DIRECTION DE l'ÉNERGIE NUCLÉAIRE
DIRECTION DU CEA CADARACHE

DÉPARTEMENT D'ÉTUDES DES RÉACTEURS
SERVICE DE TECHNOLOGIE DES REACTEURS
LABORATOIRE DE CONCEPTION ET D'EXPERIMENTATIONS TECHNOLOGIQUES

NT	STR	LCET	02/032	0	5H610	A-RCGCH-03-01	NT	1/16
NATURE	SERVICE	LABORATOIRE	NUMÉRO DOC.	INDICE	IDENT. UNITÉ	ÉLÉMENT D'OTP	CLASSEMENT UNITÉ	PAGE

Note Technique

TITRE : **HTRE – Deliverable 37 of WP5**
Review of tribological problems on former HTRs and on FBR technology

AUTEUR(S) : L. CACHON

RÉSUMÉ : The aim of the WP5 of HTR-E is to update the inventory of tribological problems met in formers HTRs, to review and identify the corresponding tribological environments and finally check possible materials or coatings able to provide a reliable answer to these situations through elementary tests in a representative and tribological Helium environments close to identified components such as control rods, stator seals or hot gas duct.

This document is the contribution of the CEA to the Deliverable 37, “Review of tribological problems on formers HTRs and on FBR technology”, which is devoted to the feed back experience of the French FBRs (Phénix and Superphénix).

This synthesis shows that in Na FBRs tribological conditions, the best candidates to use are coatings such as TRIBALOY 700 or D-GUN CERMET, and also Aluminisation surface treatment.

The conditions of FBRs running are specific and very different than the HTR conditions. In tribology studies, the change of one parameter can change significantly the ”tribocontact” comportment. Nevertheless, the best candidates in FBRs tribological conditions would have to be tested in HTR ones up to 600°C. Beyond 600°C, metallic materials would not be adapted.

L’objet du WP5 de HTR-E est de mettre à jour l’inventaire des problèmes tribologiques rencontrés dans les réacteurs HTR, d’identifier les situations tribologiques correspondantes, de proposer des matériaux ou revêtements capables d’être utilisés dans ces situations et de valider ces choix au travers d’un programme expérimental représentatif.

Ce document est la contribution du CEA au livrable D37, “Review of tribological problems on formers HTRs and on FBR technology”, axée sur le retour d’expérience des réacteurs rapides français RNR (Phénix and Superphénix).

Cette synthèse montre que dans les conditions d’un RNR, les meilleures solutions sont des revêtements de « TRIBALLOY 700 » ou de « CERMET », ainsi que des traitements de surface d’aluminisation.

Les conditions des RNR sont très différentes de celles d’un HTR. Dans les études tribologiques le changement d’un paramètre peut changer de façon significative le comportement d’un « tribocontact ». Toutefois, les meilleurs candidats pour les RNR pourront être évalués dans les conditions d’un HTR jusqu’à 600°C. Au delà, les matériaux métalliques ne sont plus adaptés.

MOTS CLÉS : HTR, Tribology, FBRs.

	Rédacteur	Vérificateur	Approbateur
Fonction			Le Chef du STR/LCET
visa			
NOM	L. CACHON	E. PLUYETTE	G. LAFFONT
Date	12/07/02		

Cadre de réalisation du document.
DOB...DDIN
Domaine...............................Systèmes du futur
Projet..........RCG Technologie des circuits He
Contrat...

Classification				
DR	CC	CD	SD	SANS
				X

Indice	OBJET DES RÉVISIONS	DATE	NUMÉRO DOC.
	Émission initiale	12/07/02	02-032

References :

[1] I. BOBIN VASTRA, “WP5 Work Plan Report for : Tribology in Helium Environment”, HTR-E contrat n° FIKI-CT-2001-00177

[2] Y. DEPIERRE, « Etude comparative du comportement en frottement dans le sodium de certains couples de matériaux alliages a base cobalt, alliages à base nickel », NT CEA DRNR/STRS/SDER 82/1184.

[3] S. ROUX, « Bilan des essais de frottement en sodium et en argon effectué au STRS », NT CEA DRNR/STRS/VALORISATION 80/027.

[4] Y. DEPIERRE et al, « Résistance à l’usure et à la c orrosion dans le sodium liquide de traitements d’aluminisation sur aciers inoxydables austénitiques », NT CEA DRNR/STRA/LPCM 86/142.

