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RETROFIT OF MHD PLANT TO A 200 MW STEAM POWER PLANT

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ABSTRACT

A study is presently being carried out to assess the suitability of retrofitting an MHD plant to an existing steam power plant. The study, which is being funded by the Electricity Commission of New South Wales, is a joint project in which the participants are The University of Sydney, the Electricity Commission, and Ecogen, a private consulting firm. The aim is to determine whether or not MHD technology is of sufficient benefit to Australia and offers economic advantages over present technology to warrant further, more detailed analyses.

INTRODUCTION

At this stage in the development of MHD power generation, it is generally agreed that the appropriate next step towards commercial realization would be to retrofit existing steam plants with MHD generators. A number of detailed retrofit proposals have now been completed[1,2] or are presently underway.[3,4] While much of the technology is now well established and the advantages of reduced pollution and potential efficiency improvements are well known, certain important areas such as air preheating and seed recovery and regeneration need a considerable amount of further development. In Australia, as elsewhere, the electrical utilities are primarily concerned with the cost of electricity, and for MHD generation to be adopted, economic feasibility has to be proven.

The general aim of the present study, which is still in an early stage, is to examine the economic feasibility and relevance of MHD power generation for New South Wales (N.S.W.) within the Australian power scene. It is recognised that coal-fired MHD could offer a considerable commercial challenge to the Australian coal industry which is fighting to retain and expand its overseas markets and which in general plays a very important part in the Australian national economy.

The plant chosen for the retrofit proposal is Vales Point power station which is located in the Hunter Valley, approximately 100 km north of Sydney. At present in the state of N.S.W., there is excess generating capacity, and Vales Point is "mothballed". It is, however, being considered for refurbishing and for return into service within the next 5 to 10 years. The station has three 200 MW generating units and the intention would be to retrofit one of these.

In this paper the possible advantages to Australia of MHD are presented. An important factor which distinguishes the various retrofit proposals is the characteristics of the local fuel. Here, properties of the coal used at Vales Point are compared with those of Montana Rosebud coal, which is the fuel nominated in the retrofit proposal for the Corette plant in Montana.[1] The results of calculations carried out to compare the performance of linear generators using the two fuels are also given. The analysis suggests that the local coal does possess particularly suitable characteristics for use with MHD.

RETROFIT EVALUATION

A detailed operational, technical and economical analysis needs to allow for alternative repowering combinations, and one has to determine the optional solution considering site specific conditions. The key issues are:

- plant layout, accessibility and space
- fuel availability
- re-usability of plant and suitability for steam or gas connection
- economic variables; cost of capital, fuel costs, manpower
- equipment availability, maintenance costs
- local system requirements, capacity and demand
- technological base

It should be realised that economic conditions will differ considerably from site to site and even more so from country to country. Therefore, one cannot directly transfer conclusions derived in another country without careful assessment.

One major advantage is that regulatory requirements are minimised by building on an existing site. However, regulatory and licensing requirements are critical. Delivery, handling and storage of coal may not pose a serious problem and increased supply may be readily arranged if necessary.

RELEVANCE TO AUSTRALIA

There have to be incentives for upgrading a station by retrofit; the possible advantages that may emerge include:

- improved efficiency and heat rate
- supply of necessary additional power
- improved environmental performance
- lower running costs
- lower capital requirement
- potentially improved availability
- easier legal and environmentally approved conditions
- possible governmental support

All factors mentioned play an important role and should be evaluated.

MHD offers an improved utilisation of coal, and lower costs at considerably improved efficiencies in advanced combined cycles, when considering a freestanding MHD Steam plant with a directly fired air preheater. Efficiency drops when an indirectly fired preheater is to be used, especially if one is constrained to an existing plant for a retrofit development.

