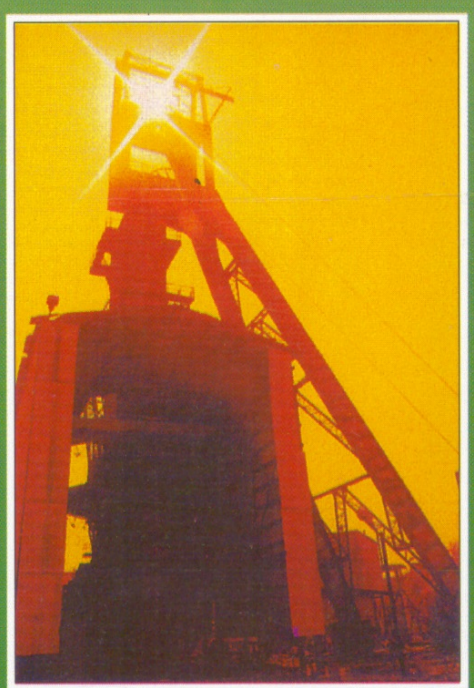
Highlights of Research
COAL S&T PROGRAMME



Government of India
Department of Coal
Ministry of Coal & Mines
New Delhi-110001

Central Mine Planning & Design Institute Limited
Ranchi

कोयला क्षेत्र
में
अनुसंधान एवं विकास

विज्ञान एवं प्रौद्योगिकी कार्यक्रम
के
तीस वर्ष

Research and Development
in
Coal Sector

30 years
of
S&T Programme

सचिव
SECRETARY

Government of India
Ministry of Coal & Mines
Department of Coal
Shastri Bhawan
New Delhi 110 001

MESSAGE

Creation of a sound technological base depends to a large extent on research and development activities. Recognising the need for coordinated and sustained R&D work in the coal sector, soon after nationalization of the coal industry the Government initiated Coal S&T Grant in 1975 to facilitate development of technology suitable for Indian conditions.

Since then a total of 226 research projects have been completed with funding from the S&T Grant. These projects have been carried out by various academic and research institutes related to the coal and allied industries with active participation of coal and lignite mining companies. Many of these projects have yielded considerable benefits, resulting in operational improvement, safer working conditions, better resource recovery and protection of the environment.

World over coal has been recognised as the most important fuel resource, which can be relied upon to meet the global energy demand for many decades. The adverse effects of using this fossil fuel on the environment are also being increasingly realized. India, a country rich in coal reserves, has to take the lead in employing clean-coal technologies, carbon sequestration and such other issues, which involve use of coal on a sustainable basis in the long term. Today's research efforts should not only focus on the immediate requirements of safer and more productive mining techniques or improving the methods of beneficiating coal, but also address long-term goals, like zero-emission combustion of coal, for the benefit of future generations.

I am glad that CMPDI is bringing out a publication highlighting the advances made in the coal sector through R&D work supported by the Ministry. The publication will not only disseminate information of interest to the industry but will also provide an impetus for intensifying future research efforts.

(P. C. Parakh)

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FOREWORD

Organized research for all round development of the coal industry started only after nationalization of the industry in the early 1970s. The Government of India established the Coal S&T Grant in 1975, which enabled research and development activities over a wide spectrum of subjects ranging from coal exploration to postmining environmental issues.

Research projects carried out so far under the S&T Grant include studies related to geophysical techniques, trials of mining methods, development of steel roof supports for replacement of scarce timber, introduction of rope stitching and roof bolting, controlled blasting techniques, studies related to mine ventilation, slope stability and a host of other operational aspects of mining. Design norms and guidelines suitable for Indian geomining conditions have also been established for roof support layout, coal pillar design, cavability of roof strata, stability of partings and for various other mine planning requirements. A number of guidelines developed through these projects have found wide application, including stipulations by DGMS enforcing their use for statutory purposes.

To ensure safety of underground workings significant advances through R&D work have been made for introduction of modern techniques like ground penetrating radar for detection of old unapproachable waterlogged workings. Trials of blind backfilling of underground voids have also been made with promising results. Advanced methods like remote sensing for mapping of underground fires have been established as a viable technique. A fully instrumented model gallery has also been established for study of mine fires and trial of fire control measures.

Meaningful studies have been carried out for improvement in coal beneficiation techniques, especially for high-ash Indian coals. Significant results have also been obtained from research related to combustion techniques for effective utilization of high-ash coals. Notable trials have also been made for re-vegetation of mined-out areas, use of fly-ash and production of humic acid from lignite for use as fertilizer.

This publication from CMPDI, which is the nodal agency for coordinating research activities under Coal S&T Grant, illustrates the achievements so far made through R&D efforts by various academic and research institutes in collaboration with coal and lignite producing companies. I am sure the publication will be of interest to the professionals engaged in coal and allied industries, and enable widespread use of the findings for the benefit of the industry.

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PREFACE

There was very little R&D activity in the Indian coal industry before independence of the country. The progress in mining methods during the early years of the industry had mostly been through limited transfer of technology carried out by British companies having coal mining interests in India. Among the first to take up research related to mining was the Mining, Geological and Metallurgical Institute of India [MGMI], which carried out some studies in mine safety, fires and explosions. The investigations conducted by the First and Second Subsidence Committees [1913 and1927] were regarded as major efforts of the time.

Following the recommendations of the Coal Mining Committee [1937] and Indian Coalfields Committee [1946], Central Fuel Research Institute [CFRI] was established near Dhanbad in 1946. This institute started research in beneficiation and combustion of coal, recovery of byproducts and coke technology.

After independence of the country, research in several key sectors received due attention with the formation of the Council for Scientific and Industrial Research [CSIR]. A number of laboratories under CSIR were set up across the country to meet the R&D requirements of various industries. For the mining industry, Central Mining Research Station [now CMRI] was set up at Dhanbad in 1955, where testing facilities for mining equipment and accessories were added and the institute was recognized as a certification body for the industry. National Coal Development Corporation [NCDC], which was founded by the Government in 1956, carried out trials of new mining methods and also laid emphasis on centralized mine planning and exploration. Several large mining companies in the private sector also undertook innovative trials in the 1950s and 60s involving stowing, roof supports and mining machinery.

It was, however, only after nationalization of the industry in early 1970s that organized research began under a Government funded scheme, created specifically for meeting the R&D requirement of the coal industry. The Coal Science and Technology [S&T] Grant was initiated in 1975 to provide much needed R&D support to an industry, which was required to make a quantum jump in production to meet the rising energy demands of the country. The industry was expected to modernize mining methods so as to improve productivity and safety levels, ensure conservation and optimum utilization of the coal resources of the country with minimum possible damage to the environment.

In the past 30 years since inception of the S&T scheme, a total of 226 projects have been completed. While some projects, admittedly, did not produce the desired results, there have been many which contributed significantly towards all round growth of the industry. Notable advances have been made through these R&D efforts in application of coal exploration techniques. Trials of mining methods for recovery of coal in thick seams have led to promising results. Improvement in safety level and conservation of scarce timber have been possible by large-scale application of steel supports, like roof bolts, for supporting roof strata in underground workings. Heavy blasting for removal of overburden

rocks and coal in opencast mines is now possible close to surface structures and populated localities without causing any damages. Significant improvement has been possible in both coking and non-coking coal washing and recovery of fine coals. Effective methods have been evolved for re-vegetation of mined-out wastelands.

While some research projects have produced tangible impact on the industry directly, there are others which have strengthened mine planning, design and technical services required by both operating mines and future mining projects. Design tools developed specifically for Indian geomining conditions are now available for a variety of problems, like underground coal pillar design, analysis of roof cavability and stability of partings between multiple seam workings, prediction of surface subsidence, optimum blast design for various rock conditions, opencast slope stability, etc. The findings from some projects, like the study on engineering classification of roof rocks, have led to stipulation by the Directorate-General of Mine Safety that the design procedure developed should be employed for all underground mines while seeking statutory permission to work.

In the following sections of this publication an attempt has been made by CMPDI, which is the nodal agency for coordinating research under the Coal S&T Grant, to compile the work so far done in different areas related to mining and allied subjects. One of the objectives of the compilation is to outline the findings from various projects so as to enable their widespread utilization for the benefit of the industry. For further details regarding any of the projects CMPDI may be contacted.

The publication is intended to serve another objective. In the light of experience gained and the ground so far covered, R&D work needs to be intensified in certain areas. Production from underground mines has been stagnating for many years. Modification of conventional extraction methods, improvement in roof support practices, development of machinery, accessories and systems to improve productivity require extensive field trials and application oriented studies. Control of hard roof strata, warning systems to safeguard against danger from water, collapse of ground over old workings in populated areas, control of old mine fires, etc, are some other areas requiring intensive R&D work. Recovery and utilization of coal bed methane (CBM), which is the subject of an on-going project, requires concerted efforts for gainful utilization of this hitherto unexploited energy resource of the country.

Although opencast operations are considerably more productive, condition monitoring of HEMM, improvement in the quality and life of spares, systems for optimizing machine performance, mine and dump slope stability, effective environmental control measures, etc, are some of the areas where further advances can be made through R&D. Further advances are also required for improving coal beneficiation techniques for high-ash Indian coals. Long term environmental issues of concern, like clean coal combustion for control of green-house gases and carbon sequestration, need special attention, not only globally, but in our country also.

It is hoped that this publication will enable identification of useful concepts and ideas in the light of achievements so far made and strengthen research effort for the benefit of coal and related industries.

M. N. Jha
Chairman-Managing Director

विषय–सूची
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INTRODUCTION

Following the nationalization of coal mines in two phases in 1971 and 1973 the Ministry of Coal and Mines [MoCM] set up the Coal S&T Grant in 1975 to intensify research for indigenous development of technology suitable for the Indian coal industry. The grant is administered by the Standing Scientific Research Committee [SSRC] of the MoCM, which is assisted by three subcommittees dealing with the three broad areas of research:

(a) Production, productivity and safety;

(b) Coal beneficiation and utilization; and

(c) Environment and ecology.

Central Mine Planning and Design Institute [CMPDI] is the nodal agency for coordination and monitoring of Coal S&T projects funded by the MoCM.

Since inception of the grant in 1975 a total of 326 projects have been approved by the SSRC, out of which 226 projects have been completed at a cost of Rs 87 crore. Due to various reasons 51 projects were terminated. As of April 2004 there are 49 ongoing projects with a total outlay of Rs 127.5 crore, out of which the number of projects costing in excess of Rs 1 crore is 10, the largest having an S&T grant of Rs 17.6 crore. The duration of earlier projects varied around 5-6 years, but recent and current projects are mostly of shorter period of 2-3 years. An overview of the broad quantum of R&D work being done over the years is given in table 1 below.

The projects are implemented mostly by research and academic institutes either independently or in collaboration with coal and lignite mining companies. Among the institutes which have carried out considerable work so far are CSIR laboratories like Central Mining Research Institute, Dhanbad, Central Fuel Research Institute, Dhanbad, and Regional Research Laboratories at Bhopal, Bhubaneswar and Jorhat. Other government laboratories include National Institute of Rock Mechanics, Kolar, and National Geophysical Research Institute, Hyderabad. Some projects have been and are being executed by academic institutes like Indian School of Mines, Dhanbad, Anna University, Chennai, Indian Institute of Science, Bangalore, and Indian Institutes of Technology at Kharagpur, Delhi and Madras.

There has been active participation of public sector coal and lignite companies of the MoCM in research work carried out so far, either by associating directly as a co-implementing agency or by providing logistic and manpower support to the various scientific and academic institutes. Many of the projects were and are being partially funded by the companies as well. These companies are the subsidiaries of Coal India Limited [CIL], Singareni Collieries Company Limited [SCCL] and Neyveli Lignite Corporation [NLC]. A number of projects have been implemented by CMPDI, which carries out planning, design and exploration work for CIL and MoCM, besides being the nodal agency for the Coal S&T Grant as mentioned earlier.

Table 1 : R&D Activities in Coal Sector

Plan	*Year*	*Disbursement Rs. in Crores*	*Projects carried over from previous year*	*Projects Sanctioned*	*Projects Completed*	*Projects Terminated*	*Projects under implementation*
IX	1997-98	4.56	42	8	11	1	50
	1998-99	5.49	38	4	5	-	42
	1999-00	4.34	37	19	15	2	56
	2000-01	4.92	39	13	11	1	52
	2001-02	6.85	40	12	6	4	52
X	2002-03	6.03	42	12	10	-	54
	2003-04	9.82	44	16	10	1	60

Coal Exploration

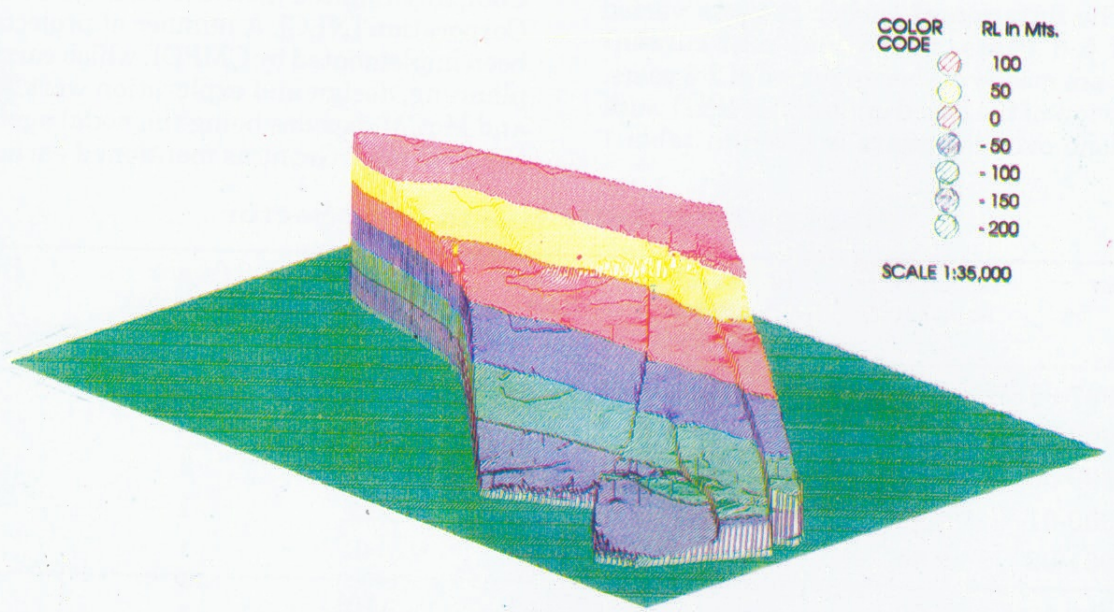
Following nationalization of the coal industry in the early 1970s major strides have been made in geological exploration work, leading to the current total inventory of nearly 246 billion tonne of coal reserves. About 2,45,000m of exploratory drilling is being done annually. Large capacity mechanized mines have also been started, both opencast and underground, which call for accurate exploration data so as not to jeopardize high capital investment because geological anomalies, like faults, dykes and presence of stone bands, can adversely affect mining operations resulting in delays, unproductive expenditure, loss of production and unsafe conditions.

A total of 19 research projects have been completed under the Coal S&T Grant in the area of exploration techniques. Efforts have been made through sustained R&D work, mainly at CMPDI, to enhance both the pace and accuracy of coal exploration for improved geological modeling of the coal resources of the country. Many of the exploration techniques introduced through these R&D efforts are now employed on a routine basis. Research projects completed in this area are listed in table 2.

Introduction of geophysical techniques, which were hardly used for coal exploration before nationalization of the industry, has resulted in significant gains by reducing the earlier practice of 100% core drilling of boreholes for exploration. Core drilling is both time consuming and expensive; whereas non-core drilling, though much more economical, requires high degree of accuracy for identification and delineation of rock strata by geophysical techniques. Not only within the country, nearly 50% of the drilling carried out by CMPDI in Mchuchuma coalfield of Tanzania was of the non-coring type. As a result of the successful application of geophysical methods, demonstrated by the S&T projects, other coal producing companies also have adopted this highly cost saving tool for their exploration needs.

Multi-parametric Geophysical Logging

One of the S&T projects has enabled multi-parametric geophysical logging for Indian coal measure strata, which produces a suite of geophysical logs consisting of resistance, focused resistivity, natural gamma, density,



Geological Model

neutron, sonic and caliper records. Multi-parametric geophysical logging is used to provide accurate information regarding the thickness of coal seam, presence of dirt bands and lithology of rock strata in the boreholes leading to precise sub-surface information.

Interpretation of the logs is done mostly through a software called SASLINT developed for the purpose. The technique is being regularly employed now for both coring and non-coring boreholes to identify lithology of the strata encountered along with ash, moisture and volatile matter contents of the coal seams. CMPDI has so far used this technique for logging of 7,21,872m in 3848 boreholes till March 2004.

Geophysical equipment on mobile loggers

The system of geophysical logging has been integrated into the routine exploration programmes of the coal sector and presently a total of eight mobile geophysical loggers are used on a regular basis by CMPDI for logging of about 50,000 depth metres annually, providing useful inputs to mine planning.

Other projects carried out involved studies related to micro-gravity, seismic and electrical resistivity tomography, in-seam seismic technique and high-resolution shallow seismic survey.

High Resolution Shallow Seismic Survey

In the 1980s through a project funded under Coal S&T Grant CMPDI introduced high resolution shallow seismic survey [HRSS] for the coal industry in collaboration with ONGC and a UK mining consultant company. A 24 channel digital seismic unit was procured from the USA and the R&D project involved extensive field investigations involving data acquisition, processing and interpretation. The project succeeded in generating useful information for detailed mine planning and later the technique was integrated into the routine exploration programme for the coal sector. Since 1998 HRSS data processing has been shifted from earlier mainframe computer based software to a PC based system. Up to March 2004 about 160 line km of survey has been done by CMPDI in 30 coal blocks.

Digital seismic equipment for HRSS survey

24 Channel Engineering Seismograph

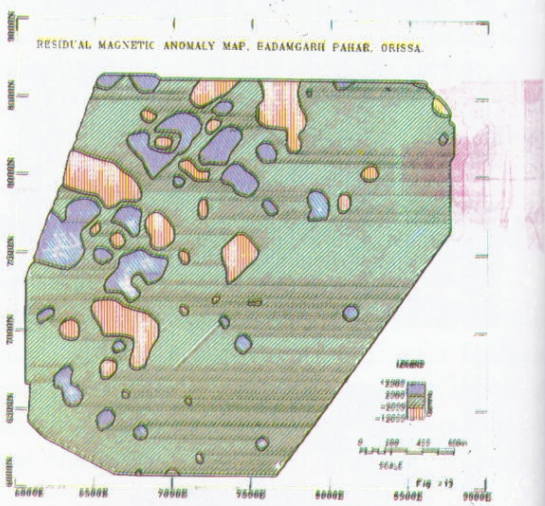
Geophysical Exploration Strategy

Investigations carried out under Coal S&T Grant have defined the exploration strategy for application of geophysical techniques for depicting sub-surface structure, strata sequence, coal seam in-crop, occurrences of intrusions, etc. A number of exploration tools are now available for specific applications.

Seismic refraction survey was originally used for delineation of coal seam in-crop, but later the technique has also been found useful for determination of rippability characteristics of near-surface rocks to help opencast mine planners. This method has been successfully used also to find the thickness of hard cover [15m mandatory requirement] for underground mine planning. A total of about 205 line km has been surveyed by this method so far by CMPDI for various mines.

Two types of electrical resistivity surveys, namely Electrical Resistivity Profiling [EPR] and Vertical Electrical Soundings [VES], are routinely used by CMPDI. The first method, EPR, has been found useful for delineation of seam in-crop, demarcation of sedimentary-metamorphic boundaries and delineation of faults. The other method, VES, is being used for basement studies and to locate ground water resources in order to obtain hydro-geological inputs. Up to March 2004 approximately 1300 line km of electrical resistivity profiling has been done besides 1142 vertical electrical soundings for various coalfields.

Gravity survey has been found useful for demarcation of major faults and sedimentary-metamorphic boundaries. Another method, magnetic survey, has been successfully utilized for accurately demarcating location of dykes in coalfields. The combination of the two techniques has also been successful in exploration of non-coal minerals, like manganese and iron ore. So far CMPDI has conducted nearly 800 line km of magnetic survey and approximately 100 line km of gravity survey.

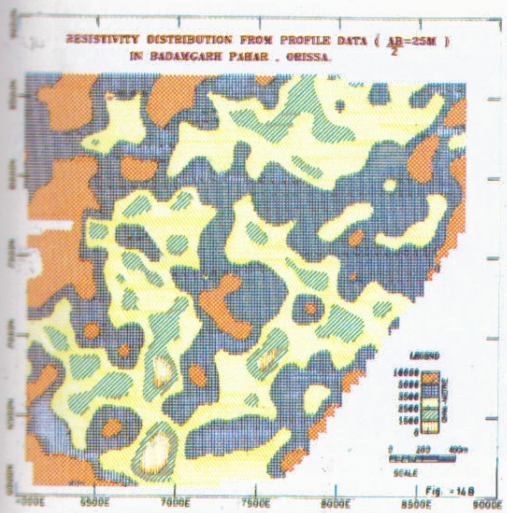


Residual magnetic anomaly map

Application of powered-support longwall mining requires accurate prediction of structural disturbances within the coal seam so as to avoid unproductive stoppage of capital intensive mining equipment. To this end in-seam seismic survey [ISS] has been found to play a key role for demarcation of areas free from geological discontinuities, like faults and intrusions. With projected rise in longwall mining the ISS method is going to find much greater application in the Indian coal industry.

