FIXED
TRUNION ROTATES
16 O/D X 1.5 W.T.
HYD. STEEL PIPE
2060 B.H.S.
1840 CRS
1880
M12
50
25
20
10


M/C AND THD. TO SUIT Ø40 KNOB
x MILLED CENTRALLY TO 8mm THK
2-HOLES DRILL Ø6 SELOC PINS
DRILL THRU FOR Ø6 SELOC PIN
Ø13 HOLE
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
STD. SURFACE N6
QUIET ROCK DRILL CONTROL LEVER DETAIL
DRAWN T.SCANLON
DATE 960803
CHK'D
APR'VD
SCALE 1:1
RD-032



MATERIAL:

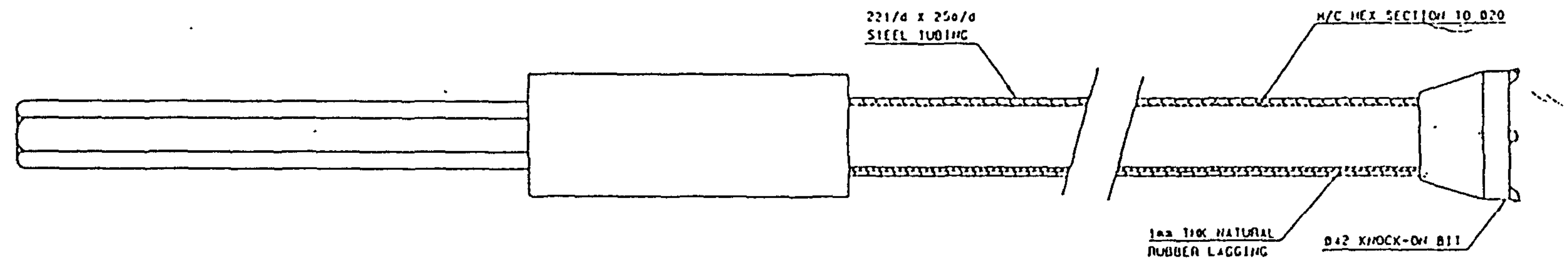
Ø10 MILD STEEL

DIMENSIONS WITHOUT TOLERANCES	
0-6	± 0.1
6-30	± 0.15
30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD. SURFACE: N6	

QUIET ROCK DRILL
DRILL RETENSION
DETAILS

DRAWN	T.SCANLON
DATE	960814
CHK'D	
APR'VD	
SCALE	1: 2

RD-028



MATERIAL:

DIMENSIONS WITHOUT TOLERANCES	
0-6	0.1
6-30	0.15
30-120	0.2
120-400	0.3
400-	0.5
STD. SURFACE NG	

QUIET ROCK DRILL
AIR THRUSTED
MODIFIED DRILL STEEL

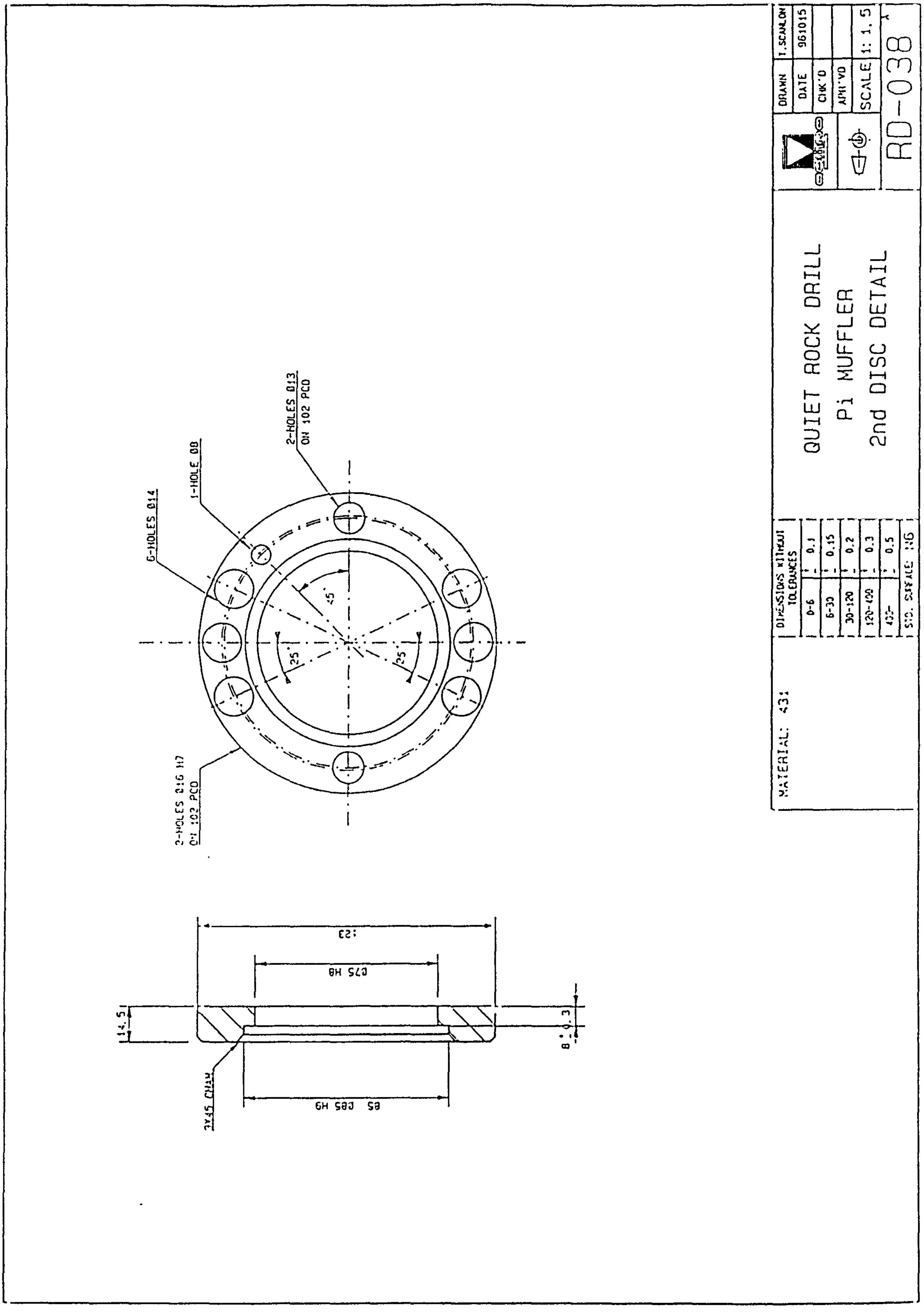
DRAWN	I.SCANLON
DATE	971204
CHK'D	
APP'VD	-
SCALE	1: 1.5