With better utilisation of fuel resources comes improved land usage and a reduced demand on scarce water resources. This is particularly relevant in Australia where 80% of all electricity is generated in coal-fired power stations. After converting coal-fired power stations to MHD for N.S.W. alone, one could expect:

(1) cumulative savings in coal consumption over the next 40 years of the order of 500 million tonnes of coal, based on reasonable forecasts for electricity demand growth, efficiency improvements likely from MHD, and implementation timetable;

(2) a substantial increase of net electricity output from current power station sites;

(3) a halving of water consumption per megawatt-hour of electricity generated;

(4) an absolute reduction in emission of CO_2 as well as that of oxides of nitrogen and sulphur.

Perhaps, more significantly, it should help to secure the competitive position of Australian coal in steaming coal export markets relative to other electricity generation fuels such as uranium, oil and gas.

From the perspective of its buyers, Australia is not so much exporting steaming coal as it is exporting a fuel for electricity generation. To maintain their share of world energy fuel markets our black coal suppliers must meet price competition in these markets, where price is measured on the basis of the cost to generate a megawatt-hour of electricity.

One of the many initiatives required to ensure that Australian black coal remains competitive should be a long term programme aimed at securing significant increases in the thermal efficiency of its utilisation for electricity generation. The only way this can be achieved is by using binary cycles, i.e., by adding topping cycles to the conventional steam-based cycle as used in virtually all coal-fired power stations.

In practice there are several potential alternative topping cycles that could be considered. For Australia, MHD could be the best of these to support because of its greater potential for efficiency increases, in spite of the considerable advances made in the development of gas turbine technologies.

The recent fall in world energy prices must be seen as working to lower market prices for electricity generation fuels. Since 1973, Australia has built up a huge black coal export industry, so the consequences to Australia being unable to compete in world electricity fuel markets would be much more serious than they were, say, in the 1950's.

AUSTRALIAN PERSPECTIVES ON MHD POWER GENERATION

MHD retrofit and other power generation studies carried out in the northern hemisphere reflect the properties of coals available there, and technologies employed for their utilisation. Similarly, retrofit studies in Australia should be based upon Australian coals and conditions, and draw upon technologies developed in Australia for their utilisation where possible.

Hence, an Australian MHD retrofit study needs to consider, and where possible take advantage of, these factors:

(1) Australia has abundant reserves of both black (bituminous) and brown coals. The former have been developed to the extent that Australia is the world's largest exporter of steaming and coking coals. In contrast, Australia has much smaller reserves of liquid fuels, and new reserves are increasingly likely to be found in deep waters subject to tropical cyclones, therefore their development will be expensive.

(2) Australia's black coals are, by world standards, low in sulphur content (typically less than 0.5 percent S by weight on a dry ash-free basis). They also tend to have a relatively high mineral content, the primary constituents being silica and alumina, making for highly abrasive, refractory ashes. In contrast, Australia's brown coals, generally confined to Victoria where there are vast deposits, tend to have low ash levels, although their water content typically exceeds 60 percent by weight. Their high moisture content means that thermodynamic efficiencies obtained from conventional brown coal-fired power stations are low, to the point where pressure to move away from this resource on greenhouse emission grounds is being exerted from some quarters.

(3) Black coal-fired boiler stack gases are difficult to clean using traditional electrostatic precipitators, which has obliged some Australian utilities, the New South Wales Electricity Commission in particular, to adopt the alternative of bag filtration. The Commission has achieved great success with this technique, to the extent that particulate removals of 99.98 percent are routinely achieved on its two most modern large (4 x 660 MWe) pulverised fuel power stations, Eraring and Bayswater.

Point (1) indicates that in an Australian context there might be more merit in schemes involving coal pyrolysis, in which liquids and gases were distilled off from coal either to refine and distribute for transport and other markets, to pre-heat combustion air for the MHD generator, or to meet local process needs, perhaps including firing gas turbine-based combined-cycle power stations. The char would be an improved fuel for MHD power generation, having a lower hydrogen content, meaning that less air pre-heat or oxygen enrichment would be required.