Along with the introduction of advanced exploration techniques, development of computer software for data analysis and interpretation has also been an area of intense R&D effort. A PC based software package CEMPGEODOC has been developed, which can

be used as a front end for mine planning software like MINEX. The package enables validation of basic lithology and provides output of analytical data, graphic lithologs, seam correlation, seam structure, borehole location plans and graphic correlation charts on PC based plotters.



Resistivity distribution from profile data

Hydrogeology

Water in sub-surface strata encountered during mining is a part of the hydro-geologic cycle and needs to be managed both for ensuring safe operations and also for preservation of the eco-system. While mine workings under heavily water-bearing strata need to be safeguarded against possible inrush of water, it is also necessary to protect the natural water resource in a mining area, both in terms of quality and quantity. Studies related to the hydro-geological regime of a coal-bearing area, therefore, play an important role in planning future mining operations.

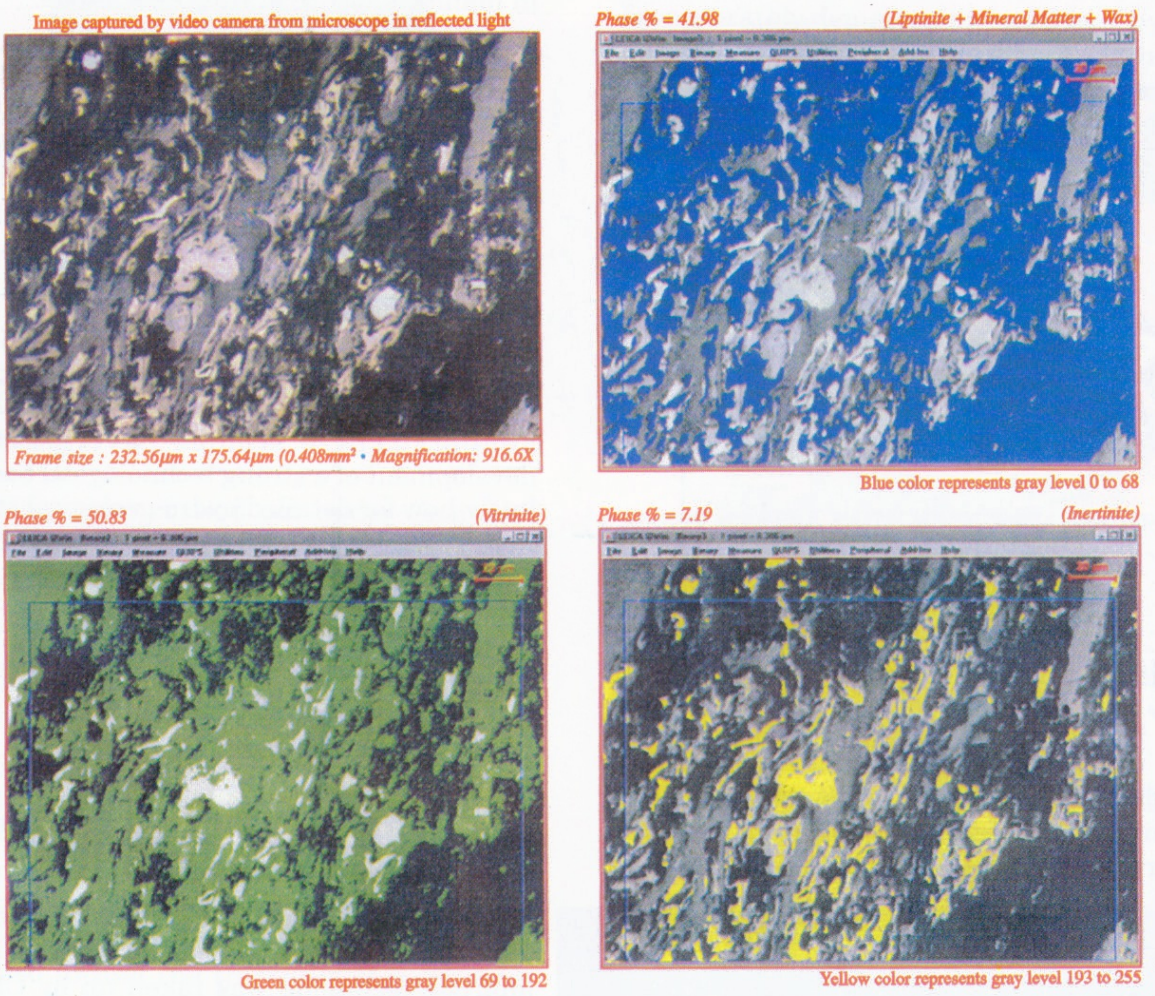
Well testing under S&T project in Rajasthan

Hydro-geological investigations have been carried out under Coal S&T Grant for lignite deposits at Merta Road in Rajasthan. Similar studies have also been carried out for modeling and control of water systems in Chandrapur area of Wardha Valley coalfield and in Rajmahal area of Lalmatia coalfield under a UNDP assisted project. The procedures established through these projects have been gainfully employed for a large number of mines in BCCL, ECL and in WCL where underground mining is being carried out under heavily water-bearing aquifers. These studies have led to the development of a strong technological base and know-how for detailed hydro-geological studies, water supply investigations, deep-seated dewatering, well rehabilitation, long duration pumping tests and data analysis through computer based programmes for groundwater modeling and futuristic projections with socio-economic interface to enable total water resource management.

Automated Petrograph Image Analysis System

A research project on characterization of Indian coals by use of digital image analysis technique was taken up by CMPDI. Under this project an Automated Petrograph Image Analysis (PIA) system using digital image analysis technique was developed for maceral analysis of coal pellets and for measurement of reflectance of vitrinite in coal pellets. A total of 242 coal samples (borehole coal cores and low volatile high reflectance coals) from the major coalfields of India, viz. Ranigunj, Jharia, East Bokaro, West Bokaro coalfields, and also 18 LVMR coal samples from East Bokaro and Jharia coalfields were studied and validated for maceral analysis. It was observed that the PIA system can speed up maceral analysis to the extent of three samples per day (one shift operation) per person in

comparison to that of one sample per day (one shift operation) per person using the point-count method of conventional petrography, which would mean a cost saving of 30%. Similarly, reflectance measurements on vitrinite could be performed on six samples per day (one shift operation) per person in comparison to that of two samples per day (one shift operation) per person using the conventional petrography method, which would provide a cost saving of 45%. Thus, the PIA system developed under the project was nearly three times faster and cost saving than manual work.



Identification of macerals / minerals using gray-level detection technique

Table 2 : S&T projects on coal exploration and hydrogeology

Sl. No.	*Title of the Project*	*Project Code*	*Imple-menting Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1.	Resistivity survey for estimation of overburden, locating out-crops and mapping bed-rock geology	CE/4	CMPDI	1982	0.80
2.	Resistivity survey for estimation of river sand	CE/5	CMPDI	1982	0.80
3.	Seismic refraction survey for sub-surface gological mapping	CE/6	CMPDI	1982	10.15

4.	Geophysical strategy to solve coal exploration problem	CE/8	CMPDI\ Osmania Univ.	1982	1.50
5.	Geophysical logging of boreholes	CE/3	CMPDI	1983	41.51
6.	Estimation of reserves of coal volume of overburden by electronic data plotter	CE/13	CMPDI	1983	13.87
7.	Physico-mechanical properties of rocks and coal from exploration data	CE/11	CMPDI	1984	8.00
8.	Hydrogeological investigation	CE/1	CMPDI	1985	36.00
9.	Computerisation of geophysical logging data	CE/14	CMPDI	1985	2.20
10.	Geo-statistical analysis for optimisation of drilling	CE/15	CMPDI	1985	2.89
11.	Carbolite coke oven	CE/2	CMPDI	1986	5.00
12	Development of computer based geo-data bank	CE/12	CMPDI	1988	34.60
13.	Geothermal investigations in Manuguru area of Godavari valley coalfield	CE/20	SCCL	1988	10.85
14.	Identification and delineation of abandoned underground colliery workings in Raniganj Coalfield	CE/22	MGMI	1991	4.50
15.	High resolution shallow seismic reflecton survey	CE/9	CMPDI	1992	224.63
16.	Development of methodology for thermal studies of mine fires using remote sensing technique in Jharia Coalfield	CE/23	CMPDI NRSA	1992	179.00
17.	Identification and delineation of abandoned and unsurveyed colliery workings in Raniganj Coal Fields - Geophysical Studies	CE/24	CMPDI MGMI IDRC (Canada)	1995	57.5
18.	In-seam seismic survey	CE/21	CMPDI	1999	184.00
19.	Development of methodology for characterisation of Indian coal by computer aided petrographic image analysis	CE/26	CMPDI	2001	114.50

MINING METHODS

The phenomenal rise in coal production, nearly six-fold in the past three decades, necessitated rapid but judicious mechanization of mining methods. While opencast operations are now fully mechanized employing large capacity earth moving equipment, introduction of machinery in underground workings has been gradual. In conventional bord and pillar workings coal loading and transport have been mechanized, eliminating human labour and drudgery to a large extent. There have mostly been increasing use of Side Discharge Loaders [SDLs] and Load Haul Dumpers [LHDs] for loading of coal at the faces along with armoured face conveyors and belt conveyors for coal transport.

The use of such equipment for underground operations required elimination of conventional timber support or other roof-to-floor type of supports to allow movement of machines in confined spaces. Extensive studies have been made under Coal S&T Grant for determination of physico-mechanical properties of coal measure rocks and observation of roof behaviour in bord and pillar workings with SDL/LHDs. As a result of these studies it has been possible to introduce roof bolting on a wide scale, reducing dependence on scarce timber. Adoption of roof bolting even in depillaring areas has allowed the use of loading machines during extraction of pillars and not in development galleries alone.

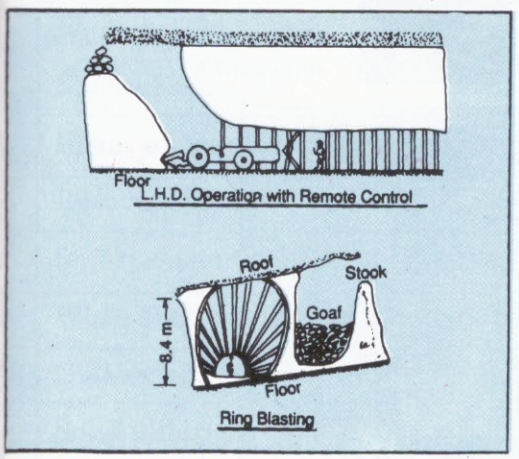
Coal loading is mechanized in most of the underground mines of CIL and SCCL with over 900 SDLs and 50 LHDs in operation, contributing over 40 million tonnes of production per year.

Side Discharge Loader [SDL]

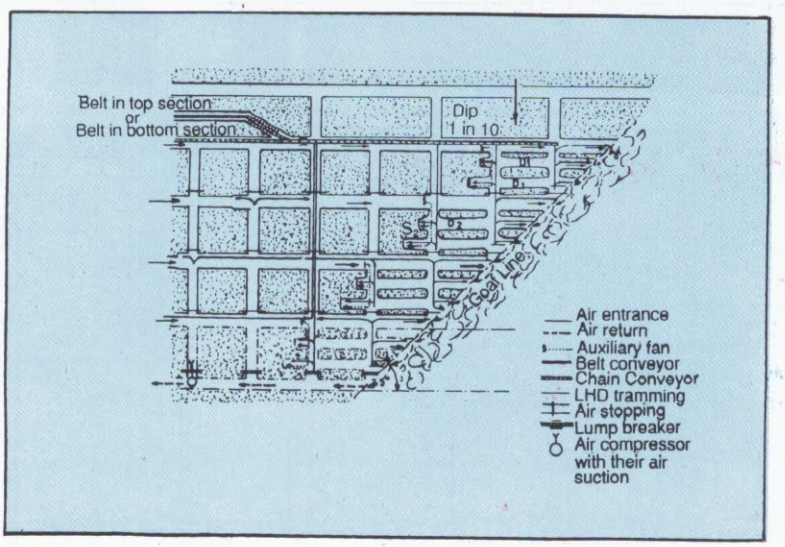
Load Haul Dumper [LHD]

Blasting Gallery Method

Conventional bord and pillar mining in thick seams is associated with very low percentage of extraction [around 30% in a panel] even under favourable conditions. Extensive development of pillars carried out earlier in thick seams had also resulted in large reserves of good quality coal locked up in developed bord and pillar workings [over 2,500 million tonnes]. Scientific investigations were initiated under Coal S&T Grant for safe and speedy liquidation of such developed pillars with maximum possible percentage of recovery.



Blasting gallery method



Dipillaring layout and LHD tramming in Blasting Gallery Method

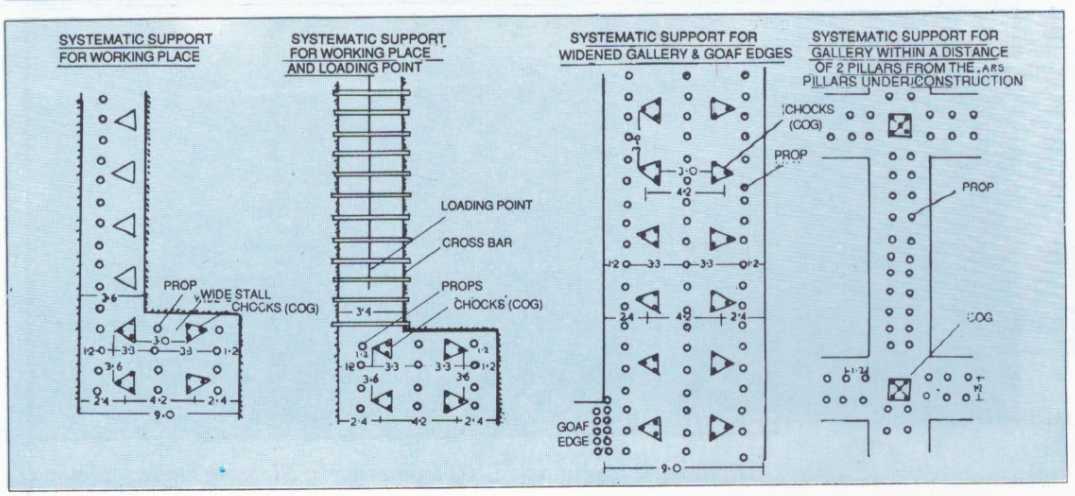
Blasting gallery method was introduced as an R&D project in technical collaboration with CdF, France, in 7.5m thick X seam of East Katras Colliery, BCCL. The method was a derivative of an earlier procedure adopted in France, which involved blasting of the full seam thickness in one operation. The system as adopted in India involves blasting of a series of holes drilled into the sides and roof of galleries in a single operation. After the ring-hole blasting, as it is commonly called, remote controlled LHDs are employed for loading of the blasted coal and transporting to conveyors.

After successful extraction in three panels the new method was replicated in Chora Colliery of ECL. Coal recovery was found to be about 70% in the panels, which was substantially higher than what was possible through conventional means. The output per man-shift [OMS] was also substantially higher at 2 tonnes. The method has been repeatedly employed in GDK-8 and GDK-10 mines of SCCL for working medium-thick seams with a high degree of success. A production level of 900 tonnes per day on a sustained basis with an OMS of over 5 tonnes could be achieved with as high as 85% recovery of coal.

Wide Stall Method

Of the large reserves of coal locked in developed pillars a substantial portion is sterilized due to the presence of structures and inhabited localities on the surface. In such cases only partial extraction from these pillars can be considered in view of the need to avoid subsidence and damage to the surface. The prevailing method under such conditions is splitting of the coal pillars, without further extraction of the resultant stooks, followed by stowing with sand. The drawback of this method, however, is that the percentage of recovery is low and comes down sharply to as low as 30 with increasing seam thickness due to adverse slenderness ratio of the pillars.

Wide stall mining at East Bhuggatdih Colliery

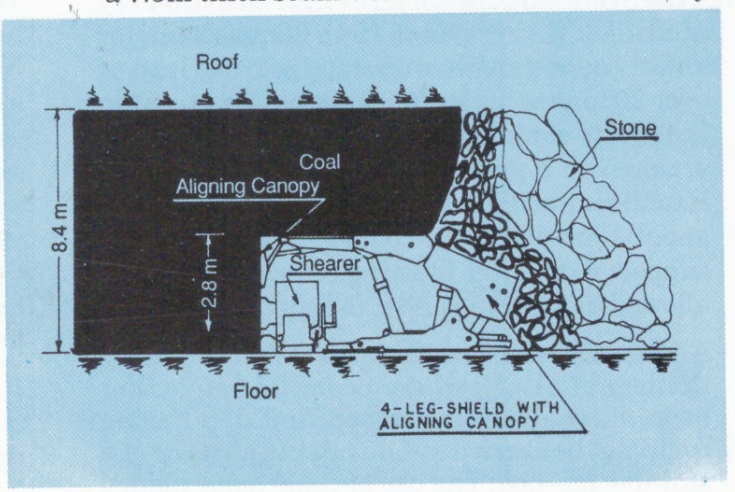


Support plan of wide stall method

Wide stall method was conceived to improve coal recovery under such conditions. The method was tried on a laboratory scale with the help of equivalent materiel modeling and then experimented by a field trial at East Bhuggatdih Colliery of BCCL in a 16.5m thick seam lying below built-up areas on the surface. The extraction procedure involved formation of 7 to 9m wide stalls, which were extended to full working height, leaving the pillar core as a natural support to the roof. Over 45% overall recovery could be achieved with a safety factor of more than one for remnant pillar cores left for long-term stability. A comparison of extraction percentage and safety factors of pillars between conventional bord and pillar system and wide stall method of working is given in table 3.

Sub-level Caving

In addition to the development of a suitable method for extraction of developed coal seams R&D effort was also directed towards optimum extraction of virgin thick seams, which constitutes a large percentage of the total coal reserves in India. The prevailing method of bord and pillar mining was inadequate as recovery was low and required stowing with sand not easily available in many areas. The feasibility of applying sub-level caving was examined with respect to two variants: sub-level caving and total under-winning, also known as soutirage. The first sub-level caving face was opened at East Katras Colliery of BCCL. It was possible to achieve a production level of about 850 tonnes per day in a 7.5m thick seam with over 60% coal recovery.



Sub-level caving [Soutirage]

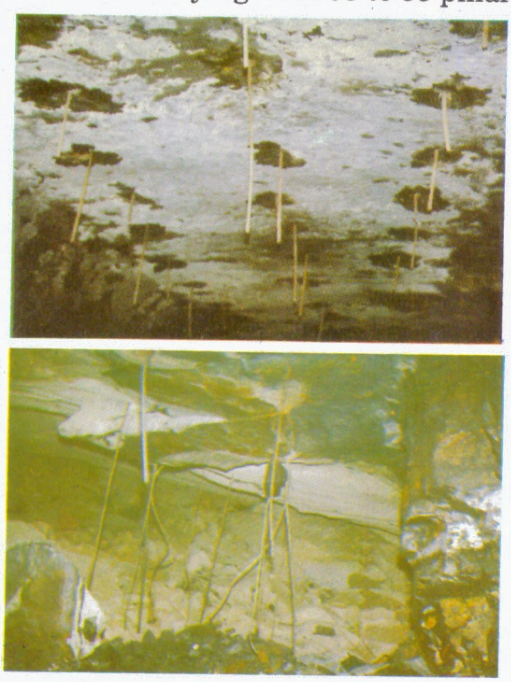
Table 3 : Coal recovery and safety factor of pillars for wide stall method

		Gallery Size (m)				
		3.6	4.0	4.5	5.0	5.5
1.	**Conventional stooking and splitting method**					
A.	**Development in two sections of 2.4m height**					
	Recovery %	6.5	7.2	8.1	8.9	9.6
	Safety Factor	4.6	4.5	4.4	4.3	4.2
B.	**Final extraction in two sections of 7.2m + 6.4m and pillar 15 x 15m size 3m parting**					
	Recovery %	34.6	37.8	41.7	45.5	49.1
	Safety Factor	1.05	0.98	0.90	0.82	0.75
2.	**Wide stall method with 2 sections of 7.2m + 6.4m and 3m parting**					
	Gallery size, m	6	7	8	9	10
	Solid pillar, m	24	23	22	21	20
	Recovery, %	29.5	33.7	37.8	41.7	45.5
	Safety Factor	1.56	1.44	1.32	1.21	1.11

Thick Seam Extraction by Cable Bolting

In order to obviate the high capital investment required for operating sub-level caving faces, which require powered-support longwall equipment, a new mining method, commonly referred to as thick seam mining by cable bolts, was developed under an S&T project mainly for extraction of thick seams with developed pillars. The method was successfully tried in 6m thick Seam III at Chirimiri Colliery of SECL. Wire ropes of 19 to 22mm diameter and 6 to 8m length with safe bearing load of over 20 tonnes under tension were grouted into the roof to avoid roof coal from sagging and bed separation. A part of the cables so grouted went into the immediate roof strata up to a height of about 1.5m above the coal seam and provided support even after blasting of roof coal, which allowed coal loading under the supported strata.

