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HTR-Recommendations of Cobalt content in Helium turbine materials

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A	07/06/2002	First issue
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Summary

The dust concentration proposal to be taken into account in the GT-MHR Project primary circuit is 0.5 µg/m^3 with an average size of particles of 0.6 µm.

The application of an estimated erosion rate prediction based on experimental results feed back to GT-MHR leads to a negligible amount of cobalt which can be transferred from cobalt alloyed turbine materials to the core through the helium circuit.

Consequently, no significant cobalt activation risk has been identified on PCS components.

The recommendation of a selection of Cobalt free material as candidate materials for the GT-MHR turbine is not required.

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1. Introduction

The purpose of this document is to analyse the problematics of Cobalt content of GT – MHR (figure 1) turbine disks and blades materials in case of erosion by dust particles issued from the core flowing in all the primary circuit.

A recommendation could be required if necessary on the turbine material to be used.

2. Review of turbine candidates materials

The different candidates for turbine application including disks, blades and the first stage stator are separated in categories :

- High technology materials : the materials are the results of the most recent technology and this technology has to be validated for the size and geometry of HTR turbine. This effort requires the cooperation of a material producer : oxide dispersion strengthened material for disks as MA 6000 (ODS), single crystals for blades as CMSX-4 or PWA 1483 enter in this category. In addition MA 6000 (ODS) is a cobalt free material. CMSX-4 is preferred to CMSX-2 for its improved strength properties and appears with respect to corrosion as aluminium-oxide former. PWA 1483 which has an higher chromium content (chromium-oxide former) is better in case of carburising or decarburising risks in slightly oxidising atmospheres.

- Materials to be adapted to HTR : these materials are produced by a more conventional fabrication process (forging or casting). The adaptation required a more effective manufacturing process in order to increase the size or to improve the high temperature properties. HIP Udimet 720 for disks, directionally solidified cast alloy as MAR M247 DS, CM 247 LC DS or IN 792 DS for blades enter in this category. Higher chromium IN 792 DS is better in case of carburising and decarburising risks.

- High temperature conventional : Forged products (IN718, IN706 for instance) for disks, conventional cast materials for blades, forged Hastelloy XR for stator enter in this category.

- Cobalt free high temperature materials : for disks it is the forged Inconel 718 but this material is limited in high temperature creep strength and a material must be defined in case of cobalt free requirement for disks. For blades the cobalt free materials are MAR M004 or SC16 but if the blades are coated, the base material needs possibly not to be cobalt free.

Single crystals, directionally and conventionally cast alloys must be hot isostatically pressed (HIPed) and characterised in this delivery condition.

The blades must be coated and fatigue testing must be performed taking into account this surface condition.

The chemical composition of candidate materials for turbine <u>blades</u> is given in table 1. For turbine disks, blades and stator, the HTR-M project proposed a restricted selection of candidate materials in the different categories mentioned here-above which is presented in table 2.

At this stage of the project, it remains unclear if alloys containing additions of Cobalt would be selected for use.

Nevertheless, many of the high temperature alloys with cobalt have the highest mechanical properties and need to be kept in back-up solution, and the potential radioactive contamination by Cobalt particles examined.

3. Characterization of the dust in the primary circuit

The dust concentration and the size of the dust particles flowing in the primary circuit of the GT-MHR is based on the experience gained in AVR.

3.1 Dust concentration

The figure 2 gives the dust concentration in the coolant of AVR measured with filters allowing retention of dust particles down to 0.3 µm diameter and with an efficiency of 50 %.

The steady-state operation generates a low concentration in the range of 1 – 2 $\mu g/m^3$, the transient conditions adding much higher peaks.

The average dust concentration in the AVR is derived for an operating year : 5 $\mu g/m^3$. The dust concentration measured in AVR could be considered as an upper bound.

Nota : the amount of graphite dust in the old AVR – plant was 3 kg per year. It should be taken into consideration, that the AVR was an "experimental" reactor. In this reactor, many types of fuels were tested, from the oldest one until new types.

Therefore, it is plausible to take a lower value.

3.2 Size of the particles

The figure 3 represents the number – weighted distribution of dust particles sizes in the AVR coolant.

This distribution indicates an average dust particle diameter of about 0.6µm. Most of the particles has a size comprises between 0.2 and 1 µm.