It is possible that seed reprocessing and recovery systems could be simplified, in that the installation of a full seed recovery plant able to recover potassium from complex aluminium silicate-based minerals could be avoided. Potassium levels (as K) in ash in Great Northern Seam coals average around 1.25 percent by weight; close to the average for most Australian coals, although the range is from almost no potassium to around three percent by weight of ash dry solids.

In passing through a MHD generator, this potassium will combine with sulphur in the coal to form potassium sulphate. It would be vaporised, so would not be removed along with molten slag from a slagging combustor. This salt may be leached out of the ash by counter-current decantation or filtration, and crystallisation. The crude potassium sulphate would be recirculated to an extent required to maintain the minimum potassium concentration in the plasma.

With brown coal, a combination of drying and pyrolysis could yield a high quality MHD fuel at little cost. Drying brown coal generally has had to rely upon thermal means, with all that this implies for energy consumption. Mechanical dewatering has not worked well, mainly because of the cellular structure of brown coal, which still resembles that of the wood from which it was formed. A new technology, hydrothermal drying, promises to achieve partial dewatering and de-ashing of coal at the same time. In this technique, brown coal is heated in water under high pressure, under which conditions the cells shrink, displacing their aqueous contents, including any ash-forming minerals in the form of dissolved salts.

When it is dry, brown coal tends to present a high spontaneous combustion risk because of its very high surface to volume ratio. If it is pyrolysed, which would be beneficial from a MHD prespective just as it should be for black coal, the risk of combustion is heightened. A solution is to pyrolyse the dried coal in the presence of potassium hydroxide, whence a carbonaceous "clinker" is formed, a char which can be handled and stored much more conveniently. The potassium hydroxide, of course, could serve as the seed in a MHD generator.

Points (2) and (3) together suggest that caesium could be an alternative seed material. Caesium has the advantage that less air preheat or oxygen enrichment would be required.

Once there was general confidence that essentially complete removal of solids from stack gases could be achieved, caesium, with its ability to give higher plasma conductivities relative to potassium, could be used instead of potassium. Although there is no evidence of significant deposits of caesium-bearing ores in Australia, nobody has particularly looked. In any case, the principal caesium ore, pollucite, is a suitable seed material, and substantial deposits of this occur in Canada. With a strong tendency to form caesium sulphate in the MHD generator, which can be recovered for recycling, and little pressure to reduce sulphur dioxide emissions given the low sulphur content of the coals, there is the makings of a simple seed recovery system.

The use of caesium as a seed and pyrolysis of coal should reduce air preheat temperature requirements to the point where recuperative heat exhangers made of metals, rather than much more expensive and fragile ceramics, could be used.

There is a speculative element to some of these suggestions, but they are indicative of the type of insights which will be required to make MHD a success in Australia, and to stand a chance of furnishing future export industries based upon supply of the technologies for the efficient and environmentally benign utilisation of Australian coals as well as of the coals themselves.

GENERATOR PERFORMANCE USING HUNTER VALLEY COAL

In this section the performance of a 200 MW_{th} linear MHD generator using Hunter Valley coal is described and compared with an equivalent generator using Montana Rosebud coal (which is the coal selected for the Corette study).

Hunter Valley Coal Characteristics

Data for coal from the Great Northern seam[5] were used to calculate the combustion gas properties. This coal is of the bituminous type, and was chosen since it is used at Vales Point power station and would be a likely fuel source for a retrofitted MHD generator. The ultimate analysis for this coal is given in Table 1. Also in Table 1 is the analysis for Montana Rosebud coal.

	Great Northern	Montana Rosebud
% Carbon	66.5	65.9
% Hydrogen	4.2	5.2
% Nitrogen	1.4	1.0
% Sulphur	0.4	1.3
% Oxygen	7.5	14.5
% Ash	20.1	11.9

Table 1. Ultimate Analysis, dry basis of Great Northern and Montana Rosebud coals.