A full-scale trial was also undertaken at NCPH Colliery of SECL, where Seam III had earlier been extensively developed and depillaring could not be carried out due to the absence of a suitable method. The use of cable bolts yielded excellent results in coal recovery, production and productivity. The trial was successfully repeated in seam thicknesses of 6.5m, 7m and 8m and at depths of 70m, 103m and 256m in panels of size varying from 38 to 55 pillars.



Cable bolted roof before and after blasting

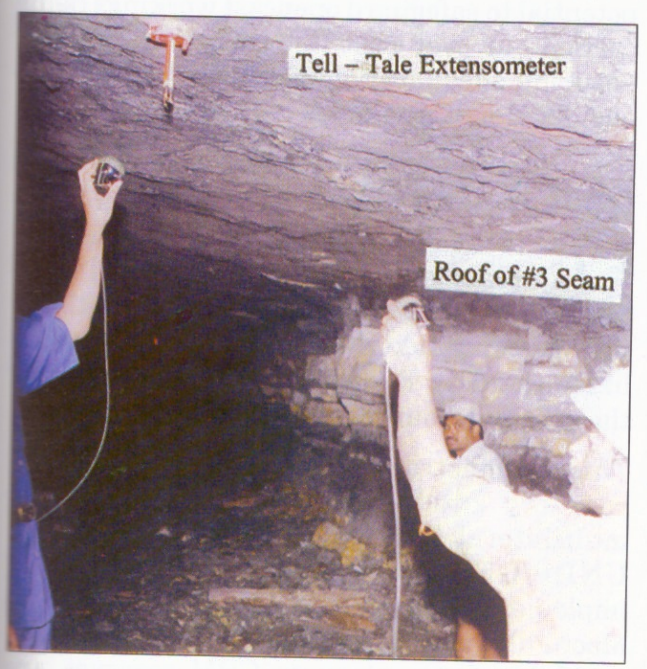
Extraction of Coal Locked in Pillars of Multiple and Thick Seams

In India large reserves of coal are locked in pillars developed in multiple and thick seams, which are not amenable to normal depillaring operation as the percentage of extraction achieved is very low and unsafe operating conditions are also likely to occur.

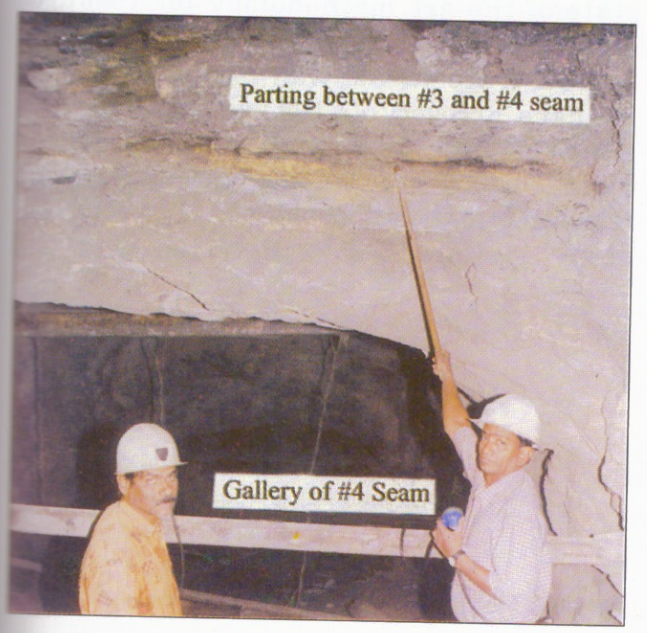
To overcome such problems a trial has recently been conducted by National Institute of Rock Mechanics at RK-8 Incline, SCCL for simultaneous extraction of pillars in three seams, each of about 2.5 m thickness with partings of about 7-9 m between the seams. To assess the stability of partings and to design a suitable support system, observations of strata behaviour were made during simultaneous extraction of the pillars in the experimental panel, which included the three seams.

It was observed that maximum roof to floor cumulative convergence was about 8mm in the panel. The maximum rate of convergence was 2 mm / day prior roof falls in the goaf. Vertical supports near the goaf edge experienced a maximum cumulative load of 6T. The maximum load on the support in the galleries remained within 4T. The average rate of change of load near goaf edge was 1.5T/day prior to the roof fall. It was found that estimation of support requirement based on "Q" classification tended to overestimate the actual requirement for lower seams. The intensity of abutment load in the experimental panel was not high. The maximum change in stress over the pillars was only about 0.8 MPa, 0.7 MPa and 0.6 MPa in No. 3, 4 and 5 seams respectively, which were attributed to the destressing due to regular roof falls in the overlying seams. The results of the numerical model using FLAC-2D were in close agreement with the observed field behaviour. In the model, the stability factor for the partings in the development workings was estimated to be greater than 1.0 for parting thicknesses more than 6m. The extraction of three rows of pillars in No. 3 seam was also simulated using numerical modeling. In the model, the safety factor of the partings between No. 3, 4 and 5 seams was less than 1.0 in the goaved out area.

This was in accordance with the actual conditions as observed from the collapse of parting after extraction of three rows of pillars in No. 3 seam. As compared with the conventional system of single and double seam extraction, the recovery of coal in the experimental panel with simultaneous extraction of three seams was more by about 10%.



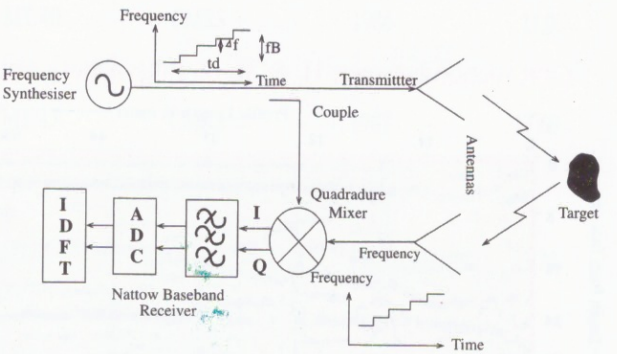
Study of roof behaviour at RK-8 mine, SCCL



Parting rocks between simultaneous extraction in two seams at RK-8 mine , SCCL

Ground Penetrating Radar

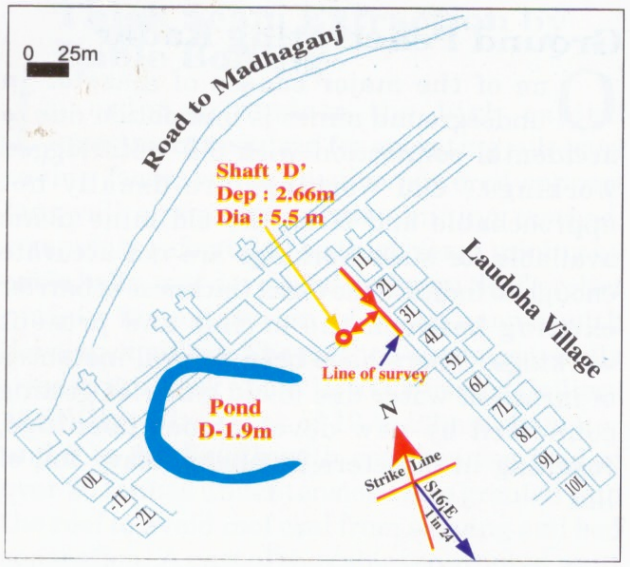
One of the major causes of disaster in underground mines is inundation due to accidental connection with old waterlogged workings. Old workings are usually not approachable and often the old mine plans available for such workings are not accurate enough to indicate the exact thickness of barrier existing between the earlier and present workings. There have been several instances of inrush of water due to old galleries getting connected by new development headings, resulting in disasters involving heavy toll of life.



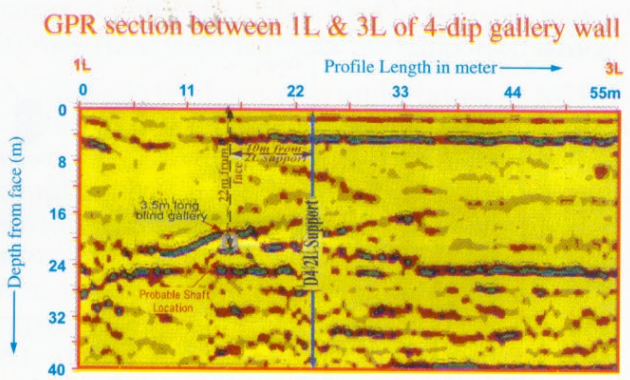
Block diagram of the stepped-frequency radar

To safeguard present workings against such occurrences an S&T project has recently been concluded in which the application of ground penetrating radar (GPR) has been established for detection of old galleries in the vicinity of present workings. The project has been carried out by the National Institute of Rock Mechanics (NIRM) in collaboration with CMPDI.

Under the project GPR survey was conducted both from surface and in underground workings in a number of collieries of ECL, BCCL, WCL and SCCL. At one of the mines pillar thickness between successive longwall panels was measured and in two other collieries mapping of pillar thickness in bord and pillar workings was done to detect blind galleries.



Part plan of 1&2 Incline / Jhanjra mine, ECL



GPR section between 1L&3L of 4-dip gallery wall

The technique was found to have a range of 35m for detecting blind galleries. Coal barrier thickness up to 25m against waterlogged workings could be mapped with an accuracy of ± 10%. This technique could detect old workings up to a distance of 40m from the current workings. The method could also be applied for mapping old workings 25-35m below the surface, thus providing an estimate of the rock parting between opencast benches presently being worked and old underground workings existing below the benches. Thus, this new technology provides a major tool for enhancing safety in underground mines close to water logged workings. The technique also has the potential to safeguard opencast workings being carried out over past underground mines by ensuring adequate thickness of cover so as to avoid accidental collapse of rock strata

Coal Bed Methane

One of the on-going S&T projects relates to a hitherto unexplored area in the Indian coal industry. Recovery of coal bed methane (CBM), being taken up under the project, is likely to add a new dimension to harnessing the energy resources of the country.

This demonstration project involving CBM recovery and commercial utilization has multilateral funding involving S&T Grant, UNDP/GEF and ONGC. It is being implemented jointly by CMPDI and BCCL at Moonidih and Sudamdih coal mines in Jharia coalfield where adequate CBM reserves are expected. The project intends not only to bring state-of-the-art methodology for resource assessment and recovery techniques but also demonstrate utilization of the exploited methane. Recovery of CBM will provide a clean source of energy and also prevent methane, a highly potent green house gas, from being released into the atmosphere.

Table 4 : S&T projects on mining methods

Sl. No.	Title of the Project	Project Code	Implementing Agency	Year of completion	Total Approved Cost (Rs. in lakh)
1	Scientific investigation on shearer longwal faces	MT/1	CMPDIL/ECL	1981	3.00
2	Stability of slopes in Opencast Mines	MT/10.3a	ISM	1981	13.18
3	Study of adoption of sublevel caving at East Katras and Kendwadih collieries	MT/18	BCCL/ Sofremine(F)	1983	11.50
4	Evaluation of workability indices of Indian coal seams and coal measure rocks	MT/8.3	ISM	1983	4.30
5	Slope stability in pit walls, dumps stability ground monitoring in and around pit with Geo-technique studies	MT/40	CMRS	1986	11.0
6	Optimisation of extraction of coal from pillars below surface structure using technique of partial stowing	MT/43	CMRS	1987	17.60
7	Evaluation of new mechanised system performance using SDL, LHD and roof bolting	MT/49	CMRS	1989	33.74
8	Hydraulic mining	MT/11	CMPDI/ BCCL	1989	818.67
9	Workability indices of coal seams	MT/8.3	CMRS	1989	24.11
10	Tests of sub-level caving from galleries in developed area in East Katras Colliery	MT/37	BCCL	1990	141.00
11	Mine Accident analysis and control a sociopsychological approach in coal mines	MT/57	BHU	1990	5.00
12	Computerized mine planning for opencast coal mines	MT/50	ISM	1990	11.59
13	Field trial of wide stall method	MT/44	CMRS	1991	19.45
14	Analysis of some time and cost over run projects	MT/75	IIM, Ahmedabad	1992	8.54
15	Induced caving of sub-level coal numerical evaluation of some geological and mining parameters	MT/71	BHU	1993	2.00
16	Assessment of status of coal mining in the state of Meghalaya	MT/79	CMPDIL	1994	15.00
17	Mechanised depillaring of 6m thick seam III of Chirimiri with cable bolted support	MT/77	SECL/ CMRI	1995	213.25

Sl. No.	*Title of the Project*	*Project Code*	*Imple-menting Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
18	Underground coal gasification	MT/62	CMPDI	1995	322.0
19	Development of method of mining for extraction of thick and steep seams of NEC	MT/78	NEC	2000	120.00
20	Extration of coal locked in pillars of multiple and thick seams	MT/107	NIRM/SCCL	2003	26.20
21	Application of ground penetrating radar (GPR) technique to locate coal water logged workings in coal mines	MT/110	NIRM/CMPDI	2003	47.00

Strata Control and Subsidence

Control of roof strata is an important requirement for the safety of workers in underground mines. An appropriate support design system is essential not only for efficient mining operations but also for safety of working persons and equipment. A total of 29 projects under Coal S&T Grant have been carried out for investigating various aspects of strata control.

Classification of Roof Rocks & Design of Roof Supports

One of the most relevant projects involved classification of roof strata for estimation of support requirement and design of support pattern. Under this project 47 underground workings under different types of roof strata were studied and an engineering classification system was developed. The system employs a quantified asessment of roof strata called Rock Mass Rating (RMR), which takes into account (i) layer thickness in immediate roof, (ii) structural features, (iii) rock weatherability, (iv) strength of rock and (v) ground water seepage. Each of these parameters was assigned weightages in order of their impact on roof stability. The values of these parameters are determined for underground galleries and the RMR is obtained for the type of strata occurring in the roof. The RMR so worked out is adjusted for different mining parameters and then is used for classifying roof strata in five categories.

Classification of immediate roof strata

RMR	Class	Description
0-20	V	Very poor
20-40	IV	Poor
40-60	III	Fair
60-80	II	Good
80-100	I	Very good

With RMR obtained for the roof strata the likely rock load can also be worked out by employing the following empirical equation developed under the project.

$$\text{Rock Load} = \text{Span} \times \text{Mean Rock Density} \times (1.7 - 0.037 \times \text{RMR} + 0.0002 \times \text{RMR}^2)$$

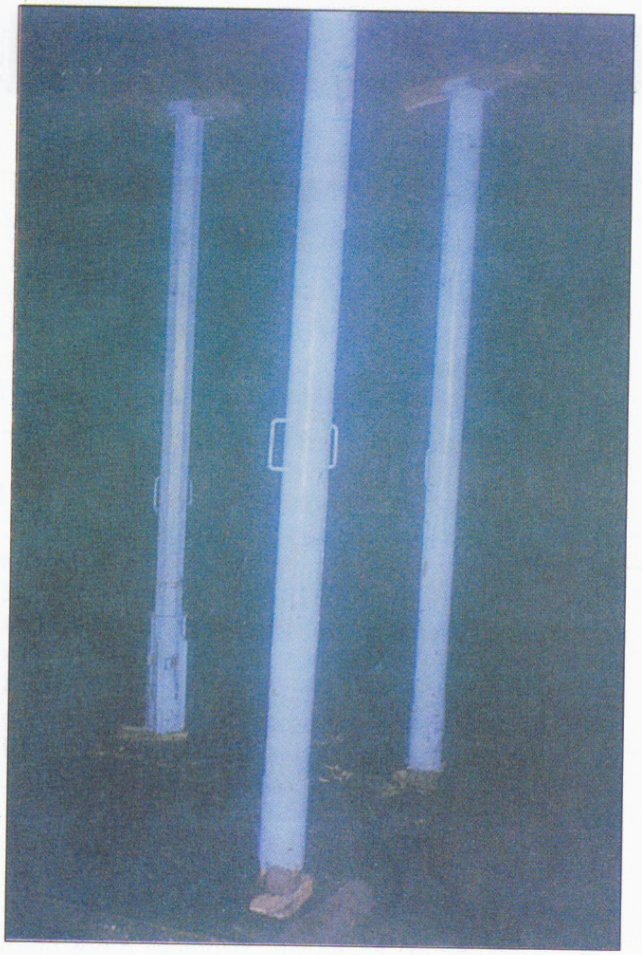
The investigtions also provided the type of support to be used for each category of roof strata along with the support density to be adopted, which is worked out with the help of the rock load value as determined by the empirical relationship given earlier.

The classification system was recommended for use in bord and pillar development galleries by a DGMS constituted committee, commonly referred to as the "Paul Committee". Subsequently the support design process was recommended by DGMS for adoption by all underground coal mines in a circular issued in 1993. Since then for all the underground mines of CIL and SCCL roof support design for bord and pillar workings is being carried out by using the method. So far over 600 underground workings in over 350 mines have been covered.

Replacement of Timber by Steel Roof Supports

A number of research projects have been carried out for introduction of roof bolting as a form of regular support by replacing timber supports which were in use for over a century. The use of roof bolts not only allows immediate support of exposed roof but also permits free movement of loading machines in the confined spaces of underground workings.

Combination of wire netting and roof bolting



A view of rigid pit prop installed in an underground mine

Rigid pit prop mounted on a load cell installed in underground workings

Studies carried out under S&T programme have also resulted in saving of scarce timber by the introduction of steel supports, which have longer life than timber and are amenable to repeated use. The types of supports introduced included screw props, triangular chocks, tubular and rectangular chocks, pit props and rope stitching. The supports developed under the various projects were subjected to large scale testing both in laboratory and also under different mining conditions.

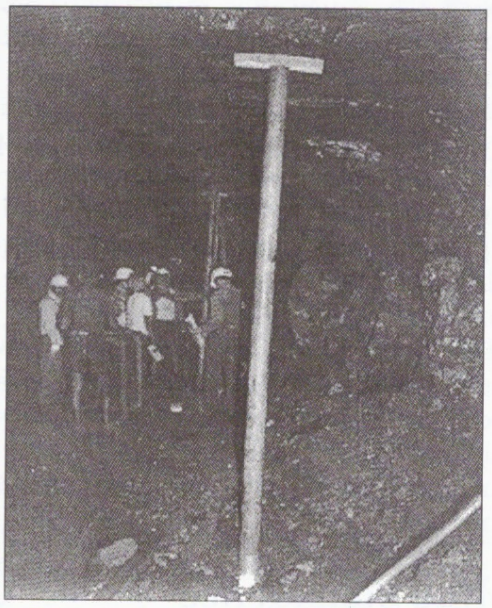
To overcome certain shortcomings in steel props an S&T project has recently been concluded by RDCIS (SAIL), Ranchi in collaboration with CMPDI.

Under the project, light-weight rigid steel props of round and octagonal tubular cross-sections of 2.8m length with load bearing capacity of 30 tonne have been developed with reduction in weight up to 20% compared to other types of steel props. High strength (minimum specified yield strength 350 MPa) weather resistant steel has been used for fabrication of these props. Adjustable height type props have also been developed for three different heights (2.7m, 2.9m and 3.1m). Field trials were successfully conducted in both development and depillaring areas of Dalurbandh Colliery, ECL.

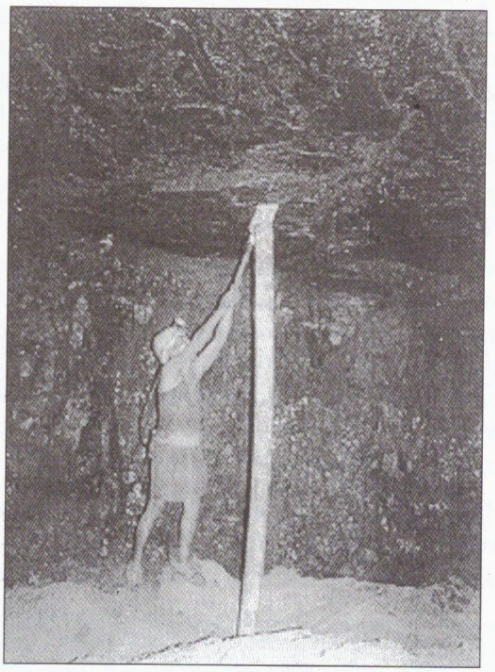
Fly-ash Based Roof Support

Fly-ash is an extensively generated waste material in thermal power plants. In India, more than 100 MT of fly-ash is being produced annually, which poses a serious threat to the environment. Hardly 15% of this fly ash is being utilized in India.

For gainful utilization of this waste material, a research project was taken up by CMRI to develop fly-ash based supports suitable for underground coal mines. Under the project, fly-ash of different thermal power stations



Fly-ash props with load cell in Horladih colliery



Dismantling of fly-ash props

polymers and different fibre were used for making a suitable composition for use as props. Various lengths and diameters of props were experimented in the laboratory as well as in mines. The load bearing capacity of fly-ash props (60% fly-ash + 35% resin + 5% fibre) of 3m length and 100mm diameter was found to be around 10 tonne, which compared well with timber props. The props were tested for repeated loading and unloading. The props were also kept in underground mines for study of the effect of mine environment on the physical and mechanical properties of the props. There was only a marginal increase in weight of 0.001 to 0.04 kg. Field trials were conducted in Horladih underground mine of BCCL. The cost of fly-ash based props of 3m length and 100 mm diameter works out to Rs. 790, which is somewhat higher than wooden props but may work out to be economical if their continued use in mines indicate considerably longer life. The use of such props is also expected to help conservation of scarce timber besides gainful utilization of fly-ash.