Nota : the size distribution of AVR dust seems to be similar for all the filters experiments. Nevertheless, we have to keep in mind that an agglomeration of dust particles is possible especially for high dust concentration.

3.3 GT – MHR prediction

It appears that a pebble bed reactor is able to generate much more dust than a prismatic block reactor due to friction between pebbles in particular during fuel handling. New reactors such as HTR-MODUL will present a lower amount of dust, in particular due to dust filtering in the fuel handling system.

Also the predicted amount of dust for the German HTR-500 is 10 kg/year, instead of 3 kg/year for the AVR, the ratio of power being 30 (1400 MWth/46 MWth). This low amount of dust, comparatively to the power, is the consequence of the use of a "OTTO" ("Once Through Then

Out") loading scheme. This case can be compared with the prismatic block reactors for which no multiple refuelling exists.

As a consequence, the lower bound of dust concentration is taken to 0.5 $\mu g/m^3$ which seems to be more appropriated for a prismatic block reactor such as the GT-MHR.

The average dust particle diameter proposal to be taken into account in GT-MHR Project is 0.6 μm.

4. GT-MHR erosion rate prediction

4.1 Hypothesis

The blades and disks materials are in a first approach supposed to be homogeneous alloys. The following assessments do not take into account of :

- the walls upper layer possible modification (embrittlement, films cracking, desquamation,…) due to HTR severe environment,
- the eroded matter quantity possibly containing more than nominal value of Cobalt.

4.2 Turbine erosion

The action is to evaluate the amount of Cobalt which can be transferred from cobalt alloyed turbine materials to the core through the helium circuit.

The cobalt problem is more important for blades than for disks (higher total surface in contact with helium flowing in the circuit, higher erosion due to higher velocity).

Main design parameters of the GT-MHR turbine are :

- Speed : 3000 rounds per minute (rpm).
- Number of stages : 12
  - blade height at inlet : 170 mm
  - blade height at outlet : 225 mm
- Root diameter of blading : 1400 mm
- Length of blade system : 1800 mm

4.3 Erosion law

The erosion rate prediction of several Ni base alloys material (Cobalt content (weight %) : 8-20) leads to :

0.02 mg/g of dust in the primary circuit/m² of blade surface.

The application of this input data linked to GT-MHR project is given here under.

Mass of dust derived for an operating year at full power is :

Helium flow rate : 105 m^3/s

Mass of dust = average dust concentration per m^3 x number of m^3 flowing during one year.

= 0.5 $\mu g/m^3$ x (105 m^3/s x 3600 seconds x 24 hours x 365 days)

= 1656 g/year of dust (graphite)

Blade surface in contact with helium flowing in the primary circuit $\simeq$ 25 m^2.

Mass of material eroded including cobalt (per year)= 0.02 $mg/g/m^2$ x 1656 g/year x 25 m^2

= 0.83 g/year

5. Transport of particles

Dust particles flowing in the primary circuit are mainly issued from the core. Cobalt particles eroded by graphite dust particles are also present in the circuit.

Risks of dust particles deposits onto the GT-MHR circuit walls exist through sedimentation and or inertia effects. Similar size graphite and cobalt particles are taken into account.

Sedimentation risks do not exist at nominal operating conditions. However during all the reactor lifetime, and considering all other operating conditions, reactor and PCS vessel bottom parts are suspected to be subject of deposits.

There is no risk of deviation in the current flow of average diameter 0.6 µm dust particles at nominal operating conditions through inertia effects. Some risks exist for Cobalt particles having more than about 5 µm average diameter. In that case, location where particles should adhere to the walls are identified.

Unsteady operating conditions may also cause dust remobilization which can lead to deposits especially in narrow spaces as in the exchangers / recuperator. Handling periods are also moments of dust production increased probability.

6. Cobalt particles activation

From the mass of material eroded including Cobalt per year (§ 4.2), the value of the total activity of Cobalt 60 is equal to 3.8×10^{10} Bq.

7. Comparison with fuel term sources

After migration through graphite, fission products (FP), predominantly silver, strontium and cesium released into coolant helium from the reactor.

At this stage of the project, the available data deal with Cs 137 ; 13.4 Tera Becquerels for 7 operating years on the primary circuit surfaces.