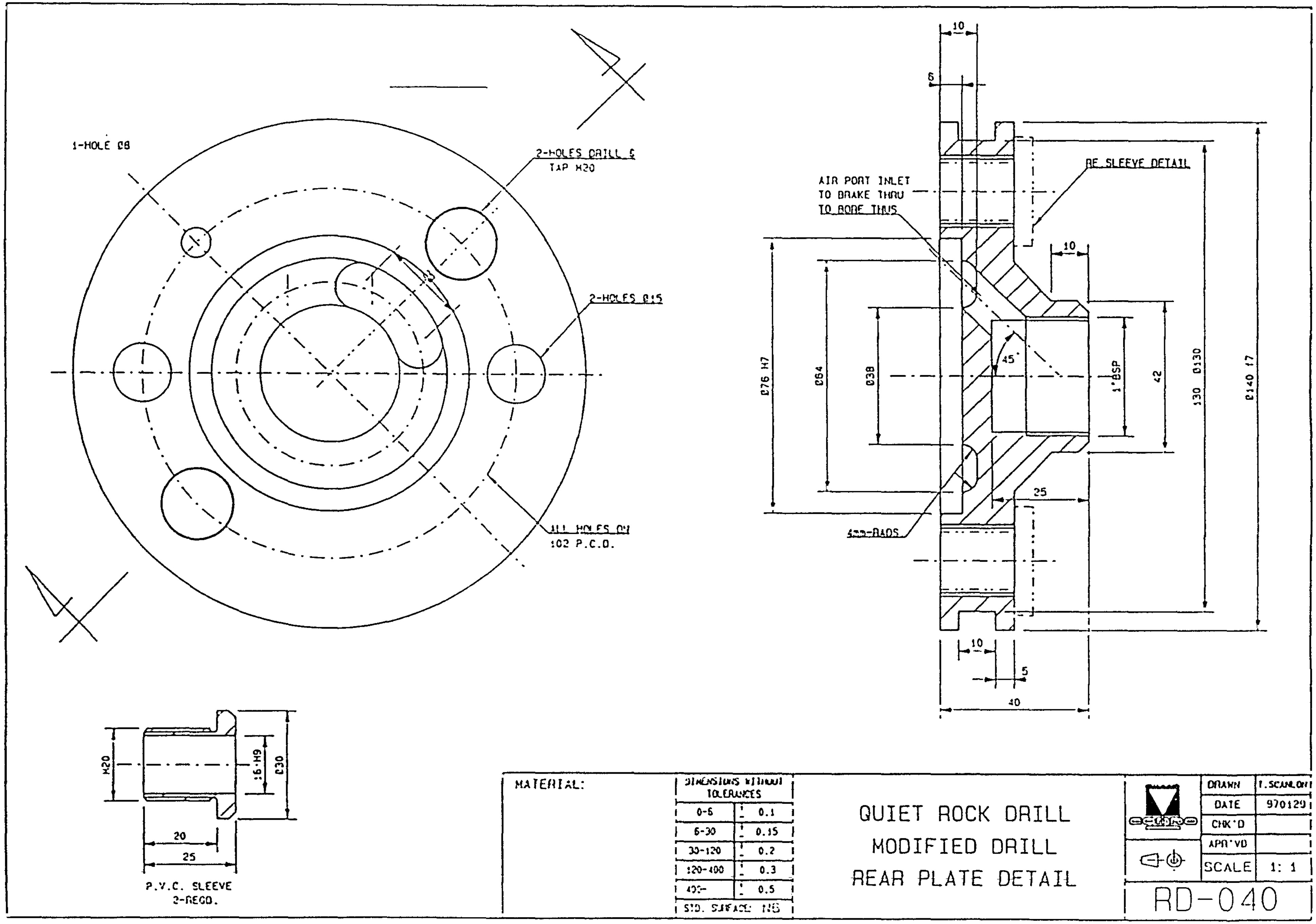
RD-045

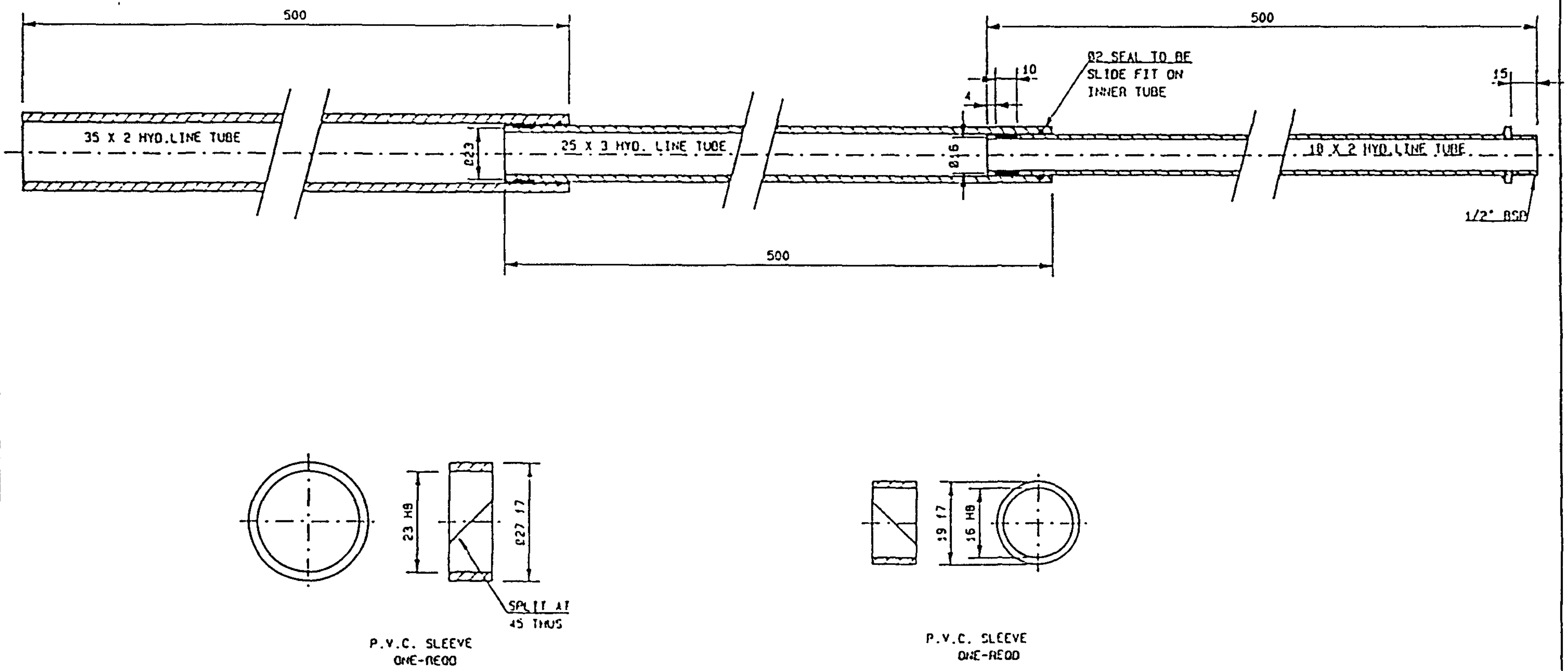
APPENDIX B - Modification drawings

Table B-1 Drawing details in Appendix B

Drawing Number	Description
RD-038	Quiet Rockdrill 2nd disc detail
RD-040	Quiet Rockdrill modified drill rear plate detail
RD-041	Quiet Rockdrill telescope No 2 detail


QUIET ROCK DRILL
Pi MUFFLER
2nd DISC DETAIL
RD-038
DRAWN T.SCANLON
DATE 961015
CHK'D
APP'VD
SCALE 1:1.5
MATERIAL: 431
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
6-HOLES Ø14
1-HOLE Ø8
2-HOLES Ø13 ON 102 PCD
2-HOLES Ø16 H7 ON 102 PCD
45°
25°
25°
123
Ø75 H8
14.5
8 ± 0.3
2X45 CHAM
85 Ø85 H9


1-HOLE Ø8
2-HOLES DRILL & TAP M20
2-HOLES Ø15
ALL HOLES ON 102 P.C.D.
AIR PORT INLET TO BRAKE THRU TO BORE THUS
RE SLEEVE DETAIL
4mm-RADS
45°
Ø76 H7
Ø64
Ø38
1"BSP
42
130 Ø130
Ø140 f7
10
6
25
5
40
M20
16 H9
Ø30
20
25
P.V.C. SLEEVE
2-REQD.
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE: N6
QUIET ROCK DRILL
MODIFIED DRILL
REAR PLATE DETAIL
DRAWN T.SCANLON
DATE 970129
CHK'D
APR'VD
SCALE 1: 1
RD-040



MATERIAL:

MILD STEEL

DIMENSIONS WITHOUT TOLERANCES	
0-6	± 0.1
6-30	± 0.15
30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD. SURFACE: N6	