It is assumed that the oxidant used for combustion is enriched to consist of 40% oxygen and is also preheated to 650°C.[1] Potassium is added in the form of potassium carbonate to make up 1% by weight of the total mass flow.

The composition, and the material properties of the combustion products were computed using the NASA chemical equilibrium composition program.[6] It is assumed that constituents of the ash do not contribute to the plasma. If ash is not included then the molar composition of the plasma is that given in Table 2.

In Figure 1, the electrical conductivity vs temperature is shown for the two coals at a pressure of one atmosphere. In Figure 2, the electron mobility vs temperature is given. It can be seen that for a given temperature, both the electrical conductivity and the electron mobility are greater for the Great Northern coal.

	Great Northern	Montana Rosebud
Carbon	1.0	1.0
Hydrogen	0.72	0.94
Nitrogen	3.44	3.48
Sulphur	0.0022	0.0064
Oxygen	2.35	2.32
Potassium	0.025	0.025

Table 2. Molar compositions of combustion products of Great Northern and Montana Rosebud coals (40% O_2 in oxidant).

At a combustor pressure of 5.1 atm., not taking losses into account and excluding the effect of coal moisture content, the combustion temperatures for Montana Rosebud and Great Northern coals are calculated to be 2835 K and 2920 K respectively. The effect 5% moisture content is to lower the combustion temperature by about 40°C for both coals.

It can be concluded that Great Northern coal would be suitable for MHD power generation. Besides producing higher combustion temperatures than Montana Rosebud coal it also has the advantage of being lower in moisture content as received at the plant, the respective values of moisture content being 7% and 25%. The low sulphur content of Great Northern coal is a disadvantage when seed is added as K_2CO_3 since the NASA code calculates K_2CO_3 to be the main product containing potassium at low temperatures and fouling of the downstream components would ensue.[7] However, if seed is added as K_2SO_4, the amount of K_2CO_3 in the exhaust gas is negligible and fouling would not occur.

For use with MHD generation, the ash fusion temperature of the coal is an important consideration. MHD channels operate with "wet" walls and as a consequence, high ash fusion temperatures, a general characteristic of Australian coals, may be a problem. The ash fusion temperature of Great Northern coal is >1560 °C, a high value relative to Montana Rosebud coal. The reason for the higher fusion temperature is that Al_2O_3 and SiO_2 occur in greater proportions in the ash. In Great Northern coal they constitute 28% and 62% respectively of the ash, while for Montana Rosebud the figures are 17% and 38%. It is clearly desirable to minimise the ash content prior to combustion. The ash content of washed Great Northern coal is approximately 12% and from the point of view of reducing the amount of slag which is rejected in the combustor and minimising carryover into the channel, washing would be desirable.

Generator Calculations

A computer program has been written to calculate the performance of linear MHD generators. The program incorporates subroutines which calculate the material properties of the combustion products of the two coals discussed above as functions of temperature and pressure.

The aim is to obtain an optimised design in which the maximum possible electrical power output is achieved. Once the thermal input and enthalpy in the combustor have been set, the important parameters controlling generator performance are; magnetic field strength, inlet Mach number, inlet pressure, channel cross-section area variation and electrical loading.

Following the Corette study,[1] the maximum magnetic field strength has been set to 4.5 T. While this is modest in terms of what can be obtained with superconducting magnets, it is a level which could be realistically achieved with a large saddle-type configuration with existing technology. It is desirable that the magnetic field be as high as possible since the power output is proportional to B^2 and the generator length reduces with increasing field strength. For the calculations here, a piecewise linear approximation to the variation in field strength along the channel has been used. The field profile along the channel is shown in Figure 3.

The type of electrical loading that produces the greatest power output is segmented Faraday. The disadvantage of Faraday loading compared to diagonal loading, which is the type used in the American designs, is that the power conditioning system is more complex. However, the maximum power output achievable with the diagonal configuration is only slightly less than for the Faraday and in practice, the dimensions of the channel calculated with the two types of loading are very similar. For the preliminary study carried out here, the choice of loading is not a major consideration but because of the ease with which a parametric study can be performed, Faraday loading has been used.