[5] R. ELBEZE et al, « Guide des matériaux, chapitre III : caractéristiques des matériaux de frottement », NT CEA DRNR/STRS/VAL 76/28.

[6] R. ELBEZE, « Frottement en sodium et en argon – application aux paliers », NT CEA DRNR/STRS/VAL recommandation n°8, Nov. 1975.

[7] X. ELIE et al, « Bilan des essais de frottement en sodium, en argon et en vapeur de sodium effectués au CEA et à EDF », CEA DRNR/STRS 71/013.

[8] Y. DEPIERRE, « Comportement de l’alliage PYRAD 53 N ou INCONEL 718 au frottement en milieux sodium et argon », NT CEA DRNR/STRS/SDER 81/1056.

[9] H. VENOBLE et al, « Influence de la teneur en oxygène du sodium sur le frottement des pièces stellitées à 400°C », NT CEA DRNR/STRS/SDER 75/324.

[10] H. VENOBLE et al, « Essais de frottement en sodium entre stellite 6 & Inconel 718 », NT CEA DRNR/STRS/SDER 75/351.

[11] Y. DEPIERRE et al, « Essais de frottement plan sur plan en sodium du TRIBALOY 700 sur lui même » NT CEA DRNR/STRS/SDER 81/1045.

[12] M. RAFFALAIC et al, « Compatibilité d’un revêtement de carbure de titane en sodium à 550°C », NT CEA DRNR/STRA/LPCM 83/08.

[13] M. RAFFALAIC et al, « Frottement en milieu sodium – Essais de couple LW1 / LW1 et LC1C / LC1C », NT CEA DRNR/STRS/SEML 76/264.

[14] M. RAPHAEL et al, « SPX1 - Galets tourillons des pots de manutention : Résultats des essais de frottements », NT CEA DRNR/SERA/LDCS 90/6005.

[15] L. CACHON, « Tribologie sous atmosphère Hélium pour les HTR - Etude bibliographique », NT DER/STPI/LCFI 00-037.

Contents

1. INTRODUCTION.

1.1 Context.

The aim of the WP5 of HTR-E is to perform firstly an up-dating of tribological problems met in formers HTRs, to review and identify the corresponding tribological environments and finally find possible materials or coatings able to provide a reliable answer to these situations through elementary tests in a representative and tribological Helium environments close to identified components such as control rods, stator seals or hot gas duct.

The WP5 is divided in 6 parts, 6 deliverables which are identified from D37 to D42 [1]. This document is focused on the D37 task which is called "Review of tribological problems on formers HTRs and on FBR technology". The objective of the document is to establish through the feed back experience from several HTRs, and from the know-how on FBR technology, a review of different cases of failure and problems on components and materials.

The organization of the D37 can be found in appendix 1.

The CEA is in charge of the feed back experience from the French FBRs (Phénix and Superphénix).

1.2 Feed back experience from French FBRs.

Sliding and rolling frictions in liquid metals or Argon sodium aerosols are important features for the good running of mechanisms such as mechanical pumps, fuel handling devices, control rods, used in liquid metal FBRs.

Like He in HTR conditions, Na liquid metal or Argon with Na aerosols are not convenient environments for well friction and wear performances. Na liquid metal has the property to reduce a lot of metal oxides (such as lubricated oxides), which is improved when this purity is very high (very low concentration of oxygen). In French FBRs [O_2] concentration does not exceed 3ppm, and in PFR [O_2] is maintained between 13 to 15 ppm.

Numerous experimental studies have been realized in CEA from 1960 to 1990. This report is a synthesis of feed back experimental studies made in CEA.

2. TRIBOLOGICAL CONTACT SITUATION.

In the different experimental programs a tribological contact was defined by the following parameters :

- Temperature : Tests have been performed between 180 and 600°C, typically 180°C, 400°C & 560°C.
- Contact pressure : 0.1 to 200 MPa, typically 0.5 MPa.
- Materials in contact (homogeneous or heterogeneous materials in contact).

- Motion type : Friction plane / plane for the most tests and rotating for bearing tests.
- Motion velocity : up to 20 m/s.
- Motion frequency : up to 10 Hz.
- Environment :
    - Na with 2 contents of [O_2] 1 and 15 ppm,
    - Argon with Na aerosols.