Steel Fibre Reinforced Shotcrete Support System

A research project on application of steel-fibre reinforced shotcrete support for long-term stability of underground galleries was carried out by Indian School of Mines (ISM), Dhanbad. The shotcrete system involved use of stone chips, sand and cement in the general proportion of 2.6:1.9:1 along with steel wire pieces for reinforcement. The mixture is sprayed with the help of a nozzle on the exposed surfaces of drivages in rock and coal to form a layer varying in thickness normally from 50 to 200mm depending on bond strength of rock. This shotcrete lining prevents rock displacement by strengthening the rock mass.

Field trials were conducted successfully in some mines of ECL, BCCL, WCL and IISCo. A comparison of the cost of different types of support in coal mine roadways reveals that the shotcrete system is cost effective with respect to the conventional steel supports like steel props, arches, girders, etc, for poor strata having RMR below 30.

Pillar and Parting Stability

The research projects completed also include investigation into coal pillar stability and stability of partings between contiguous seams or multiple sections within a seam. The studies related to coal pillars resulted in the development of a pillar design formula specifically suited for Indian geo-mining

conditions, which enabled replacement of design equations developed in other countries like South Africa and were being used earlier due to lack of an indigenous method. The equation so developed for Indian conditions have been recommended by DGMS for use in the Indian coal industry. These are given below.

Pillar Strength (s)

$$S=0.27\sigma_c h^{-0.36} + \left(\frac{H}{250}+1\right)\left(\frac{W}{h}-1\right), \text{ MPa}$$

Where,

σ_c = laboratory compressive strength of coal, MPa
h = working depth, m
H = depth of cover, m
W = width of the pillar, m

The pillar load(P) can be estimated by tributary area method

$$P = \gamma H \left(\frac{W+B}{W}\right)^2$$

Where,

γ = unit cover pressure, MPa/m^2
B = width of gallery, m
L = W+B

The pillar size can be worked out from the above equations with recommended safety factors as given below

Stowed pillar arrays	0.6-1
Unstowed pillar arrays	2.0
Chain pillar for isolation	1-1.5
Chain pillar for surface protection while using non-effective width of extraction	2.0
Yield pillar arrays within a panel	0.7-1
Ribs against goaf while depillaring	0.5-0.7

For analysis of roof cavability and other strata control problems, including stability of partings, extensive physical modeling was carried out under Coal S&T Grant by employing Equivalent Material Modeling. Facilities for modeling were developed in a number of institutes. The studies included development of suitable equivalent materials for simulating the characteristics of Indian coal measure strata. The technique was widely used for prediction of strata behaviour under different geo-mining conditions and the findings provided useful design inputs.

With the emergence of powerful computer numerical modeling techniques are now bein increasingly adopted for mine design. The us of numerical modeling has also been initiate by studies undertaken through S&T project Of particular relevance is a recently conclude project on stability of partings. As the countr has large reserves of coal in multiple seams i close proximity and also in thick seams, whic require multiple section workings, partin stability is a subject of special concern. Th project has not only enabled establishment of powerful design tool within the country but ha also led to the development of design norms fo underground workings in close proximity to on another.

Mine Subsidence

Though some degree of ground subsidence over the mined out or caved areas is inevitable, large and uncontrollable subsidence would create problems of ground stability and damages to surface installations. Prediction o subsidence behaviour, therefore, has attracted serious attention of mine planners and operators.

No reliable method was available for prediction of subsidence behaviour in Indian coalfields. A number of diverse situations were, therefore, studied by various projects under the S&T programme carried out for more than a decade, which provided a scientific basis for adequate control of surface subsidence.

Based on extensive R&D investigations spread over 85 caved and 51 stowed panels it has been possible to formulate guidelines for predicting

Surface cracks due to subsidence

Table 5 : S&T projects on strata control

Sl. No.	Title of the Project	Project Code	Imple-menting Agency	Year of completion	Total Approved Cost (Rs. in lakh)
1	Fracturing of massive sand stone roof	MT/15	CMPDI	1979	15.00
2	Physico-mechanical properties of coal measure rock	MT/9.2	CMRS	1981	3.89
3	Investigations into different strata control parameters in and around longwall mining	MT/9.1	CMRS	1982	8.12
4	Evaluation of stability of pillars and barriers	MT/10.2a	BHU	1982	1.63
5	Investigation into creap protection of Indian coals	MT/28	BHU	1983	1.75
6	Strata control	MT/3	CMPDI	1985	20.00
7	Establishment of cavability parameters of coal measure strata of Manuguru area (SCCL) for longwall caving	MT/31	KSM	1985	3.00
8	Development of roof supports for mechanised Bord & Pillar workings and fast drivage and their field evaluation	MT/33	CMRS	1986	17.30
9	Geo-mechanical classification of coal measure rock vis-a-vis roof supports	MT/34	CMRS	1986	3.45
10	Investigations into problem of rock bursts in deep coal mines	MT/8	ISM	1987	15.74
11	Optimisation of design of mines pillar parameters and feasibility of entraction below water-logged workings	MT/9.3	CMRS	1987	15.18
12	Development and evaluation of norms for longwall support system in coal mines in India	MT/41	ISM	1987	10.20
13	Assessment and control of ground movement around extraction perimeter in longwall and Bord & Pillar workings	MT/10.3 (d)	ISM	1988	1.25
14	Stability analysis of subsidence and strata behaviour using three dimensional analogue simulation and computer technique	MT/39	BHU	1989	1.65
15	Design of support for mine roadways	MT/60	ISM	1989	25.40
16	Simulation of large underground excavations in coal mines using numerical methods (Finite element technique) with special reference to longwall face	MT/58	BHU	1990	2.33
17	Development of & design Norms for contignous seam pillar	MT/67	CMRIS	1991	7.20
18	Development and application of accoustic emission technique in the mines of SCCL	MT/52	NGRI	1992	18.38
19	A study of bump proneness of Indian coal seams and measures to alleviate the bump hazard	MT/72	CMRS	1994	3.7
20	Design and experimentation of cable bolting under adverse ground conditions in thick seams containing clay bands	MT/87	SCCL/NIRM	1997	18.98
21	Development of fibre reinforced shotcrete for supporting underground openings against failure due to rock discontinuity and induced stresses	MT/88	ISM	1998	14.02

Sl. No.	Title of the Project	Project Code	Imple-menting Agency	Year of completion	Total Approved Cost (Rs. in lakh)
22	In-situ stress measurement in underground coal mines and its application to stability analysis	MT/95	CMRI	2000	57.12
23	Design and experimentation of cable bolting under adverse ground condition in thick seams for longwall gate roads and face dips	MT/105	SCCL	2000	1.80
24	Control of massive and hard roof by water injection under high pressure	MT/86	CMRI	2000	49.55
25	Development of model vis-a-vis study of parameters influencing abutment loading of pillars at a depillaring face of shallow depth cover under massive roof strata	MT/112	CMRI/ SECL	2003	40.46
26	Development of fly ash based support suitable for underground coal mines	MT/114	CMRC, BCCL	2004	46.21
27	Development of light weight steel props for underground coal mines	MT/124	RDCIS/ CMPDI/ECL	2004	55.113
28	Monitoring of strata behaviour during longwall mining using Micro-seismic monitoring technique and estimation of casing height	MT/116	SECL	2004	80.00
29	Measurement of in-situ stress by hydro fracture method & investigation on redistribution of in-situ stress due to local tectonics at WCL, Tandsi/Thesgora region to devise suitable support plan/SSR	MT/117	NIRM, CMDIL, WCL	2004	49.772
30	Application of roof bolting in depillaring operation for replacement of timber under roof conditions difficult to cave at Kuardih/Patmohna/Methani of ECL	MT/120	CMRI/ECL	2004	26.35

subsidence behaviour. The mathematical relationships for determining various subsidence parameters and also a subsidence prediction model for Indian coalfields have been developed. The predictive model closely estimates the maximum likely subsidence and other relevant parameters. It has also been possible to estimate the impact of subsidence on surface features, built up areas and suggest safe limits of subsidence movement for different categories of surface structures. The salient features emerging out of the investigations are summarised below :

Maximum Possible Subsidence

$S_{max} = 0.5(1+m)\, e'a'm'h'$

Where,

S_{max} – maximum possible subsidence, m
m – rock mass factor
e' – extracted percentage factor
a' – goaf treatment factor
m' – extraction thickness, m
h' – depth factor.

The volume of subsidence trough is related to maximum subsidence and area of underground extraction as per the following relationship,

$V - 0.527\, S.A$

Where,

V - volume of subsidence trough, m^3
S - maximum subsidence, m and
A - area of underground extraction, m^2

Norms for non-effective width of extraction

Rock Mass Factor	Non-Effective Width (NEW)
0.5	0.5h
0.6	0.4h
0.7	0.3h
0.8-0.9	0.2h

h - depth of workings from surface, m

Norms for angle of draw for flat seams

Undisturbed overlying rock mass 25°

Disturbed rock mass upto 42°

Safe limits of subsidence

(i) Railway lines	– No movement permitted
(a) Welded construction	– Maximum strain = 3mm/m
(ii) Water bodies	– Maximum tensile strain = 4.5 mm/m
(iii) Buildings	– Maximum total elongation or compression = 60 mm (for slight repairable damages)
(iv) Aerial ropeway and electric transmission high tension pylons	– Strain = 3mm/m – Slope to the extent that the displacement of top most point should not be more than one third of the radius of the base.
(v) Roads	– No stepping due to subsidence

The findings of R&D work done in this area have already been used to study more than 150 problems involving prediction of subsidence, design of underground workings, etc. It has also been used to study problems involving extraction of coal seams from underneath and in the vicinity of surface features/built up areas in different Indian conditions.

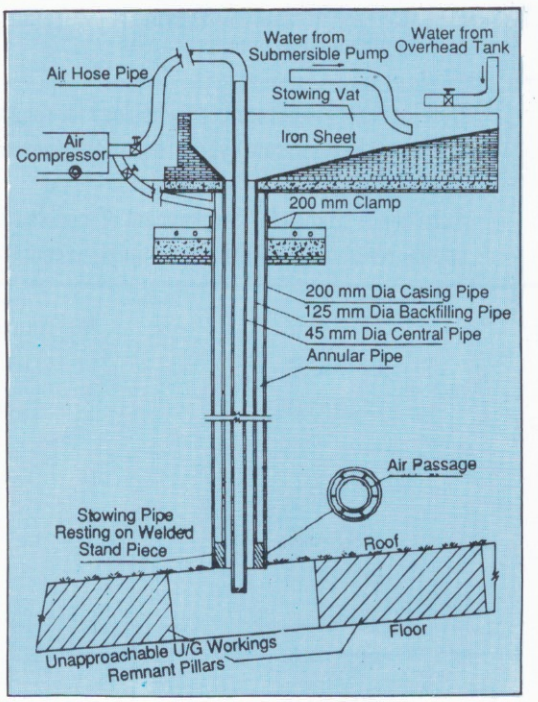
Sand / Water flushing arrangement

As a result of these studies, it has been possible to extract more than 25MT of coal otherwise left as unmineable. It is expected that substantial quantities of hitherto blocked coal reserves may be extracted in future. The results of the studies have also been useful to mine planners in preparation of Environmental Management Plans (EMP) for new projects, which have become an essential pre-requisite for clearance from the Ministry of Environment & Forests before sanction by Govt. of India.

Stabilisation of Underground Voids

In several coalfields of the country, especially Jharia and Raniganj coalfields, there are large areas having partially worked underground workings carried out in the past. Most of these old workings are waterlogged and unapproachable. Over many of these workings there are inhabited localities on the surface, which are susceptible to damage in the event of any collapse of strata resulting from failure of small pillars below ground.

In order to stabilize such unapproachable old workings it has been necessary to undertake trials of stabilization measures as the conventional method of sand stowing is not



Sectional view of stowing arrangement for Ramjeevanpur pilot study, ECL

feasible. One of the stabilization techniques tried under the Coal S&T Programme was hydro-pneumatic stowing from surface through boreholes.

This method involves drilling of boreholes from the surface into the underground area to be stabilized. Sand-water slurry, along with compressed air, is sent down the boreholes for filling the voids below ground. Air under pressure is used to carry the sand away from the borehole location so that a considerably large area can be packed from a single borehole.

Table 6 : S&T projects on mine subsidence and stowing

Sl. No.	*Title of the Project*	*Project Code*	*Implementing Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1	Assessment of surface movement and structural damage due to mineral exploration	MT/10.3 (c)	ISM	1981	1.25
2	Experimental stowing plant to study flow characteristics of different stowing materials	MT/17	KSM	1988	24.64
3	Stabilisation of water filled void through hydraulic sand stowing at Ramjeepanpur colliery	MT/36	ECL	1988	44.84
4	Correlation of surface subsidence with deformation parameters in U\G and intervening strata	MT/54	CMRS\ IIT(K)	1989	90.64
5	Waste material stowing	MT/4	BCCL	1989	176.882
6	Surface subsidience in mining areas	MT/9.4	CMRS	1990	118.23
7	Development of appropriate technology for removal of clayey material from overburden of the opencast Mines	MT/82	CMPDI	1995	59.60
8	Subsidence studies for development of models with special reference to multi-seam mining in India	MT/89	CMRI	1999	4.4

Friction Factor

With increasing depth of mining resulting in hot and humid underground conditions, efficient ventilation planning and design of ventilation system are imperative. Planning and design of an efficient ventilation system needs knowledge about coefficients of friction which till recently were based on work done in the mines of other countries.

With this in view, scientific investigations were carried out by CMRI in various mines of different coalfields under S&T grant, which resulted in defining the friction factors for various types of openings, both supported and unsupported, for effective planning of underground ventilation systems.

The mine openings have been classified in 14 categories representing commonly encountered types in Indian coal mines. The values of friction factor for these are given in table 7. In addition, the resistance values of powered support longwall and conventional longwall faces were also established.

These observations were transferred to mining companies and are being routinely used by mine planners and practising mining engineers in designing underground mine ventilation systems.

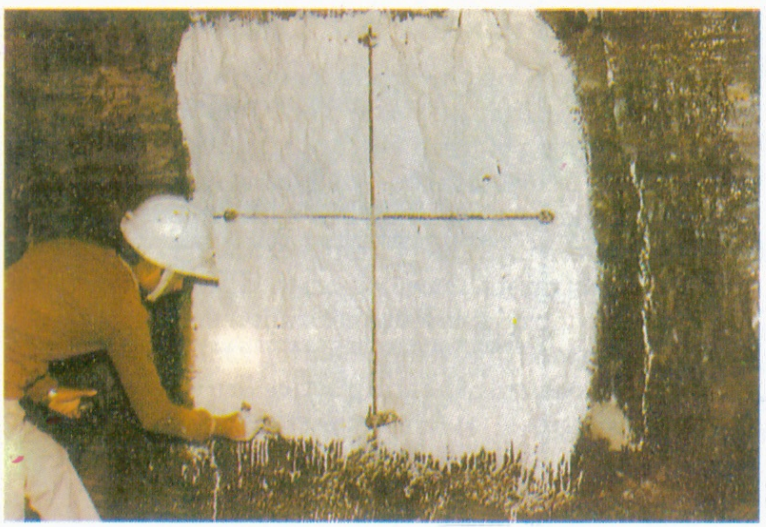
Sealants for Air Leakage

One of the main requirements of any efficient mine ventilation system is coursing of fresh air through specified paths to the work places with minimum leakage. Leakage of air cannot be entirely eliminated in a ventilation system because of practical constraints. Loose or crushed pillars can cause uncontrollable leakage of air. If such a situation happens to be near a heating zone, it will render the control of heating/active fire a very difficult task.

Table 7 : Friction factors for different types of mine openings

Type of openings	*Average values of friction factor (K) Kg s^2/m^4*
(i) Unsupported drivage in coal presenting smooth surface	0.00094
(ii) Unsupported drivage in coal presenting rough surface	0.00162
(iii) Unsupported drivage in coal presenting very rough surface	0.00293
(iv) Unsupported drivage in stone presenting smooth surface	0.00099
(v) Unsupported drivage in stone presenting rough surface	0.00184
(vi) Drivage in coal provided with belt conveyor and sparsely supported	0.00266
(vii) Drivage in coal supported with three piece timber set	0.00260
(viii) Drivage in coal supported with a single row of vertical props along centre line and cog at gallery junction	0.00385
(ix) Drivage in coal supported with horizontal steel beams	0.00187
(x) Drivage supported with steel arches	0.00263
(xi) Smooth concrete shaft with rigid guides and buntons	0.00700
(xii) Smooth concrete lined vertical shaft without any fittings	0.00069
(xiii) Unlined vertical shaft with normal fittings	0.00233
(xiv) Drivage in coal provided with belt conveyor and heavily supported	0.00505

Optimisation of various leakage sources could increase air supply to working districts by around 10 percent. Average leakage per stopping analyzed through the computer program developed for quantifying the leakage through various stoppings showed a variation of leakage quantity from 0.12 to 0.75 m^3/s depending on conditions. Field observations with the help of tracer gas SF_6 were also carried out. The variation of results through computer program STOPLEAK and field observation was found less than 2%, which was well within the norms of planning.



Sealant application on fractured coal pillar

Spraying machine - charging of sealant

In order to control air leakage through gate road stoppings, fractured coal pillars, etc, investigations were undertaken to develop a sealant composition, which could be quickly applied on the coal or rock surfaces by mechanical means, and once applied, would remain intact without peeling off or developing cracks over a period of time, thus making the coated surface impervious to air flow.

The R&D activities conducted mainly by CMRI have led to the development of two types of sealants, one mica based and other latex based. After successful laboratory trials, the efficacy of these sealants has been widely demonstrated at Madhuband colliery, BCCL, GDK-1 Incline, SCCL, Khas Kajora and Madhujore colliery, ECL. These sealants can be applied either manually with a brush or through a specially fabricated pump (Seela machine) and have already found wide application in the coal mining industry in combating mine fires and recovery of the areas. The mica based sealant is being marketed as "Thermoseal".

Methane Drainage

Methane (CH_4) or marsh gas is one of the most dangerous gases encountered in coal mines. The gas formed during the coalification process is given off during coal winning which continues even after initial development of the seam. It forms an explosive mixture with air.

The emission of methane gas is normally diluted wherever possible within safe limits by the circulating air current, but there are mines where methane emission is too large to be diluted for keeping within safe limits by normal mine ventilation. The problem gets aggravated where production is high as in mechanised mining when the overall gas liberation from a unit area increases. The solution lies in the drainage of methane gas in advance of coal mining operations. Sustained research efforts during the last decade in this direction have made it possible to achieve considerable advancement in the area of methane drainage technique.

Venturi Blower

In Kargali seam of Sawang Colliery, CCL, methane emission upto 10 m^3/min had been met, while crossing dykes or drilling boreholes.

Investigations carried out by CMPDI and CMRI led to the design, development, commissioning and successful operation of a gas drainage system using a venturi blower. Consequently, drivage of headings, abandoned for years due to large emission of inflammable gas, could be started. This expertise can be successfully applied under similar situations in other coal mines.

Gas Pump

A more critical problem prevailed at Amlabad Colliery, BCCL, a highly gassy mine with presence of contiguous seams, rendering underground operations hazardous. Methane drainage was found to be the only feasible method available. The R&D investigations carried out could define the permeability and extent of desorbable gas content of the coal leading to development of a scheme for pre-drainage of methane using a gas pump. A degasification plant was installed at the colliery.

Bio-Degasification

Another method, which is an emerging technology, of dealing with methane gas is by the use of bacteria which can be employed for absorption of methane. Laboratory investigations carried out at CMRI have led to isolation of Methanotrophs (a group of micro-organisms which oxidise methane) from soils of marshy land, mine sludge and mine water of gassy coal mines. These micro-organisms can be acclimatised to grow even in 100 percent methane atmosphere to make them suitable for injection in coal seams. They are found to grow in temperatures upto 45°C and withstand a pressure of even 30 to 35 kg/cm^2 but require near neutral pH water and nutrients like salts of ammonia, phosphorous, sulphur, iron, etc, which need to be replenished periodically.

Bio-degasification can be carried out through gravity migration of bacteria, where a rise side sump is used for growth of bacteria.

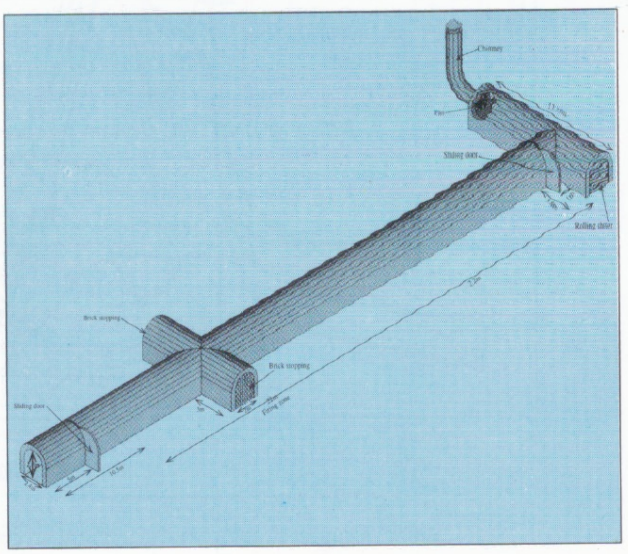
Its subsequent migration can be through fractures in the coal mass or by injection through boreholes under pressure.