The total activity of Cobalt 60 could be considered as negligible as regards releases in the primary circuit, approximately 2 % of the term fuel sources activity.

8. Conclusion

The dust concentration proposal to be taken into account in the GT-MHR Project redactors is 0.5 $\mu g/m^3$ with an average dust size of particles of 0.6 μm diameter.

The application of an estimated erosion rate prediction based on experimental results feed back to GT-MHR leads to a negligeable amount of Cobalt which can be transferred from cobalt alloyed turbine materials to the core through the helium primary circuit.

Consequently, no significant cobalt activation risk has been identified on PCS components.

The recommendation of a selection of Cobalt free material as candidate materials for the GT-MHR turbine is not required.

Table 1
Candidate materials for turbine blades

(% mass)	C	Cr	Co	Mo	W	Ti	Al	Nb	Ta	Hf	V	B	Zr
Ch120M (C or SC)	≃ 0.03	≃ 11.7	≃ 7.5	≃ 1	≃ 6.5	≃ 4.3	≃ 4	≃ 0.8	-				
EI 929 (F)	-	9 12	12 16	4 6	4.5 6.5	1.4 2	3.6 4.6	-	-				
EI 893 (F)	-	15 17	-	3.5 4.5	8.5 10	1.2 1.6	1.2 1.6	-	-				
EP 800 (F)	-	12 13.5	8.5 10.5	5 6	4 6	-	4.2 4.9	1.5 2	-				
CMSX-2 (SC)	≤ 0.03	≃ 8	≃ 4.6	≃ 0.6	≃ 7.9	≃ 1	≃ 5.5	-	5.8				
CMSX-4 (SC)		≃ 6.5	≃ 9	≃ 0.6	≃ 6	≃ 1.0	≃ 5.6		≃ 6.5	≃ 0.1			
PWA 1480 (SC)		≃ 10	≃ 5		≃ 4	≃ 1.5	≃ 5		≃ 12				
PWA 1483 (SC)	≃ 0.080	≃ 12.3	≃ 8.5	≃ 1.9	≃ 3.8	≃ 4	≃ 3.6		≃ 5	< 0.01		< 0.003	< 0.01
SC16 (SC)		≃ 16		≃ 3.0		≃ 3.5	≃ 3.5		≃ 3.5				
CM 247 LC (SC or DS)	≃ 0.07	≃ 8.1	≃ 9.2	≃ 0.5	≃ 9.5	≃ 0.7	≃ 5.6	-	≃ 3.2	≃ 1.4			
MAR M247 (C or DS)	0.13 0.17	8 9	10	0.7	9.5 10	0.9 1.2	5.3 5.7		2.8 3.8	1.2 1.6			
M21 (C)	~ 0.1	~ 6	-	~ 2	~ 10.5	-	~ 6	1.5				~ 0.02	~ 0.1
MAR M004 (C)	≃ 0.05	≃ 12	-	≃ 4.5	-	-	≃ 5.9	≃ 2	≃ 0.3	≃ 1.3			
713 LC (C)	≃ 0.05	≃ 12	≃ 0.04	4.65	-	0.74	5.82	≃ 2	4			0.009	≃ 0.1
IN 100 (C) or (DS)	≃ 0.18	≃ 10	≃ 15	≃ 3	-	4.7	5.5			-	≃ 1	0.014	0.06
IN 792 (C) or (DS)	0.11	12.15	9.25	1.8	3.78	4.1	3.45	2	-	0.52		0.012	0.09
IN 738 LC (C)	0.09 0.13	15.7 16.5	8.0 9.0	1.5 2.0	2.6	3.2 3.7	3.2 3.7	2	-	-		0.007 0.012	0.03 0.08

(F) : Forged
(C) : Conventionally, cast
(DS) : Directionallly solidified
(SC) : Single crystal

CMSX is a trade name of Cannon Muskegon Corporation
MAR M is a trade name of Martin Marietta Corporation
PWA is a trade name of Pratt and Withney

Table 2
Proposed restricted selection of candidate materials in the different categories

	Disks	Blades	Stator
Conventional High temperature materials	Forged Udimet 720	cast IN 792 (1) cast MAR M247 (2)	Hastelloy XR (3)
Materials to be adapted to HTR	Forged Udimet 720	IN 792 DS (1) CM 247 LC DS (2)	
High technology materials	HIP Udimet 720	PWA1483 (1) CMSX-4 (2)	
Cobalt free high temperature material	Inconel 718	SC16 (1) (4) MAR M004 (2) (4)	Hastelloy XR

(1) to be chosen if Cr oxide former are found better for HTR environment

(2) to be chosen if Al oxide former are found better for HTR environment

(3) To be confirmed

(4) Only in case of uncoated blade development.