More than 300 tests have been performed with combinations of theses different parameters.

3. TRIBOMETERS USED FOR TRIBOLOGICAL STUDIES.

In Appendix 2, are presented the principal 2 tribometers used for the tribological studies :

- Friction Plane / plane (fig.1) : A ring turns on a disc which is fixed. The contact surface is included between the 2 diameters : 51 mm and 37 mm. The load is applied on the ring with an lever arm.
- Rotating (fig.2), which is used only for (ball) bearing tests.

4. MATERIALS FOR FBRS TRIBOLOGICAL APPLICATIONS.

The candidates materials can be classified as following :

- Thick coatings (thickness between 1 to 2 mm),
- Thin coatings (thickness lower than 0,1 mm),
- Solid materials.

4.1 Thick coatings.

4.1.1 Cobalt base alloys.

These alloys are commonly named STELLITE [2][3][5][7][9][10]. But depending on the providers, they can also be called : HAYNES, ALACRITE, VIRIUM, AEROMETAL, FLUGINOX, …They are essentially composed with Co (45% to 70%), and Cr (15% to 35%).

They have a good comportment at Na corrosion up to 600°C. They have usually deposed by Plasma Transferred Arc (PTA).

The STELLITE 6 is the most frequently used alloy. Its deposition and its manufacturing can be made without difficulty.

This alloys was the first one used for FBRs tribological application, due to the industrial well know. The principal inconvenient of these alloys is the presence of Cobalt. Cobalt is activated under neutronic flow.

4.1.2 Nickel base alloys.

The cobalt alloys had to be substituted because of their activation under neutronic flow. So the use of hard Nickel base alloys was envisaged [2][3][5][7].

Depending on the way of manufacturing, these alloys can be classified in 2 categories :

- The alloys deposed with powder (Ni-Cr-Fe-B-Si).
- The alloys deposed by solid electrodes (Ni-Cr-W-Mo).

4.1.2.1 Alloys deposed with powder

They are commonly named COLMONOY. Because of the different technics of deposition (: PTA, welding TIG, …) the properties of the coatings can widely vary from one manufacturer to another (LEGUELLEC, PETROTHEN, SNM).

The hardness of these alloys is higher than the hardness of the STELLITE up to 400°C. Beyond 400°C, the hardness falls down. They can be used up to 600°C without problems.

Another Alloy, commercially named TRIBALLOY 700 had been tested during the experimental program. This Ni base alloy contains also Mo, Cr, Si and presents a structure constituted by 50% of Lave Phases in a hard matrix (respectively 1200 and 600 Vickers) [11].

4.1.2.2 Alloys deposed by solid electrodes.

They have a good resistance to Na corrosion up to 600°C. They are named :

- ADNIC 482 D : Its deposition is very difficult.
- ADNIC 280 & ADNIC56D,
- HASTELLOY,

4.1.3 Iron base alloys.

Iron base alloys are usually used as structural material. But coatings have been developed to improve tribological comportment. They contain Ni, Cr, Mo & W. They are well knew under the name : CENIUM [3][5][7].

4.2 Thin coatings – Surface treatment.

The choice of thick coating is not always necessary. There are various applications, where the contact pressure allows to use of a thin coating or a surface treatment [3][5][7].

4.2.1 TiC.

They are deposed by PTA or by Vapor deposition technics [12].

4.2.2 CERMET - WC.

They are deposed by Plasma or D-Gun technics, but the better performances are obtained by D-gun deposition. They are essentially made of carbide (95%) embedded in Co or Ni binder. The coatings used are TW5, …[13]

4.2.3 CERMET – CrC.

They are deposed by D-Gun. They are essentially made of carbide (70 to 80%) embedded in Co or Ni binder. The coatings used are LC1H, … [13]

4.2.4 TRIBALLOY 700

This alloy can be deposed by D-gun with a thickness of 0.15mm [11].