These methods of bacterial degasification were successfully tried at Sawang Colliery, CCL, Bhatdee Colliery, BCCL, Amlabad Colliery, BCCL, and New Ghusick Colliery, ECL under an R&D project, and it was found possible to work highly gassy patches with complete safety.

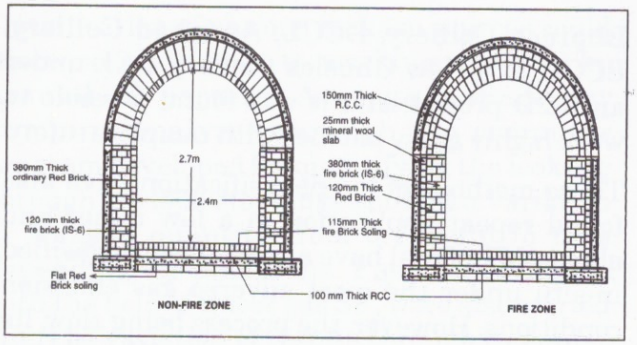
These methods of bio-degasification have also found repeat application in a few mines and about 2MT of coal have already been degasified in-situ under the most adverse gas emission conditions. However, the process being slow, its applicability is limited to small/ isolated patches, where other methods of degasification cannot be applied on cost consideration.

Mine Fire Gallery

Fire has long been recognized as a major hazard associated with coal mining as it poses an immediate life threat to underground personnel. It represents one of the two most common causes of major disasters in underground coal mining involving loss of precious lives, hindrance to coal production and sealing of entire mine or part of a mine for long periods. A study has recently been concluded at CMRI, Dhanbad for better understanding of the complex phenomenon of open fires and for working out suitable fire suppression techniques under various conditions. A full-scale mine fire model gallery of 65m length and having 5.8 sqm cross-section has been constructed at CMRI for simulation studies on open fires in underground galleries.



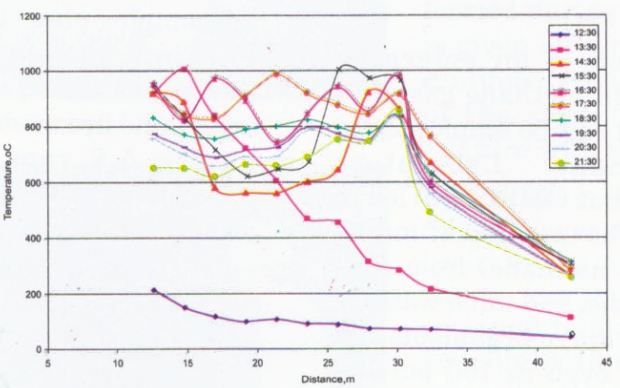
Isometric view of mine fire model gallery



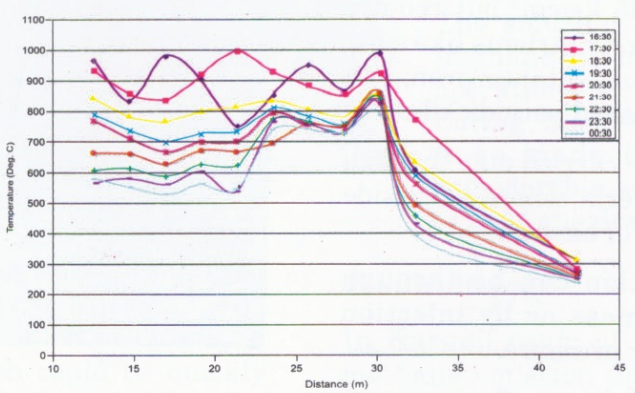
Sectional view of firing and non-firing zone

Experimentation in Model Fire Gallery

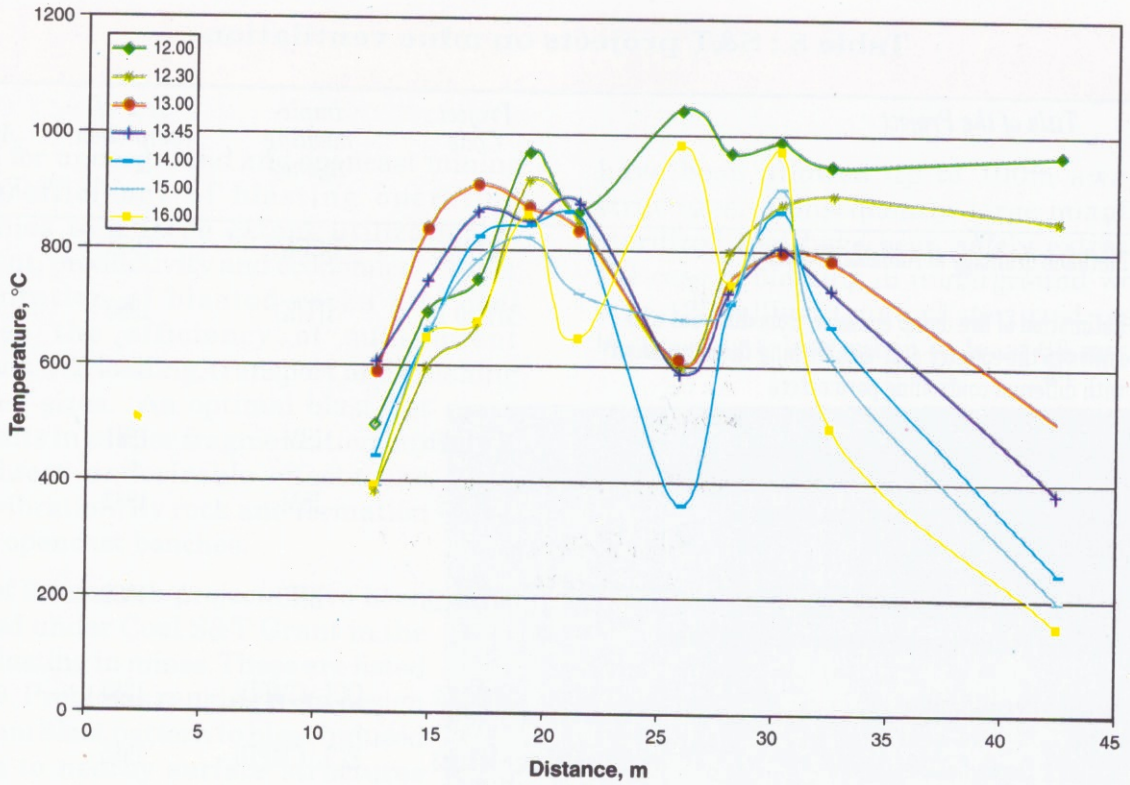
The gallery is equipped with an on-line monitoring system with 130 sensors and 2 data-loggers to monitor changes in the behaviour of fire in terms of temperature, pressure, gas concentration, heat flux, air velocity and smoke density during experimentation. In the gallery 3 sets of experiments with (i) liquid nitrogen (ii) nitrogen foam, and (iii) water mist were carried out under varied air velocities of 1.0, 1.5 and 2.0 m/sec. In each set of experiments about 18 to 20 tonne of coal was used. The study revealed that among the three techniques water mist can also be considered to have good potential in controlling fire economically.



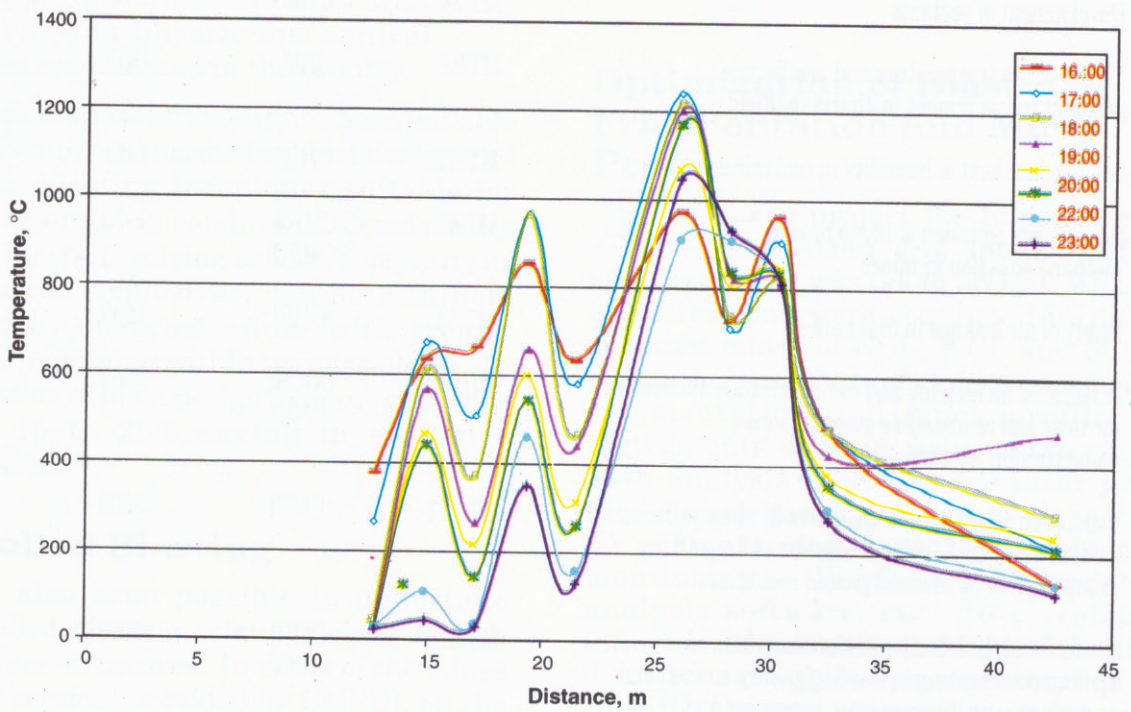
Effect of LN2 injection on temperature along the axis of the gallery in open condition of fire



Effect of LN2 injection on temperature in sealed condition of fire



Temperature distribution along the axis of the gallery before infusion of water mist



Temperature distribution along the axis of the gallery after infusion of water mist

Table 8 : S&T projects on mine ventilation

Sl. No.	Title of the Project	Project Code	Imple-menting Agency	Year of completion	Total Approved Cost (Rs. in lakh
1	Methane drainage at Amlabad Colliery	MT/2.1	BCCL\	1978	16.56
2	Estimation of fire damp emission from different coal mines in the country and establishing the correlation with different controlling parameters	MT/10.1b	IIT(K)	1980	1.55
3	Methane emission and control in mines	MT/10.3b	ISM	1981	2.60
4	Heat flow studies and problems of heat and humidity in coal mines	MT/8.2	ISM	1982	1.92
5	Study of parameters affecting flow of air in mines and developing measuring instruemnts	MT/10.2b	BHU	1982	1.00
6	Sawang Degasification	MT/2.2	CCL\CMPDI	1983	8.52
7	Ghusick Degasification	MT/2.3	ECL\CMPDI	1985	77.05
8	Determination of ventilation co-efficient	MT/16	CMRS\	1986	10.00
9	In-situ investigations into feasibility of bacterial oxidation of methane	MT/32	CMRS	1987	7.56
10	Development of sealants	MT/38	CMRS	1988	5.48
11	Virgin strata temperature and geothermic gradient measurement in Jharia coalfield	MT/48	ISM	1989	6.00
12	Studies into heat & humidity in coal mines	MT/45	CMRS	1991	20.40
13	Specific gas emission study to predict methane emission in mines	MT/65	CMRS\ CMPDI	1992	13.18
14	Study of air leakage in coal mines	MT/84	CMRI	1995	3.50
15	Integrated monitoring and communication system for toxic and combustible gases in mines using ceramic sensors	MT/102	CGCRI, CMRI	2002	42.83
16	Studies on simulation of open fires in mine galleries under varied air flow for seperation of fire and fire damp explosions in underground coal mines	MT/101	CMRI	2003	145.35
17	Study for early detection of the occurrence of spontaneous heating in blasting gallery method and to evaluate suitable measures to prevent and control spontaneous heating in thick coal seams	MT/118	CMRI/ SCCL	2003	26.32

Blasting in Mines

Both for underground and opencast mining the efficiency of blasting operation determines to a large extent utilization of equipment, productivity and economics. Proper fragmentation of blasted rocks and coal improves the efficiency of subsequent operations, viz. loading, transport and crushing to desired sizes. An optimal blast not only results in proper fragmentation but also reduces undesirable effects like ground vibration, fly rock and formation of toe in opencast benches.

A total of 9 research projects have been completed under Coal S&T Grant in the area of blasting in mines. These are listed in table 9. Problems ranging from design of optimum blast pattern to blast induced damages to nearby surface structures have been addressed by the projects. A large number of field investigations involving both normal production blasts and specially designed trial blasts have been carried out. The studies included various types of coal measure strata with widely varying physico-mechanical properties encountered in the country.

As a result of these studies it has been possible to derive empirical norms for blast design and introduce blasting techniques suitable for various geo-mining conditions. Consistently effective blasts, involving as high a quantity as 100 tonne of explosives, can be routinely executed by opencast mines with ground vibration remaining within permissible levels. Optimization of blast design in many cases has yielded 15 to 25% saving in explosive consumption.

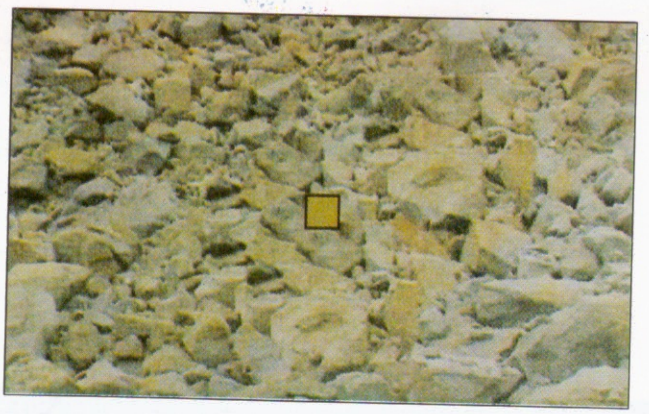
Controlled Blasting

It has also been possible to undertake controlled blasting safely as close as 10m from surface structures. In many of the mines technical services provided by CMPDI, on the basis of results obtained from S&T projects, have enabled relaxation in the statutory provision of maintaining 300m distance from surface structures. Regular production blasts have been allowed up to 100m away from structures. Consequently, large quantities of sterilized coal have been safely extracted. In the case of blasting in underground workings over 125 million tonne of sterilized coal have been safely taken out in at least 60 mines.

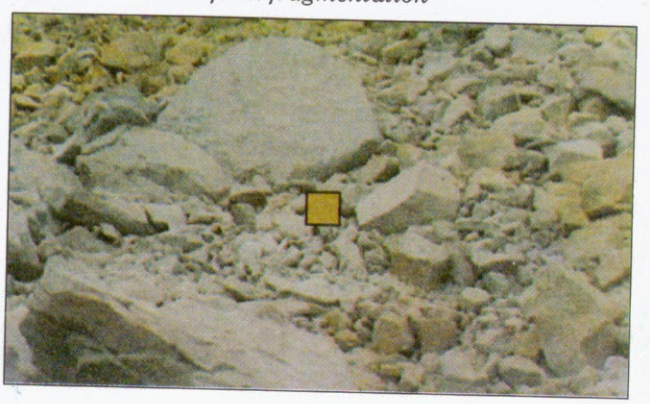
Blasting near surface structure

Optimization of Blast Fragmentation and Muck Profile

A research project for improving blast fragmentation and muck profile in opencast mines was taken up by CMRI. Field investigations were conducted in different opencast mines of NCL, WCL and SCCL for evaluating the effects of various parameters on fragmentation and muck profile. The instruments used in field monitoring and data analysis included 3-D laser profiler for rock muck profiling, close-circuit TV camera for machine performance monitoring, Wipfrag fragmentation analysis software, etc. To correlate the influence of parameters like burden-to-hole diameter ratio, hole spacing-to-burden ratio, specific charge, etc, on fragmentation, a mathematical model was developed for estimating mean optimum fragment size and muck profile applicable for Indian geo-mining conditions.



Uniform fragmentation



Less uniform fragmentation

By analysis of the performance of shovel and dumpers for different input values o specific charge and specific drilling along with resultant fragmentation, it was found that the optimum mean fragment size lies in a range o 8-10.5% of the bucket size of loading equipment. The permissible maximum boulder size recommended was 0.75 times the bucket size. It was also observed that fine particles smaller than 0.03 times the bucket size did not help in improving the bucket fill factor significantly. Similarly, based on the loading cycle time analysis for various muck profiles, it was concluded that optimum muck profile angle lies between 44 and 47 degree. Under this project an optimum blast design software, named VISFOT, and an indigenous image analysis software, named FRAGALYST, for assessment of rock fragmentation have been developed. The softwares allow blast design for different strata and mining conditions for improving overall productivity of blasting and loading operations in opencast coal mines.

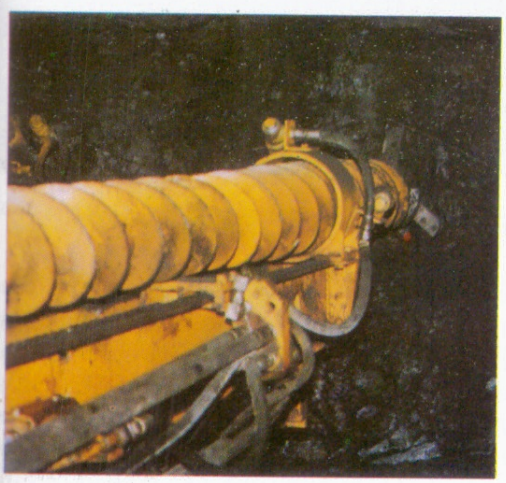
Table 9 : S&T projects on blasting

Sl. No.	*Title of the Project*	*Project Code*	*Imple-menting Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1	Optimisation of blasting parameters in coal mines	MT/24	CMPDI	1982	6.80
2	Wokability parameters of drilling and augering machines (including raise bores and road heading) in mines	MT/56	BHU	1990	8.63
3	Control of pollution due to toxic gases produced during blasting operation with explosives in U\G coal mines	MT/51	CMRS	1991	18.919
4	Investigation into thermal behaviour of explosives to assess their safety characteristics use in hot borehole conditions	MT/64	CMRS	1992	25.90
5	Techno-economic assessment of drilling and blasting parameters vis-a - vis establishment of cost effective optimum blast pattern for open cast mines.	MT/92	CMRI	1997	10.50
6	Evaluation of damages to underground coal mines caused by surface blasting vis-a-vis establishment of blast vibration threshold	MT/93	CMRI/CMPDI	2000	44.32
7	Evaluation of explosive performance through in the hole detonation velocity measurement	MT.96	NIRM/SCCL	2001	23.84
8	Development of innovative models for optimisation of blast fragmentation and muck profile applying image analysis technique and sub system analysis concept in Indian Surface Coal Mining regime	MT/103	CMRI	2001	42.2
9	Investigation to optimise blast design and charge loading parameters in coal and ring hole blasting and in stone for induced blasting in degree-I seams for blassting galling method in underground mines of the SCCL	MT/125	CMRI/SCCL	2004	38.30

Auger-Cum-Drill

Development of equipment required by the industry and suitable for Indian conditions were undertaken by a number of research projects under the Coal S&T Grant. The objectives of these projects were to develop such machinary which were not readily available in the market or to improve upon existing performance.

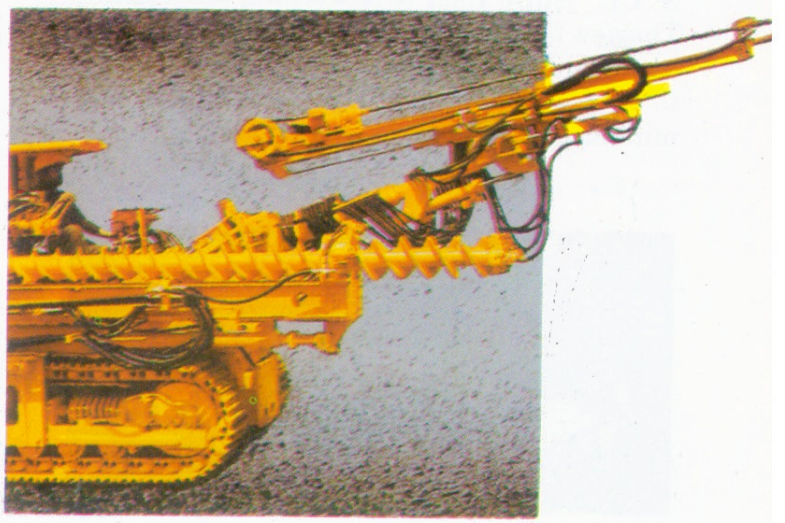
In the conventional bord and pillar underground mining, drivage of development headings requires creation of a "free face" to ensure safety and satisfactory blasting by explosives. Creation of a free face is presently avoided in a large number of mines due to the non-availability of coal cutting machines which are also slow in operation and difficult to transport from one coal face to another. These shortcomings led to the adoption of blasting-off-the-solid, which has its own inherent disadvantages, viz. poor fragmentation and high explosive cost apart from the likely damage to the immediate roof strata.



Two Photos: Auger-cum-drill at Coal face

To overcome these difficulties an auger-cum-drill machine was designed and a prototype was manufactured suitable for Indian conditions. Several important technical considerations involved in the development of the equipment were :

- providing a free face by auguring adequate size boreholes.
- ensuring directional drilling for better pull.
- effecting economy in manpower by mechanisation.