Figure 1

GT-MHR module overview

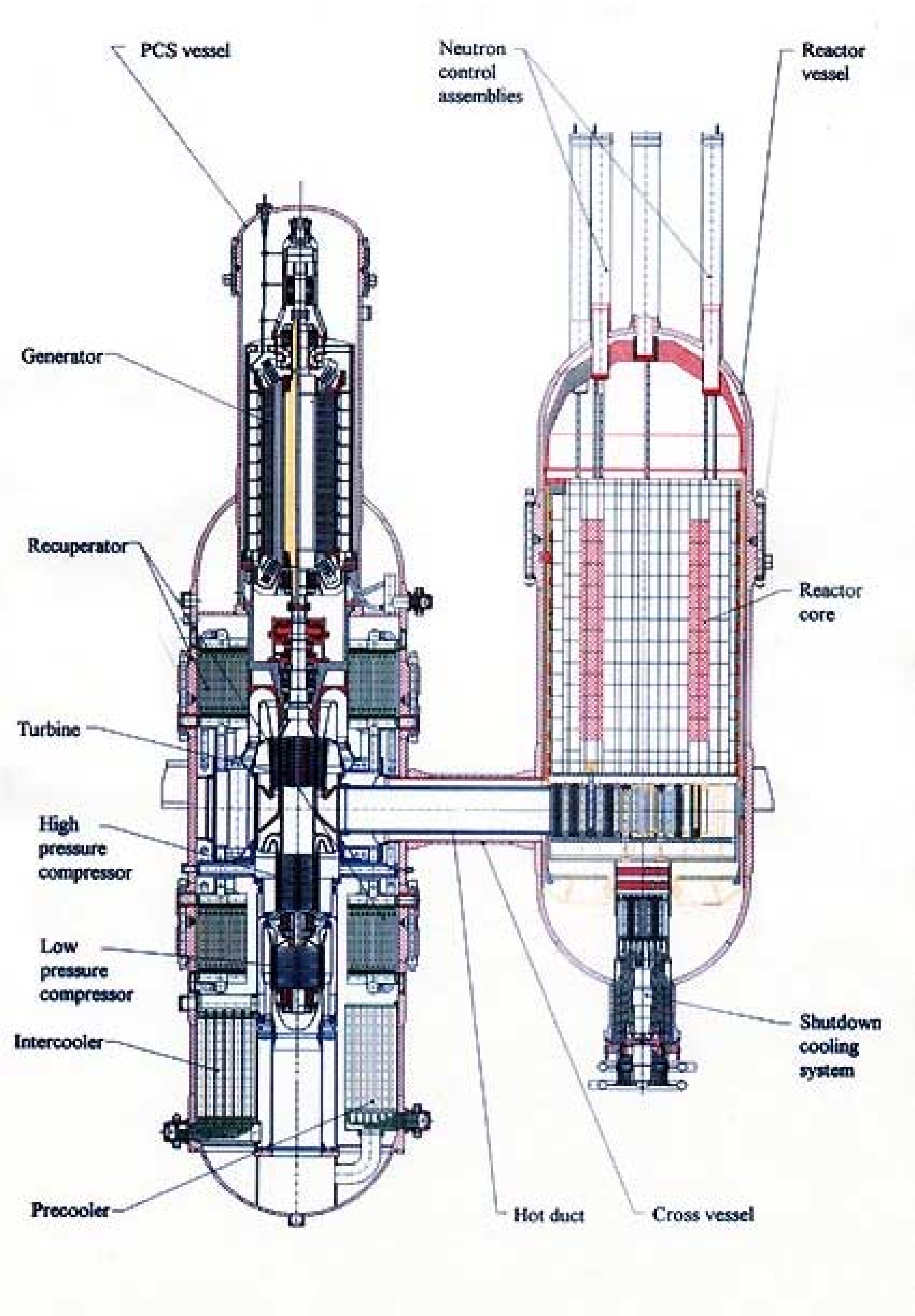

Figure 2