4.2.5 Surface treatment.

These surface treatments are made to improve the wear resistance of the 2 bodies in contact, which are usually stainless steels. We can list :

- Chromisation : The structure metal is heated up to 1000°C in CrCl gas. The thickness of the treated layer can reach 0,02 to 0,1 mm.
- Nitruration :
    - Gas Nitruration : The structure metal is heated up to 550°C. The thickness of the layer is lower than 0,2 mm.
    - Ionic Nitruration : The structure metal is heated up to 550°C. The duration of the treatment is lower than Gas Ni-plating. The thickness of the layer is lower than 0,15 mm.
- Aluminisation : This treatment named HC17 was developed by HEURCHROME. The first phase of the deposition (up to 780°C) consists to introduce the piece into a cement with a high Al activity. The second phase, diffusion under protective atmosphere, heats the structure up to 1000°C. The thickness of the layer is lower than 0,15 mm [4].

The last surface treatment (Aluminisation) is the best treatment for Na FBRs tribological applications.

4.3 Structural materials.

The use of structural material for tribological applications is made only for specific devices, such as, ball bearings, …

Different alloys can be used [3][5][7].

4.3.1 Iron base alloys.

When the tribological conditions are not very hard, stainless steels can be used, i.e. 304, 316L. Other iron base alloys can be listed :

- Haynes 90, (27% Cr) very hard (600 Vickers),
- Virium 30, (20% Ni),
- ZNZ, (25%Ni, 10%W),
- NITRONIC 60, (Cr, Ni, Mn).

4.3.2 Nickel Base alloys.

Ni base Alloys such as Inconel 718 (or PYRAD 53 N) will be used for ball bearings application, in Na at temperature lower than 250°C [6][8].

5. DIFFERENT COMBINATIONS TESTS.

The table 1 presents the principal tests performed on the different materials. The different parameters are :

- Plan / plan contact on tribometer fig.1,
- Face / counter face materials,
- Na temperature.
- Contact pressure 0.5 MPa,
- [O2] <1 ppm
- Velocity 5cm/s , duration 100 hours.

Face / counter face materials	Temperature	Nb of tests	Friction coefficient	Wear (cm^3/cm.daN)
PYRAD 53 N	180°C	1		$21.6\ 10^{-11}$
/	400°C	4	0.68<μ<0.92	$12\ 10^{-11}$
PYRAD 53 N	560°C	6		$6.4\ 10^{-11}$
Ni-Plating	180°C	2		Na Corrosion
/	400°C	2	0.38	Material transfer
PYRAD 53 N	560°C	1	0.51	De-stratification
LSR1 (TiC)	180°C	1	0.17	$0.5\ 10^{-11}$
/	400°C	/////		
LSR1 (TiC)	560°C	1	0.29	$0.4\ 10^{-11}$

LC1H / LC1H	180°C	1	0.58	De-stratification
	400°C	5	0.63	De-stratification
	560°C	3	0.6	$0.4\ 10^{-11}$
STELLITE 6 / STELLITE 6	180°C	1	0.26	$60\ 10^{-11}$
	400°C	3	0.41	$47\ 10^{-11}$
	560°C	1		$383\ 10^{-11}$
STELLITE 6 / STELLITE 12	180°C	1	Same Results than STELLITE 6 / STELLITE 6.	
	400°C	3		
	560°C	1		
TRIBALLOY 700 (SNM) / TRIBALLOY 700 (SNM)	180°C	3	0.54	$24\ 10^{-11}$
	400°C	1	0.38	$0.6\ 10^{-11}$
	560°C	1	0.76	$30\ 10^{-11}$
TRIBALLOY 700 (LEGUELLEC) / TRIBALLOY 700 (LEGUELLEC)	180°C	2	0.4	$<1\ 10^{-11}$
	400°C	2		
	560°C	2		
COLMONOY 4 (LEGUELLEC) / COLMONOY 5 (LEGUELLEC)	180°C	2	$0.3<\mu<0.42$	$<10\ 10^{-11}$
	400°C	1		
	560°C	1		
COLMONOY 5 (LEGUELLEC) / COLMONOY 6 (LEGUELLEC)	180°C	2	$0.35<\mu<0.56$	$<3\ 10^{-11}$
	400°C	1		
	560°C	1		
COLMONOY 5 (Plasma SNM) / COLMONOY 6 (Plasma SNM)	180°C	1	$0.48<\mu<0.55$	$100\ 10^{-11}$
	400°C	2	0.21	$<0.38\ 10^{-11}$
	560°C	2	$0.48<\mu<0.55$	$100\ 10^{-11}$
Stainless steel & HC17 / Stainless steel	180°C	8	0.4	$<2\ 10^{-11}$
	400°C	6	$0.4<\mu<0.5$	$<7\ 10^{-11}$
	560°C	14	$0.3<\mu<0.55$	$<7\ 10^{-11}$

Table 1 : Principal tests lead for tribological studies in Na environment.