The constraints on the computations are: the thermal input is 200 MW, the heat loss in the combustor and nozzle are 6% of that produced by combustion and the wall temperature is set to 1500 K. For each calculation, the inlet Mach number is specified and an iterative procedure is used to calculate the plasma flow variables at the channel inlet. Computation proceeds until the exit boundary condition is satisfied: the diffuser exit pressure after a normal shock should be 1.05 atm. with an assumed diffuser efficiency of 0.7.

With the constraints and boundary conditions specified above, a parametric study was carried out in which inlet Mach number, channel inlet area, Faraday loading parameter, and channel area profile were varied to optimise generator performance for both Great Northern and Montana Rosebud coals. The respective combustor temperatures used, taking coal moisture content and combustor heat loss into account were 2750 K and 2705 K. The results are summarised in Table 3. The most important feature of the results is that an approximate improvement of 25% in power output is obtained with the Australian coal over the American variety. This is mainly a consequence of the higher electrical conductivity in the channel achieved with the Australian coal arising from the greater combustion temperature. In Figure 4, the electrical conductivity vs length is shown for the optimised channels.

In the following figures, some important features of the optimised channels are shown. In Figure 5, the Mach number vs length is shown. At the beginning and end of the channel, the flow is accelerated because of the lower interaction resulting from the reduced magnetic field strength (Fig. 3) while in the region of strong interaction, the flow is decellerated. In Figures 6 and 7, the temperature vs length and the pressure vs length are shown. The effect of the reduced interaction is also evident in these figures.

	Great Northern	Montana Rosebud
channel length (m)	8.3	8.4
area ratio	3.51	2.82
load parameter	0.76	0.72
power output (MW)	24.8	19.8
heat loss (MW)	9	9
E.E.(%)	12.4	9.9

Table 3. Properties of optimised linear channels.

The power density along the channel is shown in Figure 8. In the region of strong interaction, the power density is fairly uniform for both cases with better performance achieved with Great Northern coal.

SUMMARY

The suitability of an MHD retrofit to an existing steam plant in the context of the Australian energy environment is presently being studied. In this paper, some aspects of the study have been outlined, particularly with regard to the use of local coal.

It has been shown that the coal which would be used at the proposed retrofit site has general characteristics which would make it a satisfactory fuel for an MHD generator. The low sulphur content and high ash fusion temperature of the coal would probably not be major impediments to its use.

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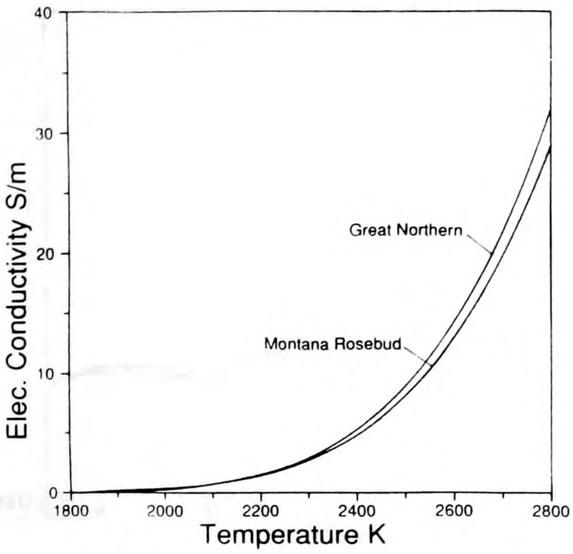

Figure 1. Electrical conductivity vs temperature at a pressure of 1.0 atm. for combustion products of Montana Rosebud and Great Northern coals.