QUIET ROCK DRILL
TELESCOPE No.2
DETAILS

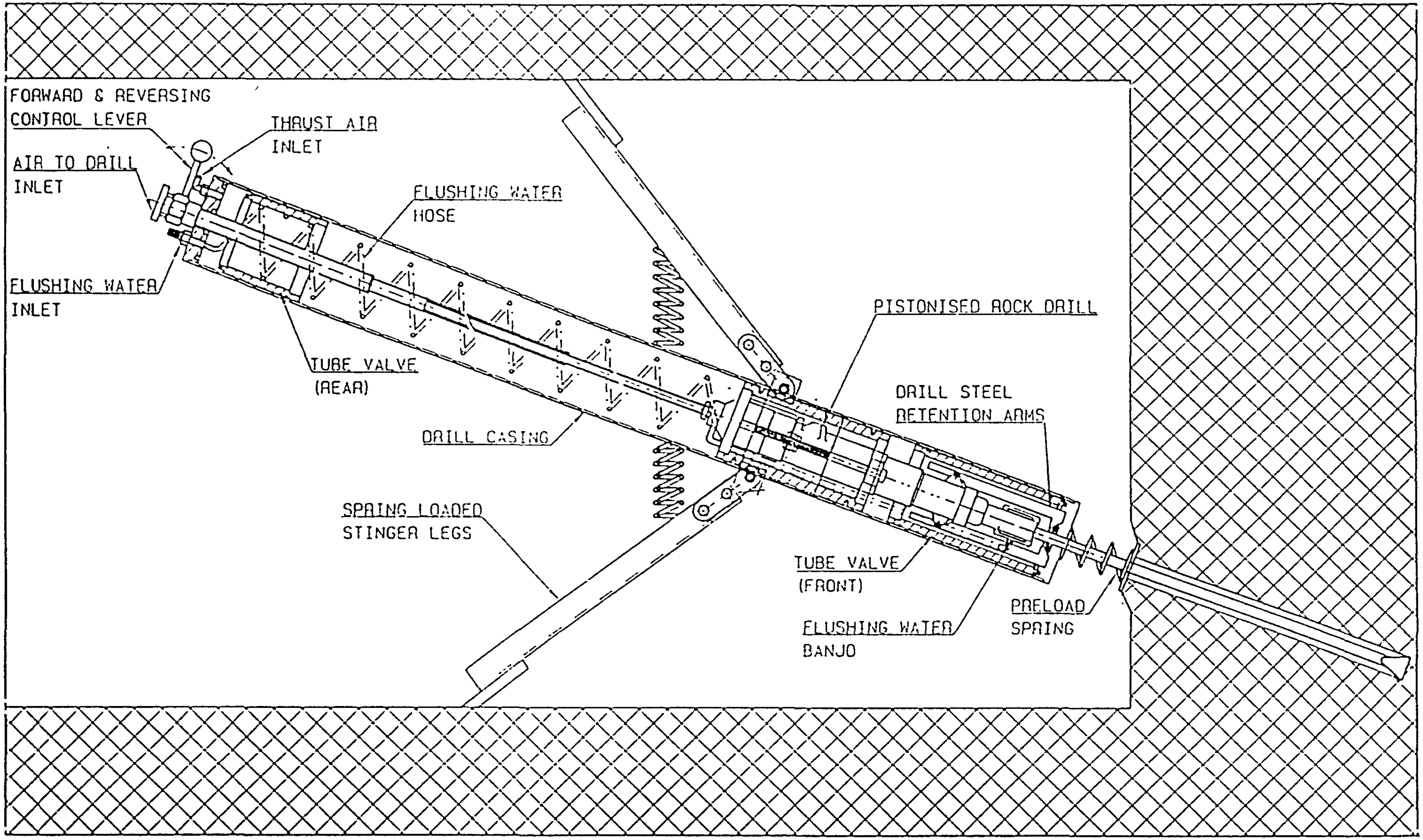
DRAWN	T.SCANLON
DATE	960129
CHK'D	
APP'VD	
SCALE	1: 2