Auger-cum-drill

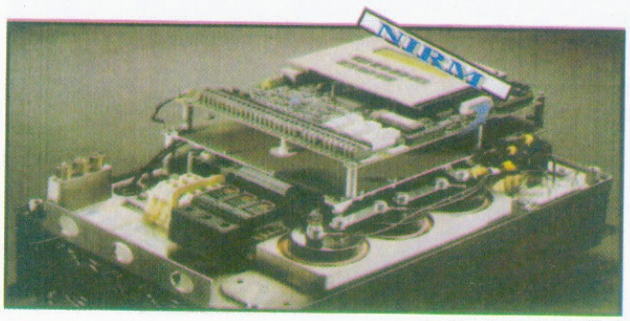
The prototype machine was extensively field tested at Churcha Colliery, SECL with promising performance. The results achieved were :

Average number of round/day	— 9 to 10
Maximum number of rounds/shift	— 6
Average production/blast	— 28 to 31 t
Powder factor	— 4.2 t/kg of explosive
Detonator factor	— 2.15

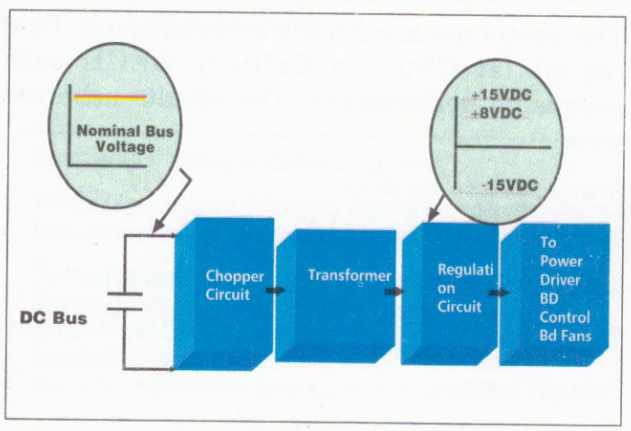
MBSC System for Mine Haulers

Mine haulers play a vital role in underground mining operations by providing necessary transport for coal and materials. Substantial power is consumed by these haulage machines. The conventional hauler works on non-linear resistance controls with brush gear three-phase slip induction motor. It requires frequent maintenance of various parts of the hauler and sometimes

replacement, besides high power consumption. The National Institute of Rock Mechanics has successfully developed an innovative technology to overcome these limitations of the conventional hauler. This new system called "Micro-Processor Based Solid State Control (MBSC)" works on variable frequency and is a linear controller. The system has successfully been interfaced with the conventional 40 HP hauler at GDK-9 Incline, SCCL. Since then it is working successfully. The new technology developed under the project has enabled saving of power consumption up to 40% with cost of spares and maintenance minimized.



Microprocessor based solid state control (MBSC) system

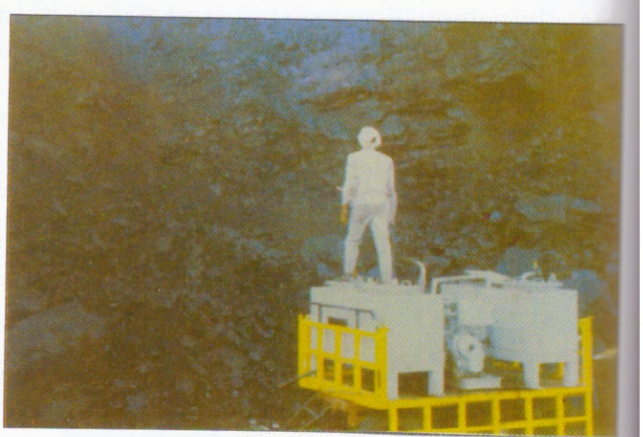


Schematic diagram of MBSC

Mechanized Spraying System

Acute problems of fire have been encountered in opencast benches in several mines. Fire starts in opencast benches due to coal quality (low rank), low crossing-point temperature and ignition-point temperature, low incubation period, long exposure of coal benches to the open atmosphere and presence of micro and macro cracks in the bench walls providing air entry into the coal mass. Though protective coating materials are available, the lack of suitable spraying machines to cover about 20m high benches restricted application of such materials in large opencast mines to prevent spontaneous combustion.

A mechanized spraying system was developed by CMRI under Coal S&T Grant to spray fire protective coating material up to 20 m height of coal benches. The system comprises a storage vessel for storing the material and water, which is connected to a diesel operated engine driving the equipment through which the fire protective coating is delivered to the spraying device. The whole system is mounted on a trolley. The system delivers fire protective material at the rate of 40 l /min.



Spraying of fire protective coating at 20m height of coal bench

Field trials with the system were conduced in Jhingurdah Opencast Mine, NCL. The exposed Jhingurdah top seam benches of 19m height were covered by fire protective coating material fully and after the lapse of incubation period (five weeks) temperature was measured and no indication of temperature rise was found in the coated zone. Temperature of the coated zone was around the ambient level.

The developed system can effectively be applied for spraying of fire protective material in the freshly exposed coal benches of opencast mines, coal stacks etc.

MINE FIRE

Coal mine fires and resultant loss and hazards are problems being faced by the coal industry for over a century. Jharia coalfield which is the store house of prime coking coal in India, has severely been affected by fires. The first mine fire was reported in this coalfield in 1916. Over the years, the number of such fires has increased to an alarming 70 odd locations covering a cumulative area of 17 km^2. It is estimated that nearly 50 million tonnes of good quality coking coal have been lost and about 200 million tonnes of coal are locked up due to fires. Besides, the mine fires also continuously pollute the environment by releasing large volumes of carbon monoxide and sulphur dioxide gases. Hence, precise mapping as well as monitoring of fires are pre-requisites for effective implementation of an action plan for fire fighting operations.

Thermal Infrared Remote Sensing for Mine Fire Mapping

The conventional methods of ground/underground thermometric survey have limitations due to both technological and accessibility constraints. In view of these problems a research study was taken up by CMPDI in collaboration with NRSA, Dept. of Space, Govt. of India, in which a successful attempt was made to develop a methodology for thermal studies of coal mine fires using comprehensive remote sensing supplemented

Effect of mine fire on land & property

by geophysical methods. Daedalus 1268 airborne multispectral scanner was used to acquire both pre-dawn and day-time thermal data of the project area.

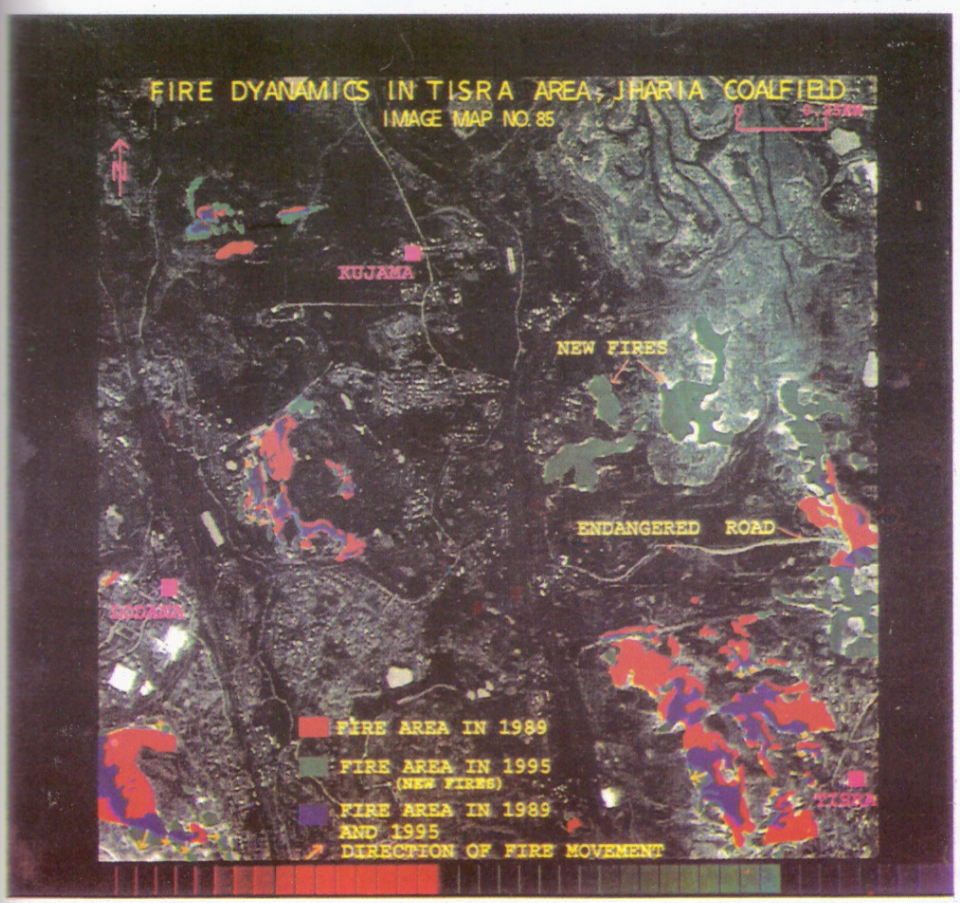
The integrated study, encompassing uses of airborne thermal infra-red scanning, ground thermometric and surface magnetic surveys, was carried out on a pilot scale over a part of Jharia coalfield covering about 30 km^2 Mukunda opencast project area. The methodology has proved to be an effective tool in rapidly acquiring information on the location and intensity of thermal anomalies caused by fires in coal mines. The high resolution scanner data (of the order of 1.2m x 1.2m) have facilitated preparation of black and white thermal IR imageries as well as pseudo colour images, temperature contour maps and 3-D plots of surface temperature distribution. The optimal designing of the technique for mapping coal mine fires was re-examined and validated with ground truth by a repeat fight coverage later.

During the study, a unique versatile software 'GEOSCAN' was developed for airborne scanner data rectification.

Fire Control

The very process of underground coal mining creates conditions which are conducive to self-oxidation of coal. This self-oxidation in turn may result in heating or even fires under certain conditions. The occurrence of fire, therefore, cannot be totally ruled out in coal mining operations, but its possibility can be minimized and controlled.

Though over the years a number of technologies have been developed to control mine fires, a large number of fires continue with varying intensity, posing a challenge to the mining community. While more conventional methods like digging, trenching, blanketing, isolating, flooding, etc, have been tried to control and combat mine fires, the use of inert gases to render the fire deficient in oxygen remained largely unutilized. Research projects were, therefore, undertaken to study the methodology to produce and inject inert gas in fire areas and determine its effectiveness.



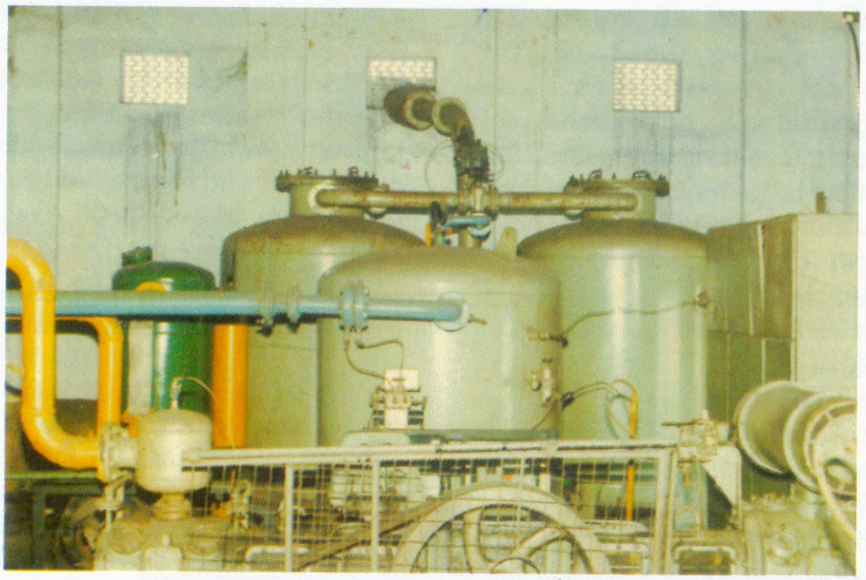
Change detection image, showing mine fire dynamics

Carbon Dioxide/Inert Gas Infusion

The first trial of CO_2 infusion at Sudamdih Colliery, BCCL helped in combating the fire with a minimum risk of methane explosion and thus proved effective. This was followed by another trial at South Tisra Colliery, BCCL which helped in controlling the fire at the mine. In order to overcome the problem of procurement and transport of CO_2, an inert gas generating plant using kerosene/diesel as feedstock was installed at Laikdih Deep Colliery,

BCCL, which demonstrated the efficacy of inert gas (CO_2 + N2) infusion, and could prevent the fire reaching the main transport roadway and save the mine. A coal based inert gas plant utilizing fluidized bed combustion process (500Nm^3/hr) has also been installed and tested at CFRI, Dhanbad.

be transported over long distances. In addition, the transport of liquid nitrogen requires special containers made of cryogenic material. To overcome this constraint, a small nitrogen producing pit head plant (500Nm^3/hr) was commissioned at Lodna Colliery, BCCL. The plant based on the "Pressure Swing Adsorption"



Nitrogen infusion plant at Lodna, BCCL

Experimental set-up for generating foam

Foam generation and movement

Nitrogen infusion can also be used for making the atmosphere inert in the fire area. This gas also does not have any detrimental physiological effects. However, the required quantity of nitrogen gas for the purpose has to

technology uses carbon molecular sieves for separating nitrogen from the atmosphere. It has been possible to produce nitrogen gas with consistently high purity of over 99%. The effect of nitrogen infusion on arresting spread of underground fire was successfully demonstrated at Lodna fire area, BCCL

Development of foam has been yet another step in the process of underground fire fighting. Sustained R&D efforts have led to the development of appropriate foam composition,

methodology of generating foam, application and demonstration in mines. The composition of foam found effective on the basis of large scale investigations is a solution of 0.2% ammonium sulphate along with required amounts of booster and stabilizer. The solution when sprayed on a net at a pressure of 4 to 5 kg/cm^2 produces foam of required stability, which can be moved by air currents of 40 to 100 m/min. The system of foam generation and application is simple and may help in providing an approach to a fire area.

Table 11 : S&T projects on mine fire

Sl. No.	*Title of the Project*	*Project Code*	*Implementing Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1	Chemical eradication of green growth	MT/20	ECL	1979	0.60
2	Application of CO_2 in combating mine fires	MT/9.6	CMRS	1981	5.30
3	Coal stack heating	MT/22	CMPDI	1982	4.25
4	Thermal infrared imager	CE/16	CMPDI	1982	1.00
5	Study of spontaneous heating of coal	MT/23	CMPDI	1985	4.65
6	Development of fire extinguishing foam including application technology for use in mines and allied industries	MT/42	CMRS	1987	3.00
7	Nitrogen infusion	MT/26	CMPDI	1988	43.00
8	Assessment of status and control of u/g coal mine fires	MT/46	CMRS	1990	27.23
9	Development of suitable fire protective coating for preventing sponteneous combustion in the benches of open cast / underground mines vis-a-vis consolidation of dust.	MT/83	CMRI	1996	7.00
10	Development of a mechanised spraying system for spraying the fire protective coating material for industrial application in the coal benches of large opencast projects	MT/100	CMRI	1999	5.27
11	Handy method of coal categorisation and prediction of spontaneous risks in mines	MT/90	CMRI/CFRI/ ISM	1999	28.06

Coal Beneficiation

Beneficiated Non-Coking Coal for Power Generation

With depletion in availability of good quality power coal and large scale mechanized opencast mining, the ash content in raw coal supplies to power sector has increased over the years. The thermal power industry in the country has tackled to some extent the problem of high ash inputs by designing boilers that can burn such coals, but high cost of transportation and requirement of large area for dumping of ash could not be avoided. Beneficiation of coal helps in not only improving performance of power plants but reduces transportation cost besides bringing down the adverse effects on the environment. A research and demonstration project was undertaken for a commercial trial of using beneficiated non-coking coal from Nandan Washery, WCL, for a period of one month at the Satpura Thermal Power Plant of Madhya Pradesh State Electricitey Board. The demonstration was undertaken jointly by CMPDI, WCL, MPEB and NPC. The demonstration brought out highly encouraging results, amongst which were :

* Improvement in plant utilization factor from 73 to 96%,
* Improvement in generation from 3.71 MU/day to 4.83 MU/day
* Reduction in coal consumption from 0.77 kg/kWh to 0.553 kg/kWh
* Elimination of support fuel oil from 5 ml per unit generated to nil,
* Savings in operation of coal mills from 5 units to 4 units,
* Savings in operation of coal mill rejects from 0.35 to 0.031%,
* Reduction in smoke and dust emission from 29.78 gm/m^3 to 17.23 gm/m^3 at ESP inlet and from 1.375 gm/m^3 to 0.299 gm/m^3 at ESP outlet,
* No furnace wall slagging, boiler tube leakage, clinker formation and abnormal erosion,
* Reduction in alpha quartz from 14.5 to 11%.

Based on the encouraging results of the trial run at Satpura TPS a coal beneficiation plant at Piparwar mine of CCL was commissioned in 1997, which is supplying beneficiated non-coking coal to NTPC power station at Yamuna Nagar, Haryana and Dadri, UP. Another coal preparation plant for beneficiating non-coking coal at Bina, NCL, has also been commissioned. Installation of several more such plants is underway.

Ministry of Environment and Forests, Govt. of India has made it mandatory through a gazette notification that power stations located beyond 1000 km and in critical, sensitive and urban areas will have to use washed coal with ash not exceeding 34%.

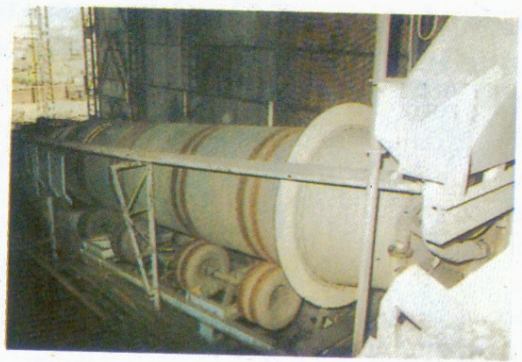
Fine Coal Beneficiation

Mechanized mining operations have brought about substantial changes in ROM coal quality such as increased percentages of dirt, coal fines and moisture, which eventually add to the problems of coal beneficiation. The fine coal circuits in coal washeries are intricate, needing close attention and careful operation. Increase in fines in raw coal feed to washeries also adversely affects the material balance in fine coal circuits of the currently operating plants creating operational problems, e.g. jamming of thickeners, which may result in complete shut down of the plants for several days. Frequent bleeding of the thickeners thus becomes essential. Recirculation of fine laden thickener overflow creates further problems in the processing circuit.

In Indian coal washeries the fine coal circuits are the least effiçient ones, resulting in substantial loss of fine coals along with effluents and eventually leads to pollution of the nearby waterways. This problem of additional fines in

generated coal slurry as the media requires less capital and operating cost and low power consumption.

The process consists of beneficiation of raw coal (< 50 mm) in barrel washer with self generated slurry as media or separator. The barrel floats are crushed and beneficiated by a set of cyclones.



Barrel washer

Pilot plant. incorporating barrel washer

Based on this technology, a 120 TPD modular washery was installed at Lodna, BCCL. Though there were teething troubles during the commissioning stage, sustained R&D efforts involving certain modifications, led to successful commissioning and operation of the barrel washer. The typical results of plant operation are as follows :

Samples	*Wt%*	*Ash%*	*Moisture%*
Raw coal	100.0	27.7	3.00
Clean coal	33.3	17.6	9.45
Middlings	41.2	28.0	7.16
Rejects	18.9	44.8	—
Slurry	6.6	—	—

The major advantages of this process are :

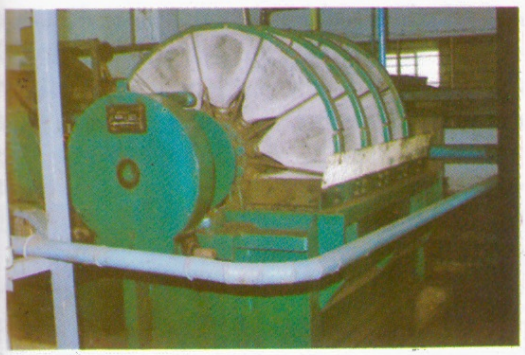
- ★ Low capital investment and operati cost
- ★ No external media (i.e. magnetite, e required
- ★ Simplicity of design with on-li adjustment facility
- ★ Easy to operate and control
- ★ Low power consumption, low spa requirement
- ★ Les operating and maintenance staff
- ★ Low gestation period
- ★ Flexibility due to modular structure
- ★ High utilization factor

Because of low capital cost and low operatin cost four more plants at Dhanbad, Damoa Kaimur and West Bokaro starte employing this technology fo beneficiation/deshaling of coal.

Simulation of Different Dewatering Systems

Coal washing in India started i the 1950s with the objective o supplying coking coal of require quality to the steel sector. Due t depletion of good quality coking coal washery feed coal now require crushing to smaller sizes fo liberation of coal particles from overall coal matrix. This results i generation of large quantity of fines with deterioration in quality. These coal fines are required to be beneficiated for maintaining the overall quality of clean coal.