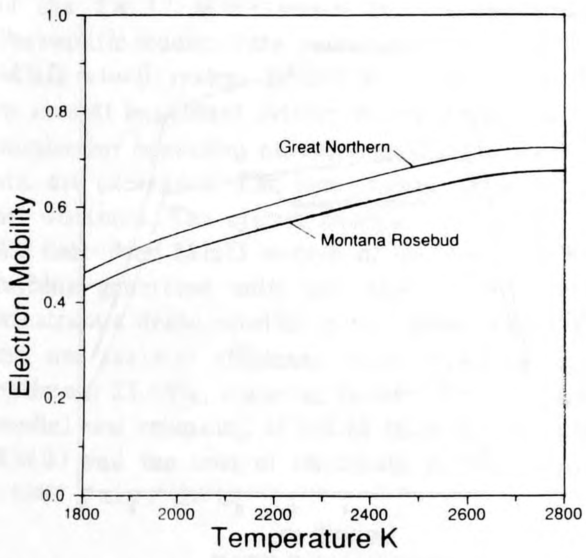

Figure 2. Electron mobility vs temperature at a pressure of 1.0 atm. for combustion products of Montana Rosebud and Great Northern coals.

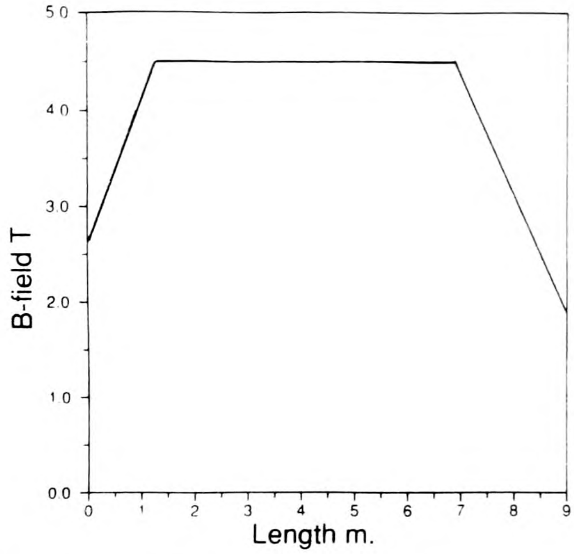

Figure 3. Magnetic field strength vs channel length used in generator calculations.

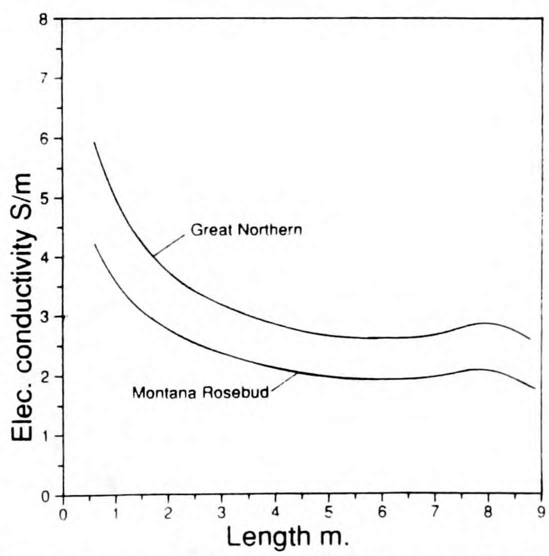

Figure 4. Plasma electrical conductivity vs generator length for optimised generator designs using Montana Rosebud and Great Northern coals as fuel.

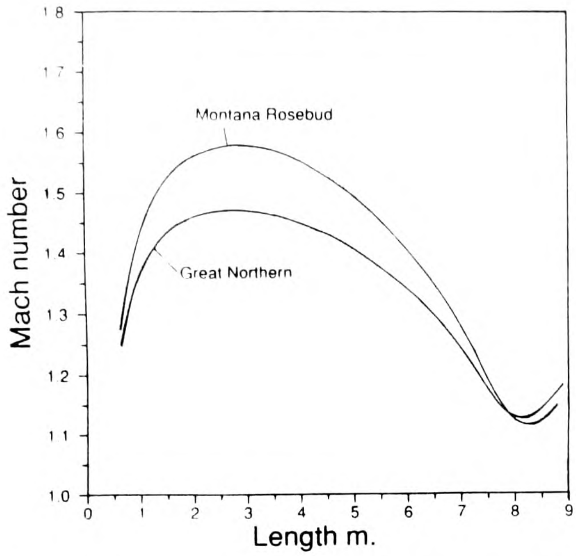

Figure 5. Mach number vs generator length for optimised generator designs.