RD-041

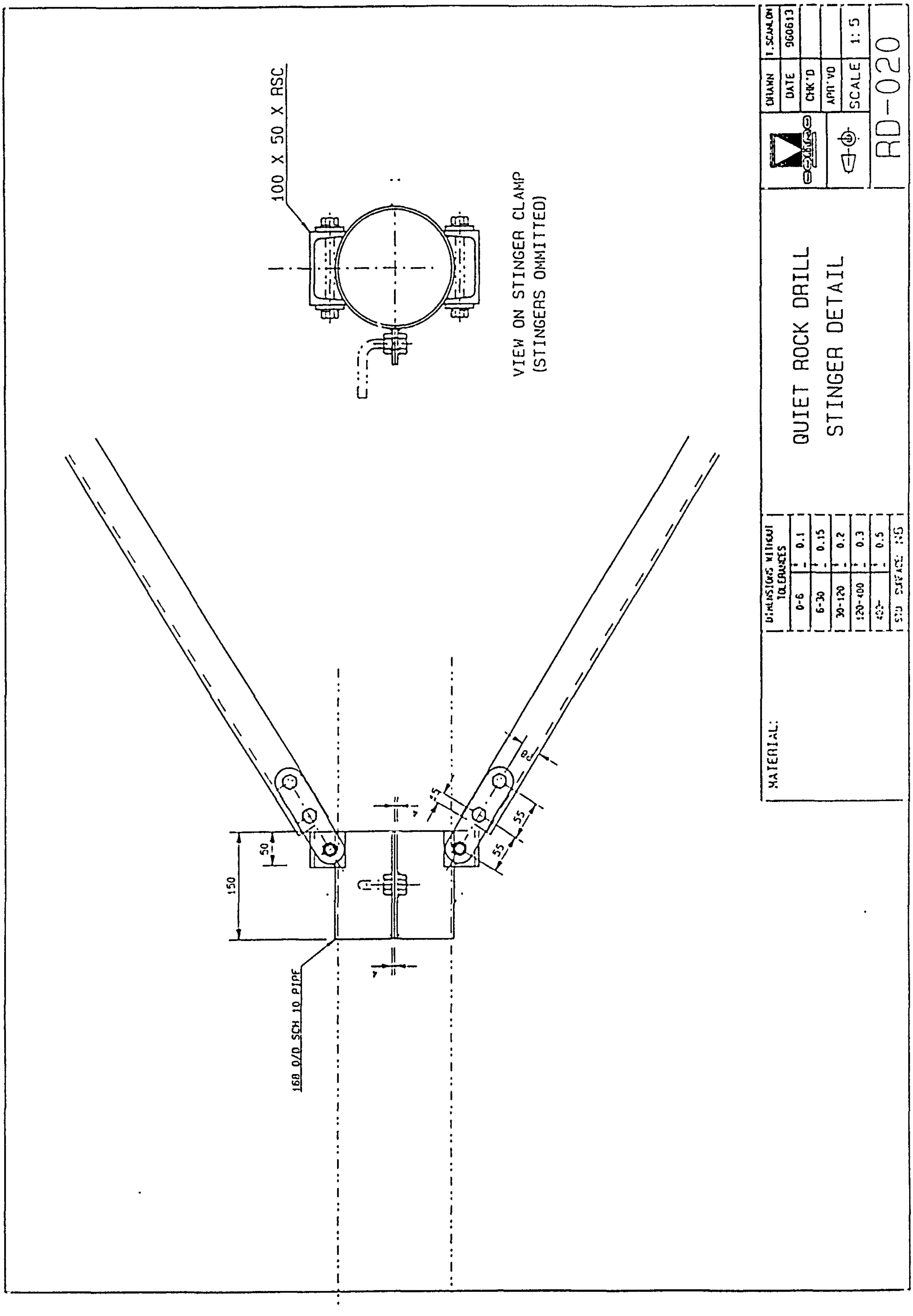
APPENDIX C - Stinging drawings

Table C-1 Drawing details in Appendix C

Drawing Number	Description
	Concept drawing of first prototype
RD-020	Quiet Rockdrill stinger detail



GENERAL ARRANGEMENT OF DRILL


100 X 50 X RSC
VIEW ON STINGER CLAMP
(STINGERS OMMITTED)
QUIET ROCK DRILL
STINGER DETAIL
DRAWN T.SCANLON
DATE 960613
CHK'D
APR'VD
SCALE 1:5
RD-020
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
MATERIAL:
150
50
55
55
15
8
168 O/D SCH 10 PIPE

APPENDIX D - Drawings of alternate concept

Table D-1 Drawing details in Appendix D

Drawing Number	Description
RD-101	Quiet Rockdrill sheave rope model general arrangement
RD-102	Quiet Rockdrill rod-less cylinder guide clamp detail