Dust concentration

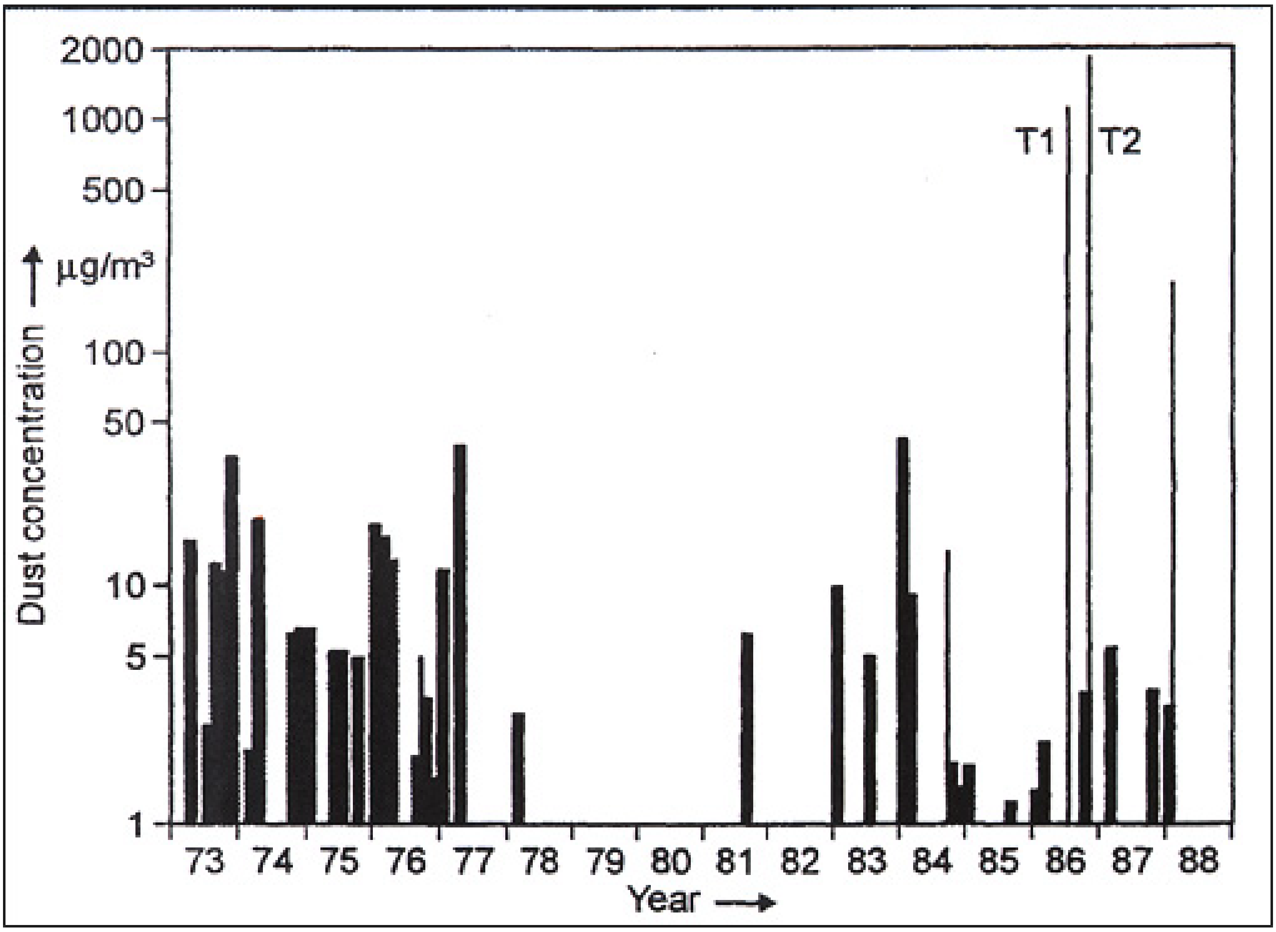

Figure 3

Size of the particles