Appropriate selection of cost effective and efficient dewatering system is essential for maximizing the recovery of fine coal with minimum possible moisture content in the dewatered products along with protection of the environment. Considering its importance, dewatering of fine coal was identified as one of the thrust areas for research in coal beneficiation.



Disc filter

Screen bowl centrifuge

For judicious selection of a cost effective and efficient dewatering system a pilot plant consisting of the following dewatering systems with state-of-the-technology was installed at Rajrappa Washery to facilitate techno-economic studies on different dewatering systems,

(i) Disc filter

(ii) Drum filter

(iii) Screen bowl centrifuge

(iv) Horizontal traveling vacuum belt filter

(v) Solid bowl centrifuge

(vi) Filter press

The Pilot Plant was commissioned in 1995. The investigations were jointly conducted by CMPDI and CCL with flotation concentrate and tailings to find out the capability of each dewatering system in respect of recovery, moisture content in the dewatered product and clarity of effluents. The findings of the study are summarized in table 12.

Table 12 : Performance of dewatering systems

Sl. No.	Name of equipment	Type of slurry	Recovery of product (dewate-ring)%	Total moisture in the product %	Turbidity of effluent (Avg.) gpl
1.	Solid bowl centrifuge	Flotation tailings	99.65	22.42	1.67
2.	Disc filter	Flotation concen-trate	99.84	19.07	0.85
3.	Drum filter	Flotation concen-trate	98.00	25.05	9.30
4.	Filter press	Flotation tailings	99.90	28.80	0.25
5.	Screen bowl centrifuge	Flotation concen-trate	97.50	14.30	6.00
6.	Horizontal travelling vacuum belt filter	Flotation	96.50	25.90	13.30

On the basis of the test results it was concluded that screen bowl centrifuge was best suited for dewatering of the flotation concentrate and solid bowl centrifuge for dewatering of flotation tailings.

Solid bowl centrifuge

The pilot plant can be utilized for testing various coals and generation of data for selection of cost-effective fine coal dewatering system for other coal preparation plants to maximise the recovery of fine coal and to meet the stringent requirement of quality in respect of moisture content of washed coal and to prevent water pollution in the neighbourhood of washeries.

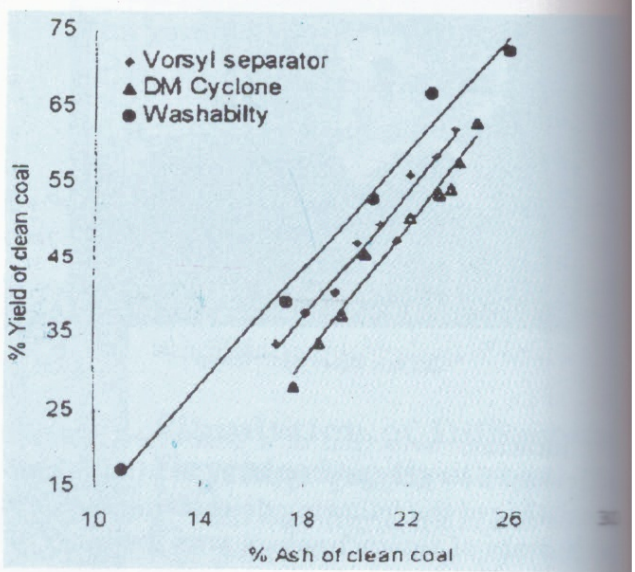
Spiral Concentrator and Slurry Jig

A research project was undertaken by CMPDI in association with CCL to optimize the recovery of clean coal by use of slurry jig and spiral concentrator. A pilot plant with slurry jig and spiral concentrator was installed at Rajrappa Washery. At the washery –16mm coal was treated in small coal Batac Jig after de-sliming at 0.5 mm and -0.5mm coal was treated in a froth flotation plant. Under the scheme, coal of - 16 mm size from the under-flow chute of USK (unbalanced weights circular motion screen) screen was tapped and fed on to a 50mm belt conveyor for discharge to a vibrating screen of 3mm aperture. The underflow of the screen was collected in a sump in the form of slurry and transferred to the pilot plant for further treatment in spiral and slurry jig. Ultra-fine coal below 0.1mm size was removed by a 250mm hydro-cyclone and 3 to 0.1mm size coal slurry was fed to a spiral concentrator and slurry jig alternately.

It was observed that 1 to 0.1mm feed yielded better results with both the systems. Spiral concentrator was found to have an edge over slurry jig both in quality and quantity of clean coal. Moreover, slurry jig is costlier and needs sophisticated control mechanism to operate effectively. In addition to this, the spiral concentrator demonstrated several other benefits such as: (i) low capital cost, (ii) low energy consumption, (iii) low operating and maintenance cost and (iv) additional recovery of coal.

Vorsyl Separator

A prototype of Vorsyl separator of 500 mm diameter with a couple of vortex finders and spigots was designed and fabricated for plant level trial under a research project taken up by RRL, Bhopal. Laboratory studies on 76 mm Vorsyl separator and Dense Medium [DM] cyclone had earlier been carried out with encouraging results for Dugda coal samples of size –2 + 0.5 mm. Plant trials on a 500 mm Vorsyl separator installed parallel to the existing DM cyclone in D circuit of Dugda coal washery were thereafter conducted by varying vortex finder and spigot diameters. The tests were conducted at three levels of vortex finder and three levels of spigot diameters of the separator.



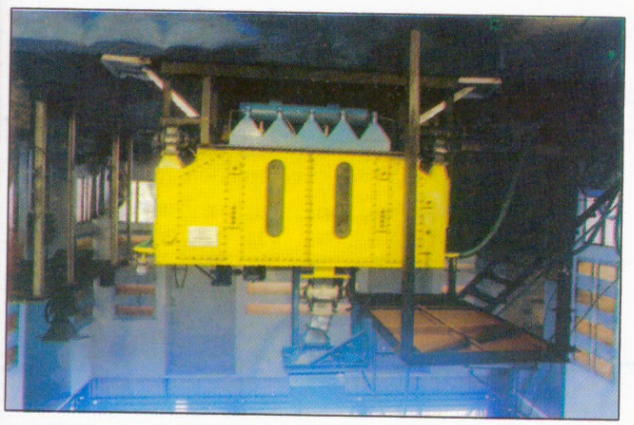
Performance of 76 mm Vorsyl Separator and DM Cyclone

It was observed that performance of the Vorsyl separator was superior to that of DM cyclone and was able to produce about 3.5 to 5% more yield at the same ash levels. The generalized probable error for Vorsyl separator was found to be low both in laboratory (Epg 0.046) and plant (Epg 0.026) units, which revealed that better sharpness of separation could be achieved employing a Vorsyl separator.

Dry Beneficiation of High Ash Non-Coking Coal

Beneficiation of high ash non-coking coals has been a subject of concern in recent years and the Ministry of Environment and Forests (MoEF) has also issued guidelines restricting transport of coals having more than 34% ash beyond 1000 km from pit-heads. One

of the S&T projects involving coal beneficiation, completed in 2003 by RRL, Bhubaneswar, had the objective of employing an air dense medium fluidized bed separator for reducing the ash content of high-ash coals.

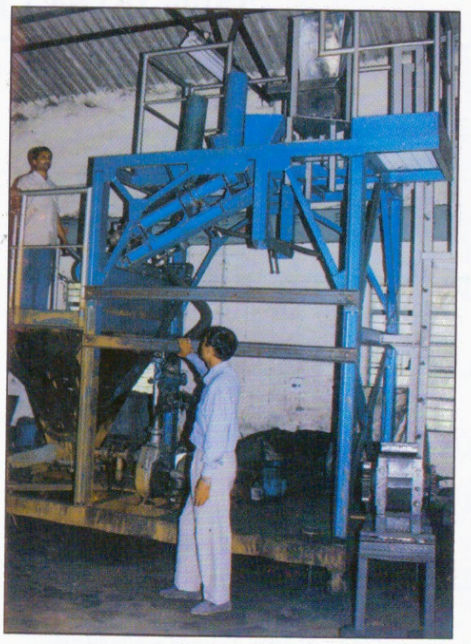


Air dense media fluidized bed separator

In pneumatic dense medium separators, a medium is created by suspending solid particles in an upward air flow. By means of two gas-solid phases with pseudo-fluid as beneficiation medium, the light and heavy materials stratify in the fluidized bed according to density. The dynamic stability of the medium plays an important role in the sharpness of the separation and the system can be made to operate under particulate fluidization. Laboratory models of different geometries were used for these studies, where magnetic powder below 45 micron size was fluidized by compressed air at different airflow rates to create the dense medium. Based on this basic study, a laboratory model of dense medium fluidized bed separator with capacity of 600 kg/hr was designed and fabricated to carry out continuous study of the system. Trial runs were made with different process variables. The ash percentage could be reduced from 40% to 30% with 70% yield. It is expected that the study will be followed by pilot plant scale trials.

Tri-flo Separator

One of the other projects showing promising results for beneficiation of Indian coals involves application of Tri-flo separator. The basic design of a Tri-flo separator offers great potential for treating Indian coals with high near-gravity materials compared to other unit operations because in one pass a two stage separation is possible with high sharpness of separation. Therefore, a systematic study has been conducted at RRL, Bhopal to evaluate the effect of various operating and process variables on sharpness of separation of different Indian coals in a Tri-flo separator. The test results have indicated the possibilities of producing clean coals with high efficiency.



Tri-flo separator test ring

Kelsey Jig

For treating fine coals a recently concluded S&T project has shown good potential for future application. Kelsey Jig, originally developed for recovery of fine particles of gold has been examined under this project by RRL, Bhopal, for processing coal fines. Kelsey Jig

Kelsey jig

operates on the principle of jigging in a centrifugal force field which ultimately helps in processing fine particles. The project has demonstrated its suitability to process Indian coal fines. This environment-friendly gravity concentrator may form an important unit in Indian coal preparation plants.

Table 13 : S&T projects on coal beneficiation

Sl. No.	*Title of the Project*	*Project Code*	*Implementing Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1	Development of computer programme for simulation of coal beneficiation processes	CP/8	IIT(K)	1983	2.20
2	Utilisation of rejects of coal washeries and beneficiation plants	CP/5	CMPDI/ Roorkee	1985	2.50
3	Installation of 5 TPH Batac Jig at Patherdih washery	CP/2	CMPDI	1985	61.50
4	Flocculation of coal fines and clarification of washery water	CP/10	ISM	1986	8.00
5	Development of a process of coal preparation eliminating slurry handling and its beneficiation	CP/14	CMPDI	1986	10.364
6	Studies on beneficiation characteristic of non-coking coal from Talcher coalfield viz. reduction of ash content and alpha quartz	CP/21	CMPDI	1986	1.00
7	2 TPH oil agglomeration plant at Lodna	CP/1	BCCL/	1986	34.18
8	Testing of coal samples at photometric ore sorter in Canada	CP/11	CMPDI	1986	2.48
9	Development of an effective frother systems for the recovery of fine coal by flotation	CP/23	RRL, Bhopal	1988	4.93
10	Trial of beneficiated non-coking coal from Nandan Washery at Satpura Thermal Power Station	CP/19	CMPDI	1988	476.00
11	Response to beneficiation of low grade coking coal at finer sizes	CP/22	RRL, Bhopal	1989	5.25
12	20 TPH eleo flotation, pilot plant for beneficiation of fine coal	CP/24	CMPDI	1989	10.00
13	Non destructive rapid estimation of ash by nuclear technique	CE/17	CMPDI	1989	2.70
14	Modernisation of crushing circuits to maximise the yield of clean coal	CP/20	ISM	1990	11.074
15	Pilot plant to simulate different dewatering system at Rajrappa Washery	CP/18	CMPDI	1992	56.00
16	Installation of 120 TPH modular washery	CP/15	CMPDI	1992	340.00
17	10TPH Oil agglomeration pilot plant at Patherdih Coal Washery, BCCL	CP/7	CMPDI	1993	72.84

18	Modelling and scale up studies on water only cyclones treating coal.	CP/25	ISM / RRL, Bhopal	1996	11.00
19	Performance evaluation of air-sparged hydrocylone to clean Indian Coal Fines	CP/27	RRL, Bhopal	1997	10.30
20	Application of GCV method for classification of non-coking coal	CP/29	CFRI	1998	5.80
21	Development of viable techno-economic know-how for beneficiation of non-coking coal for power generation	CP/26	CFRI	1999	24.00
22	Industrial application of vorsyl separator in BCCL/CCL Coal washeries	CP/28	RRL , Bhopal	1999	4.2
23	Introduction of automation system in the Coal Preparation plant at Swang Washery	CP/16	CMPDI	1999	334.102
24	Installation of 1 M dia column flotation pilot plant at Sudamdih Washery	CP/12	CMPDI	2000	41.35
25	10 Tph Slurry Jig Spiral Concentrator Pilot Plant at Rajrappa Washery CCL	CP/13& CP/17	CMPDI	2001	207.48
26	Deminerlisation of North Eastern Coal using chemical dispersants	CP/30	RRL, Jorhat	2002	11.55
27	Performance evaluation of Tri-flo separator	CP/31	RRL, Bhopal	2002	28.36
28	Beneficiation of non-coking coal by dry methods	CP/34	RRL Bhubaneswar / CMPDI	2002	15.00
29	Development of operator friendly simulation package for coal preparation plant	CP/35	ISM/CMPDI	2002	15.95
30	Dry Beneficiation of high ash non-coking coal using air dense medium fludised bed separator	CP/36	RRL Bhubaneswar / CMPDI	2004	17.00
31	Study on Kelsey centrifugal jig for treating coal fines	CP/37	RRL Bhopal / CMPDI	2004	12.80

Special Smokeless Fuel (SSF)

The use of coal as a clean and efficient domestic fuel required R&D efforts by the coal industry and a number of research projects were initiated soon after the start of Coal S&T Grant.

One of the projects led to the development of mechanized domestic coke process for manufacture of Special Smokeless Fuel (SSF) and Coal Agglomerate.

The projects had the objective of establishing a substitute for the primitive method of soft coke manufacture (open *bhatta*) which causes serious air pollution apart from loss of valuable by-products.

After reviewing various technologies for conversion of coal to domestic coke, the concept of processing of coal (low grade, low volatile with caking index in the range of 8 to 12) in shallow bed continuous de-volatiser with an internally heated system was considered to be the most suitable and a scheme based on this process was conceptualised by CMPDI for mechanised conversion of low grade coking coal to domestic coke with a view to :

— obtaining a consistent quality coke,

— obtaining valuable by-product in the form of tar,

— minimising air pollution.

The scheme was executed by CMPDI in collaboration with a company at Dhanbad. A pilot plant consisting of four retorts of different capacities, i.e. 6, 13, 15 and 30 tonne per day, using sized low grade coking coal 30 to 100mm was set up at Mugma, ECL. The plant retorts exceeded their rated capacity during trials. The coke yield was found to be around 80% and tar yield 1 to 2%, depending on the volatile matter of coal. The residence time of coal for conversion to coke within the retorts was generally about one hour.

SSF Plant

Retorts in operation

On continuous operation of the plant all the four retorts gave an optimum output of products (coke and tar) with about 25% recycling of product gas, and the quality of the products was found to be satisfactory. The process was thereafter patented. Following the successful demonstration of the process at Mugma there was repeated response from entrepreneurs for commercial use of the technology. About 65 SSF plants were successfully commissioned by CMPDI in different parts of the country.

Coal Agglomerate

R&D efforts were made with a view to finding a gainful outlet for low grade, low rank slack coal and for providing much needed domestic fuel.

Coal agglomerate is a spherical shaped fuel, made out of slack coals with a suitable binder and which can be conveniently used in conventional domestic *chullah*. Coals crushed to desired fineness and mixed with required quantity of binder is agglomerated in a pelletiser. The pellets/agglomerates in green condition are soft but attain reasonable physical strength on drying. These are easily ignitable compared to parent coal and have better heat release rate. Strength of the pellets for coping with handling and transportation can be varied by changing the quantity and type of binder. The agglomerates basically constitutes a low cost fuel for use in areas near the production centre. The concept has been tried on a pilot plant scale by setting up a 50 TPD plant at Chitra Colliery of ECL. The advantages of the technology may be summarized as follows :

- The process can utilise any rank and size of coal. This widens availability of the resource base for domestic fuel production.
- The technology can be adopted on a small scale with economic viability. For small capacity plants, the only mechanical equipment required are fine coal crusher and pelletiser. Most of the other jobs may be done manually.
- Even uncarbonised pellets give a bright fire after initial smoke and unburnt portion is negligible due to higher porosity of the agglomerates.
- Such fuels can cater to the demands of lower income group.
- There is no pollution effect from the agglomeration plant. But, users of the fuel may have to tolerate some initial smoke during ignition of the fuel bed.

The process has been covered under a patent.

Coal Gas

A few coal based gas plants are being operated in other countries for commercial generation of electricity. These coal gas plants require sized coal having ash within 30%, which is not abundantly available in our country.

A research project was taken up by Indian Institute of Chemical Technology (IICT), Hyderabad to set up a small gasification plant (4 TPD coal throughput capacity) based on fluidised bed gasificiation technology for producing fuel gas for replacement of fuel/ furnace oil in small industries. This technology is capable of accommodating coal of lower quality in slack fraction, the availability of which is not a problem.

Ash discharge arrangement fluidised Bed Gasifier

The gasifier was installed at IICT, Hyderabad and extensive trial runs conducted to perfect the system. The plant attained the stage of smooth and trouble free operation and the technology is ready for commercial application. The gas produced can also be burnt in hot condition.

Basic designs for units of various capacities ranging from 1 to 5 TPD coal throughput for preparation of detailed design package for such small units have also been prepared. These basic design packages are now available for consumers and may serve the purpose of replacement of furnace oil with coal based gas using lower grade coal.

Coal gasification pilot plant

In view of the inherent merits of integrated gasification combined cycle (IGCC) system over conventional system of power generation, active consideration is being given on introduction of IGCC system in this country for quite sometime. Two R&D projects in this area were taken up under coal S&T programme. In the first project various gasification techniques were assessed keeping in view the availability of coal from North Karanpura area. All the foreign technologies were assessed on the basis of coal quality parameters and it was decided to carry out R&D investigations on moving bed process (indegenously available) with North Karanpura coal. Thereafter, the second project was taken up for conducting investigation through a 24 TPD moving bed gasification set-up at IICT, Hyderabad and 150 TPD demonstration plant at BHEL, Trichy.

Moving bed process coal gasification plant

The feasibility of indigenous design, installation and operation of high pressure moving bed gasification plant using high ash Indian coals has been established through trial runs conducted at IICT and BHEL with air- steam and oxygen-steam modes. The trials brought out strong possibility of scale up of such plants. Typical operating data collected from the plant on gasification of North Karanpura coal are given in table 14.

Table 14 : Operating data for moving bed gasification plant

Item	*Parameter*	*Air-steam (10 bar)*	*Oxygen-steam (23 bar)*
Coal	Flow, kg/h	416.3	897.6
Crude gas	Pressure, kg/cm^2	10	23
	Flow, Nw^3/h	896.0	1223.0
	Calorific Value, kcal/Nm^3	1412.0	2648.0
H.P. Steam	Pressure, kg/cm^2	30.8	29.8
	Temp.°C	241	385
	Flow, kg/h	199.2	914.6
Oxygen or Air	Pressure, kg/cm2	12.6	914.6
	Temp.°C	27	40
	Flow, Nw^2/h	512.0	169.1

Use of oxygen results in higher calorific value of gas, reduced loss of combustibles in the ash and consequent high carbon conversion, reduced volume of gases to be handled and reduced size of equipment.

Based on the successful trials IGCC has been considered a viable power generation option for high ash Indian coals. Among the other gasification technologies considered for adoption in India, KRW or similar fluidised bed technologies have been found useful for high ash coals. Moving bed process has also been found acceptable in view of availability of indigeneous capability.

Production of Bio-fertilizer Using Lignite as Carrier Material

A pilot plant of 100 TPD capacity was established and about 21 tonnes of biofertilizer strains such as Rhizobium, Azospirillum, Azotobacter Phosphobacter were produced. The produced strains were tested in the lab and by pot culture and through field crops. Field experiments were organised in about 2 acres of land in back filled areas of minespoil at Mine-I and Mine-II of Neyveli Lignite Corporation.

The findings of the study conclusively established the scope of reclamation of backfilled areas with biofertilizer inputs, which is a low cost and eco-friendly technology based on biological nitrogen fixation and phosphate solubilisation. The findings, therefore, assume significance in view of their scope for application in reclamation of back filled areas of opencast mines in India.

Grading of Indian Coals

Coals of different ranks vary in chemical composition, namely those of lower rank contain relatively lower carbon but higher oxygen, whereas for higher rank it is the reverse. Thus, even if two coals have the same amount of mineral matter and moisture, they may still vary in their calorific values due to the inherent difference in heat values of the pure (coaly) organic substances. It has also been observed that inherent moisture in coals acts not only as a dilutant of the heating value of coals but is also invariably associated with the lower rank of coals, which due to their higher oxygen but lower carbon content, have lower inherent heating value.