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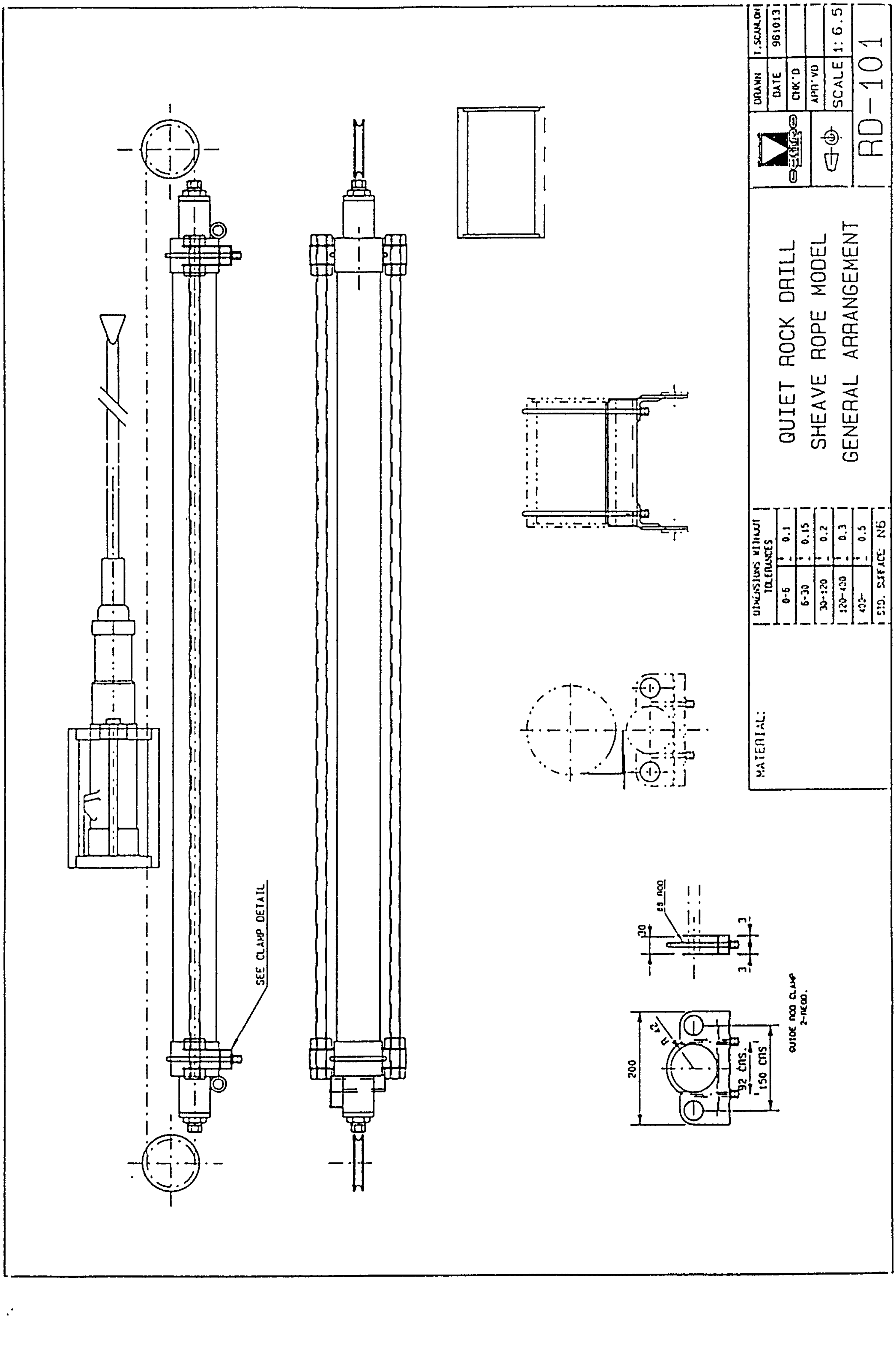
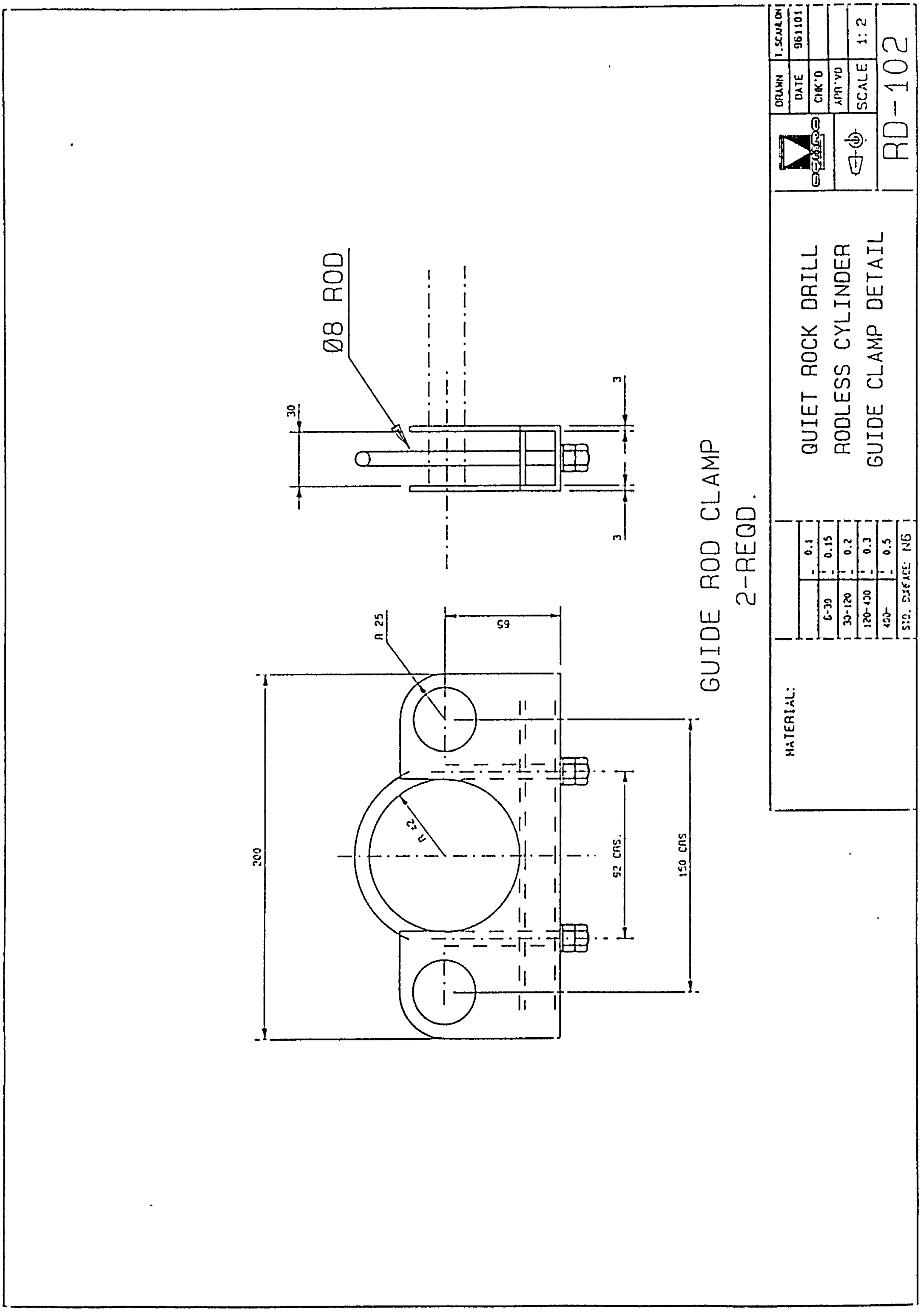

QUIET ROCK DRILL
SHEAVE ROPE MODEL
GENERAL ARRANGEMENT
RD-101
DRAWN T. SCANLON
DATE 961013
CHK'D
APP'VD
SCALE 1: 6.5
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE N6
SEE CLAMP DETAIL
GUIDE ROD CLAMP 2-REQD.
200
92 cms.
150 cms
30
3


Ø8 ROD
30
3
3
R 25
65
200
92 CRS.
150 CRS
GUIDE ROD CLAMP
2-REQD.
MATERIAL:
QUIET ROCK DRILL
RODLESS CYLINDER
GUIDE CLAMP DETAIL
DRAWN T.SCANLON
DATE 961101
CHK'D
APR'VD
SCALE 1:2
RD-102