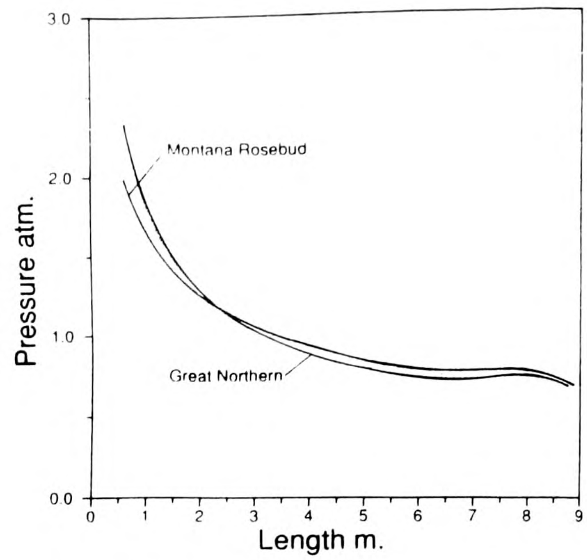

Figure 7. Static pressure vs generator length for optimised generator designs

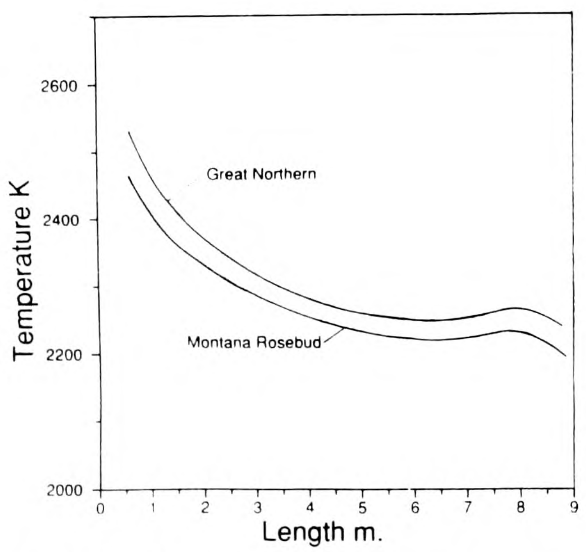

Figure 6. Plasma temperature vs generator length for optimised generator designs.

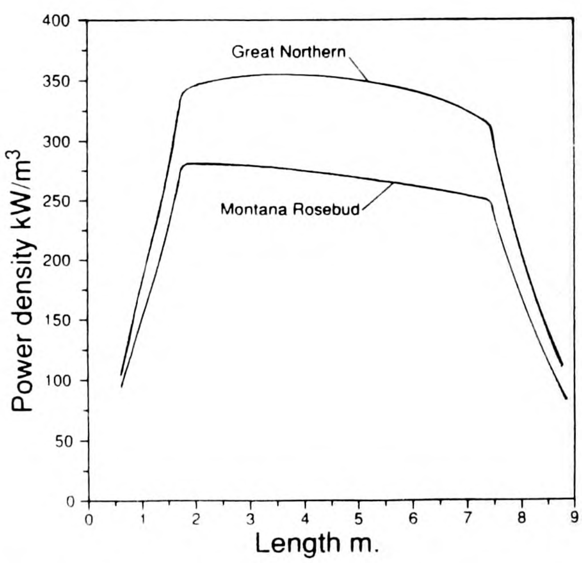

Figure 8. Power density vs generator length for optimised generator designs.