Therefore, a need arose to characterize low rank coals for free burning characteristics through Gross Calorific Value (GCV) studies, which is internationally accepted for grading of non-metallurgical coals and is also known as "Specific Energy". Central Fuel Research Institute, Dhanbad, has carried out detailed studies to provide a scientific basis for making equivalency charts between Useful Heat Value (UHV), which has so far been employed for classifying Indian coals, and GCV. A total of 103 fresh Run-of-Mine (RoM) coal samples collected from six major coalfields, covering MCL, SECL, CCL, WCL, NCL and SCCL, have been tested under a recently concluded S&T project to work out relationships between UHV and GCV.

Analysis of the data in terms of experimentally determined GCV revealed some degree of scatter between UHV and GCV. The variation in the relationship of GCV and UHV within a coalfield was found to be relatively less than the variation between the samples from different coalfields. The possible reason may be that the UHV concept is based on the role of dilutants (mineral mater and moisture) and does not adequately consider the organic matrix and the petrographic mix of different coals, which ultimately decide the inherent heat value. Thus, GCV may be regarded as a more appropriate parameter for commercial grading of coals in comparison to UHV. Some of the results of UHV and GCV for coal samples of various coalfields determined at 60% relative humidity and 40°C are shown in table 15.

Table 15 : Variability of quality parameters of overall samples

Coal-fields	*Moist % 60% RH*	*Ash % 60% RH*	*Ash+Moist% 60% RH*	*GCV (Kcal/kg)*	*UHV (Kcal/kg)*
WCL	1.5-9.1	18.9 – 60.8	27.4-65.7	2104-5379	-167-5119
SECL	2.2-9.1	15-43.2	21-50	3555-6345	2000-6002
NCL	5.2-10	17.4-42.4	24.6-48	3541-5545	2276-5505
MCL	2.5-8.3	30.0-52.8	34.8-57.8	2585-4460	924-3380
CCL	0.8-8.4	23.5 – 46.5	27.1-52	3280-5635	1724-5160
SCCL	4.5-8.9	17.1-46.5	24.9-41.6	3311-5681	1779-5464

An equation for overall correlation covering all the earlier mentioned coalfields has been worked out and may be used for low rank coal gradation. The equation is given below.

$$GCV = 2111 + 0.6812\ UHV$$

Utilization of Fly Ash in Agriculture

R&D studies carried out by NLC in mine spoil dumps demonstrated that application of 20 T/Ha of lignite fly-ash in cultivation of paddy crop increased the yield by 20 to 40%, and of 200 T/Ha in cultivation of groundnut resulted in increase of yield by 30-60%. The tests were carried out on six crops, viz. groundnut, paddy, maize, etc. There was no heavy metal uptake. It was found that lignite fly-ash had the capacity to neutralize acidic soil and improve its physical properties, thus making the soil more productive and suitable for cultivation.

Groundnut crop grown in fly-ash treated plot

Standing maize crop in fly ash treated plot

Based on the outcome of trials, fly ash was supplied to nearby village farmers through Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Vridhachalam. The findings of the project have been of considerable impact in utilization of lignite fly ash for reclamation of land.

Table 16 : S&T projects on coal utilisation

Sl. No.	*Title of the Project*	*Project Code*	*Imple-menting Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1	Application of Indian coal in hot briquetting (BFL Technology)	CU/2	CMPDI	1979	1.00
2	Domestic briquettes from non-coking coal fines	CU/3	CMPDI	1980	1.50
3	Coal based lighting aid for domestic fuels	CU/8	CMPDI	1980	0.35
4	Carbonisation of middlings from Bhojudih and Dugda-II washeries in Salem Hearth Calciner	CU/11	BCCL	1981	0.53
5	Converstion of Lancashire boiler to fluid bed combustion system	CU/5	CMPDI	1981	5.004
6	Preliminary survey for potential of desulphurisation of high sulphur Assam coals	CU/12	ISM	1982	0.52
7	Feasibility study of DKS formed coke technology	CU/9	CMPDI	1983	2.00
8	Development of coal fired domestic chullah	CU/7	CMPDI	1984	0.67
9	Development of smokeless coal block	CU/10	CMPDI	1984	12.00
10	Preparation of FR for recovery of tar from Beehive Coke Ovens	CU/13	CMPDI	1984	1.50
11	Drying of lignite and extraction of humic acid	CU/15	NLC	1985	8.65
12	Briquetting of non-coking coal slack for production of domestic fuel	CU/14	CMPDI/ WCL	1986	2.35
13	Experimental mechanised production of soft coke	CU/4	CMPDI	1987	54.45
14	Pelletisation of coal	CU/1	BCCL	1988	73.55
15	Development of smokeless coal block	CU/19	CMPDI	1988	56.50
16	Getting coal from trials in RRL(H) coal gasification plant	CU/20	IICT	1988	10.00
17	Pilot plant for production of coal agglomerate from low rank low grade slack coal for domestic use	CU/16	CMPDI	1990	111.47
18	Testing and development facilities for coal utilisation projects	CU/17	CMPDI	1990	35.50

19	Evaluation of coal gasification technologies for IGCC programme	CU/26	CSIR/ CMPDI	1990	26.50
20	Development of oscillatory combustor for very high efficiency utilisation of coal & coke	CU/24	IISC	1991	6.821
21	Fludized bed gassification of coal	CU/23	IICT	1991	10.12
22	Data generation and scale up on moving bed pressure gasification using coal containing 40% ash	CU/25	CSIR/ BHEL	1991	155.91
23	Chemical desulphurisation of high sulphur Assam coal	CU/28	CFRI	1992	24.05
24	Synthesis of olefines chemicals and selected fractions of hydrocarbons from synthesis gas from modified RT Process	CU/18	CFRI	1992	56.00
25	Characterisation studies of Indian Coals and lignite ashes for promoting rational utilisation of coal and lignite	CU/27	CFRI	1992	36.50
26	Design and installation of two coal fired inert gas generators for combating mine fires	CU/22	CFRI	1994	22.30
27	Automatic sampling of coal and rapid determination of its calorific value	MT/61	CMPDI	1994	242.66
28	Briquetting of leco fines for production of matallurgical broqiettes	CU/29	NLC	1996	38.75
29	Development of 100-200 kW oscollatory combustor utilising low grade coal.	CU/33	IISc. (Bangalore)	1996	9.36
30	Assessment and evaluation of modern carbonate fuel cell technology using Indian coal	MT/80	TERI	1996	16.00
31	Production of biofertiliser using lignite as carrier material	CU/30	NLC	1997	15.00
32	Lignite Fines - oil - Lignite Tar slurry firing to substitute petroleum fuel in utility boilers	CU/31	NLC/BHEL	1997	21.50
33	Utilisationof syn-gas from coal synthesis of higher olefins through oligomerisation of olefins from syn-gas	CU/32	CFRI	1999	14.50
34	Development of technology for production of additives based on coal tar products for coal water slurry fuels	CU/35	CFRI	1999	11.2
35	Utilisation of fly ash in Agriculture	CU/34	CFRI/CARD, NLC	2000	33.00
36	Bio-technological conversion of lignite to humic acid	CU/36	NLC/CFRI	2003	81.24
37	The influence of rank and mecerals/ microlithotypes and physico chemical composition on cumbustion of pulverised coal	CU/38	CFRI	2003	44.4
38	Development of 25 KW industrial power generator using high ash coal in an oscillatory combustor	CU/39	IISc, Bangalore	2003	9.26
39	Development equivalency chart between UHV and GCV	CU/41	CFRI	2003	150.00

A number of research projects have been taken up in the area of environment and ecology to integrate coal mining activities with ecological conservation and to minimize air pollution, noise pollution, land degradation and other environmental hazards due to mining. The findings of these research projects have made a significant impact on the industry resulting in the adoption of proper environmental control measures.

Air Dust Pollution

The main air pollutant associated with opencast coal mining has been found to be dust, which is commonly known as Suspended Particulate Matter (SPM). In opencast coal mining, the source of particulate dust is mainly fugitive in nature and is generated due to major operations like drilling, blasting, movement of HEMM on haul roads, etc. A part of SPM is Respirable Particulate Matter (RPM), the size of which is less than 10 micron.

A research project to study air pollution tolerance capacities of selected plant species found in coal mine area of Charhi was taken up by Vinobha Bhave University. A total of 15 dominant tree species growing on the roadsides of opencast coal mine area of Charhi and Kuju region were selected to investigate the coal dust filtering capacity and stomatal index of leaves. It was observed that stomatal index was more or less the same in both affected and normal areas. A total of 27 fungal genes were isolated during investigations and these were classified into allergenic fungi, phytopathogenic fungi and bio-deteriorating fungi. Further, a total of 65 medicinal plants were also identified which could be grown in coal mining areas.

Noise Pollution

A new approach has been evolved in recent years to grow green plants in and around mining areas near urban localities to minimize ambient air pollution and noise pollution, which is regarded as one of the cheapest ways of pollution control. With this background a research project was taken up by Indian School of Mines, Dhanbad, to study the noise attenuation capacity of different types of plants trees presently growing in mining areas and to classify them based on potentiality of noise attenuation capacity. The study indicates that it is possible to attenuate noise by developing a green belt of various thicknesses for different locations in and around mining areas. A total of 10 plantation sites (four in Jharia coalfield, four in Ranigunj coalfield and two in Singareni coalfields) were considered for the study and the results obtained are given in table 17.

Table 17 : Minimum thickness of green belt for noise attenuation

Location	*Observed noise level (Leg DB(A))*	*Desirable level of noise*	*Desired minimum thickness of green belt, m*
1. Along road	70-80	65 (commercial area)	20
2. In colonies	55-65	55 (Residential area)	20
3. Near opencast mines	70-80	77	10 (industrial area)
4 Near CHPs	80-90	75	30
5 Near shafts	77-87	75	20
6. Near mine exhaust fan	85-92	75	7.5

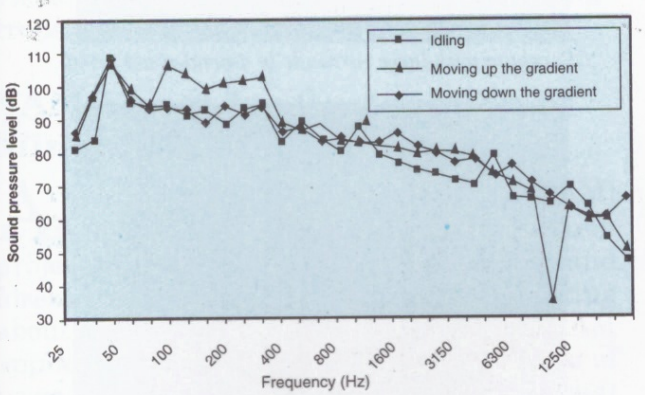
The findings from this project are expected to help mine operators to bring down noise pollution levels generated by various mining activities in and around opencast mines.

Noise Pollution due to HEMM Operation in Opencast Mines

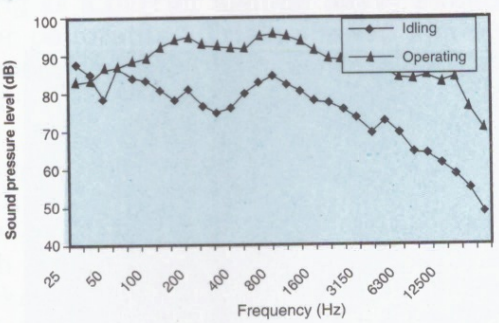
A research project was taken up by National Institute of Technology, Karnataka, to estimate the daily noise dose of the operators of various types of heavy earth moving

machinery [HEMM] and other equipment and also to study the impact of periodic maintenance of HEMM on the noise characterization.

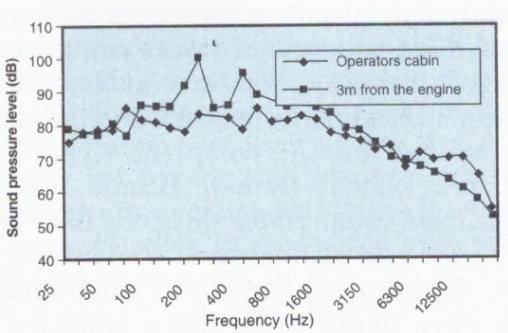
The study evaluated the variation of noise levels for different operating conditions of the machines using a frequency analyzer and measurements were made on 16 dumpers (680 HP) of 85 tonne capacity, 2 drill machines (480 HP), 2 excavators and a dozer (410 HP). The studies were conducted in the mines of SCCL.



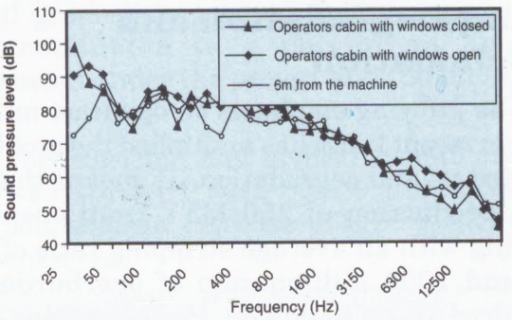
Noise level Vs frequency for dumper



Noise level Vs rrequency of dozer



Noise level Vs frequency for drilling machine



Noise level Vs frequency for shovel

The noise analyses at different operating conditions of the machines revealed that the operators were exposed to high noise level in the frequency range 25 Hz to 500 Hz when the dumper was moving up gradient with load and without load down the gradient and that peak noise level occurs at 40 Hz frequency. In case of dozers, the operators' exposure to high noise level occurred at almost all frequencies for the various operating conditions of the machine. All the drills showed high noise level between 125 Hz and 2000 Hz frequencies and peak noise level at 200 Hz and 400 Hz frequencies at 3m from the engine (supervisor position). The high frequency component of noise in 1000 Hz to 2000 Hz range was considered to produce interference with performance of operators. The excavators showed high noise level at very low frequencies, i.e. 25 Hz to 40 Hz.

One of the important results involved noise analysis with periodic maintenance of the machines. It was found that there was no significant variation in the sound pressure levels emitted by machines at 300 hrs, 500 hrs and 750 hrs of maintenance, but high fluctuation in noise level was obtained at 1000 hrs of maintenance schedule in the frequency range of 25 Hz to 3000 Hz for dozers and 25 Hz to 1000 Hz for dumpers. The study showed that proper maintenance of machines can bring down the noise level considerably, thereby reducing the operators' exposure to noise.

A mathematical model developed under the project can be used for computing the noise level at any arbitrary point from a number of noise sources, considering all parameters causing attenuation such as ground absorption, air absorption, effects of barrier and reflecting surfaces and divergence.

Land Degradation and Reclamation

The growing emphasis on opencast mining in recent times has multiplied the problems related to land degradation. It means that for coal production of 250 MTY from opencast mining with an average stripping ratio of 1:4, around 1000 million cum of overburden is required to be handled. Hence, a need was identified for research to improve technologies of back filling, soil enrichment, land reclamation, etc.

Soil Enrichment

In association with Annamalai University, NLC undertook a scientific study on soil enrichment and reclamation of back-filled areas of Neyveli opencast mines. Based on laboratory studies, field experiments were performed in about 5 acres of mine spoil area at Mine No. 1 of NLC. The dosage of organic manures, fertilizers, and micro-nutrients required for mine spoils and for different crops was standardized. Different crops, viz. cereals, pulses, oil seeds, fibre crops, sugarcane, vegetables, fruits and forest trees were tested and screened for soil enrichment. Confirmatory trials were carried out on screened crops, viz. paddy, sugarcane, maize and finger millet. In the case of paddy yield increase of about 15 – 25% was achieved with the application of coir pith in the proportion of 20 t/ha, phosphorous 100 kg/ha, potassium 100 kg/ha and Zn SO4 25 kg/ha. The findings are now being implemented on back-filled areas of NLC opencast mines with selected crops, where an increase of about 20% yield has been demonstrated.

Pond Ash Reclamation

As ash ponds near thermal power plants contain coarse ash with poor organic matter content and has low macro and micro nutrients and microbial load, voluntary vegetation is negligible. There is also a certain risk of underground water getting charged with heavy metals which may be present in ash. To sustain eco-balance and protect the environment a research project was undertaken by NLC and Annamalai University for establishing a suitable methodology for growing vegetation in ash pond areas.

Sorghum with large earheads in amended ash pond

Growth of cumbunapier hybrid grass in amended ash pong

Maize grown in pond ash with amendments and vermi compost

Based on initial pot culture and laboratory studies, field experiments were conducted in about 2.0 acres of ash pond area at Neyveli. The dosage of amendments (organic and inorganic) such as red earth, coirpith, Fym, NPK fertilizers, Lignite fly ash, Humic acid and biofertilizers required for different field crops were tested and standardized. Field crops like maize, sorghum, sunflower and cumbu napier grass were found to be more adaptive for cultivation in ash pond areas. With appropriate crop production technology and fertility

management, the ash pond was converted into productive land suitable for growing various field crops. The crop yields of maize, sorghum and sunflower were almost comparable with normal soil. Intergrated application of red earth @ 75t/ha, coirpith @ 25t/ha, Fym @ 25t/ha, Humic acid @ 50kg/ha, 200% of recommended NPK fertilizers and biofertilizers @ 4kg/ha was found to have a remarkable effect on fertility and productivity of ash pond, which in turn resulted in production of almost normal crop yields of maize, sorghum, sunflower and forage crops.

VAM Fungi for Restoration of Mine Spoils

A Versicular Arbuscular Mycorrhizal [VAM] fungus developed by NLC under a research project was tested on 20 different fruit and forest trees in three soil types, each covering about 5 acres of land. It was observed that VAM application was highly beneficial to growth of trees in adverse soil conditions. It protects soil from environmental degradation by preserving soil moisture, enhancing nutrients and by acting as a barrier against heavy metals and other pollutants. Trials showed appreciable increase in plant growth, which varied from 10 to 45%. Heavy metal concentration in fruits like guava, sapote, custard apple and pomegranate, grown in VAM inoculated ash pond, was found to be less when compared to those grown in un-inoculated condition and with respect to fruits available in the market.

Lignite Humic Acid

Humic acid works as an organic amendment to the soil and improves soil fertility leading to augmentation of crop yield. Lignite being a low rank coal contains about 60% humic acid. Through a research project under S&T Grant NLC developed the technology of extracting humic acid from lignite. A plant at NLC was set up for the purpose, which is producing humic acid as potassium humate in solid form. Further, to assess the influence of humic acid on soils and its effect on growth of crops a follow-up S&T project was also undertaken.

To examine the influence of lignite humic acid on soil properties, pot and field experiments were conducted in a poly-green house constructed under the project and the findings were:

* For capsicum and laybrid tomato crops was sprayed with 0.1% humic acid solution, an increase of 38% yield was observed.

Application of humic acid on crops : High brid tomato & cabbage (Top), Capsicum (Bottom)

* Flower plants, viz. rose and jasmine, etc, grown in soil treated with humic acid, showed considerable growth.

Well grown Zinnia flower plants with humic treatment in poly-green house

* The maximum yield of onion 150.7 g/pot was obtained from the treatment which received 20Kg/ha humic acid and 100% NPK in pot cultures. The same treatment in the field, recorded a high yield of 18.7 t/ha at Nathegoudenpudur, Tamil Nadu.

* Field experiments conducted at Narasipuram and Ponnegoundenpudur, Coimbatore district, to test the effect of lignite humic acid on yield and quality of cotton and maize, recorded high yields of 31.7 Q/ha and 65.76 Q/ha respectively from the treatment which received 20-30 Kg/ha humic acid plus 100% NPK fertilizer.

The results achieved through the S&T project have subsequently been demonstrated for the benefit of local farmers.

Table 18 : S&T projects on environment & ecology

Sl. No.	*Title of the Project*	*Project Code*	*Implementing Agency*	*Year of completion*	*Total Approved Cost (Rs. in lakh)*
1	Study relating to noise arising out of coal mining activities	EE/2	CMRS	1985	0.99
2	Study of effluents of coal washeries coke oven plants and evolve efficient effective and economical treatment processes	EE/3	CMRS	1985	2.79
3	Reclamation and consolidation of worked out coal mine site and improvement of environment and ecology through scientific land management	EE/6	CMRS	1988	3.40
4	Restoration and reclamation of abandoned Tikak Opencast Mine	EE/9	NEC	1995	75.00
5	Environmental impact and management in and around opencast coal mining complex	EE/11	BHU	1996	4.00
6	An integrated ecological study on revegetation of mine spoil.	EE/8	BHU / State Forest Deptt. of UP & MP	1996	48.71
7	Soil enrichment and reclamation of backfilled areas of Neyveli opencast mines.	EE/7	NLC/Anna Uni.	1997	44.47
8	Environment management of O.B. dumps	EE/10	CMRI	1997	35.00
9	Study of green belt regarding its noise attenuation and dust arresting capacity in coal mining areas	EE/12	ISM	1998	12.47
10	Development of technology for conversion of back filled areas in Ballarpur Area for agriculture	EE/13	WCL/IISc	1999	7.93
11	Biological method of employing VAM Fungi and Nitrogen fixing bacteria	EE/14	NLC Madras	1999	13.96
12	Geoplant ecological and aerobiological studies of coal mine areas	EE/17	Vinobha Bhave Univ. Hazaribagh	2000	6.09
13	Environment and eco-system studies in Godavari Valley Coalbelt - a geo-chemical and biological appraisal and redressal	EE/15	Osmania Univ.	2000	12.23
14	Bio- restoration of dumps through the plation of selected efficient photosynthetic / soil conserver species in Eastern Jharia, BCCL	EE/20	CFRI	2004	43.08
15	Frequency analysis and modelling of Noise Pollution for an opencast coal project	EE/23	KREC/SCCL	2004	6.30