6. CONCLUSION – RECOMMENDATIONS.

In conclusion, the couples of materials selected for Na tribological applications are listed in table 2. The best couples are listed in first.

Face / counter face materials	Temperature 180 °C	400°C	560°C	Coating type
PYRAD 53 N / PYRAD 53 N	☹	😐	☺	Massive
LSR1 / LSR1	☺☺		☺☺	Thin coating (20 – 50 µm)
Stainless steel & HC17 / Stainless steel	☺	☺	☺	Surface treatment
LC1H / LC1H	☹☹	☹☹☹	☺	Thin coating (20 – 50 µm)
TRIBALLOY 700 (LEGUELLEC) / TRIBALLOY 700 (LEGUELLEC)	☺	☺	☺	Thick coating (100 µm – 1mm)
COLMONOY 4 (LEGUELLEC) / COLMONOY 5 (LEGUELLEC)	😐	😐	😐	Thick coating (100 µm – 1mm)
COLMONOY 5 (LEGUELLEC) / COLMONOY 6 (LEGUELLEC)	😐	😐	😐	Thick coating (100 µm – 1mm)
TRIBALLOY 700 (SNM) / TRIBALLOY 700 (SNM)	☹☹	☹	☹☹	Thick coating (100 µm – 1mm)
COLMONOY 5 (Plasma SNM) / COLMONOY 6 (Plasma SNM)	☹☹	☹	☹☹	Thick coating (100 µm – 1mm)
STELLITE 6 / STELLITE 6	😐	😐	☹☹☹	Thick coating (100 µm – 1mm)
STELLITE 6 / STELLITE 12	😐	😐	☹☹☹	Thick coating (100 µm – 1mm)

Table 2 : Material couples recommended for tribological application in Na FBRs conditions..

This synthesis shows that in Na FBRs tribological conditions, the best candidate to use are :

- Coatings such as TRIBALOY 700 or D-GUN CERMET,

- Aluminisation surface treatment on stainless steel, which was envisaged on EFR project for numbers of devices like, control rods, steam generator tubes guides, …

The conditions of FBRs running are specific and very different than the HTR conditions. In tribology studies, the change of one parameter can change significantly the ”tribocontact” comportment. Nevertheless, the best candidates in FBRs tribological conditions would have to be tested in HTR ones up to 600°C. Beyond 600°C, metallic materials would not be adapted. D-GUN CERMET could be tested up to 850°C [15].

So the study of CERAMIC materials, which can run up to 1000°C in HTR conditions, is necessary. One of the potential candidates should be ZrO_2-Y_2O_3 / NiCrAlY [15].

APPENDIX

7.1 Appendix 1 : Deliverable 37

Title "Review of tribological problems on former HTRs and on FBR technology"
Schedule January 2002 – November 2002
Responsible Framatome ANP S.A.S (1)
Partners CEA (2), FZJ (5), NNC (7), FANP GmbH (15)

DOCUMENT ORGANISATION

INDEX	**RESPONSIBLE**	**INPUT NEEDED**	**DATE**
General principles			
Feed-back experience from former HTRs, AGR, tests facilities, FBR,….. giving : • The component description • The involved materials or coatings • The tribological conditions (contact pressure, speed, …) • The environment conditions (gas pressure, nature of gas, T, presence of impurities,…) • Operating and upset conditions			
Dragon project, AGR,	**NNC**		Draft available in June 2002
THTR 300, HHT, AVR, VHTR (Japanese reactor)	**FZJ**		Draft available in June 2002
FBR (Phénix, Superphénix)	**CEA**	• From FRA-ANP, for Phénix and SPX	Draft available in June 2002
Fort St Vrain (USA), HTTR, HTR10,	**Framatome-ANP**	From HTTR and HTR10 (HTR TN agreements)	Draft available in June 2002
HTR modul (tests)	**FRA- GmbH**		Draft available in June 2002
Conclusion: synthesis of documents	**Framatome-ANP**		Draft : Sep 2002 for partner comments Final : Nov 2002

7.2 Appendix 2 : Tribometers used for tribological studies.

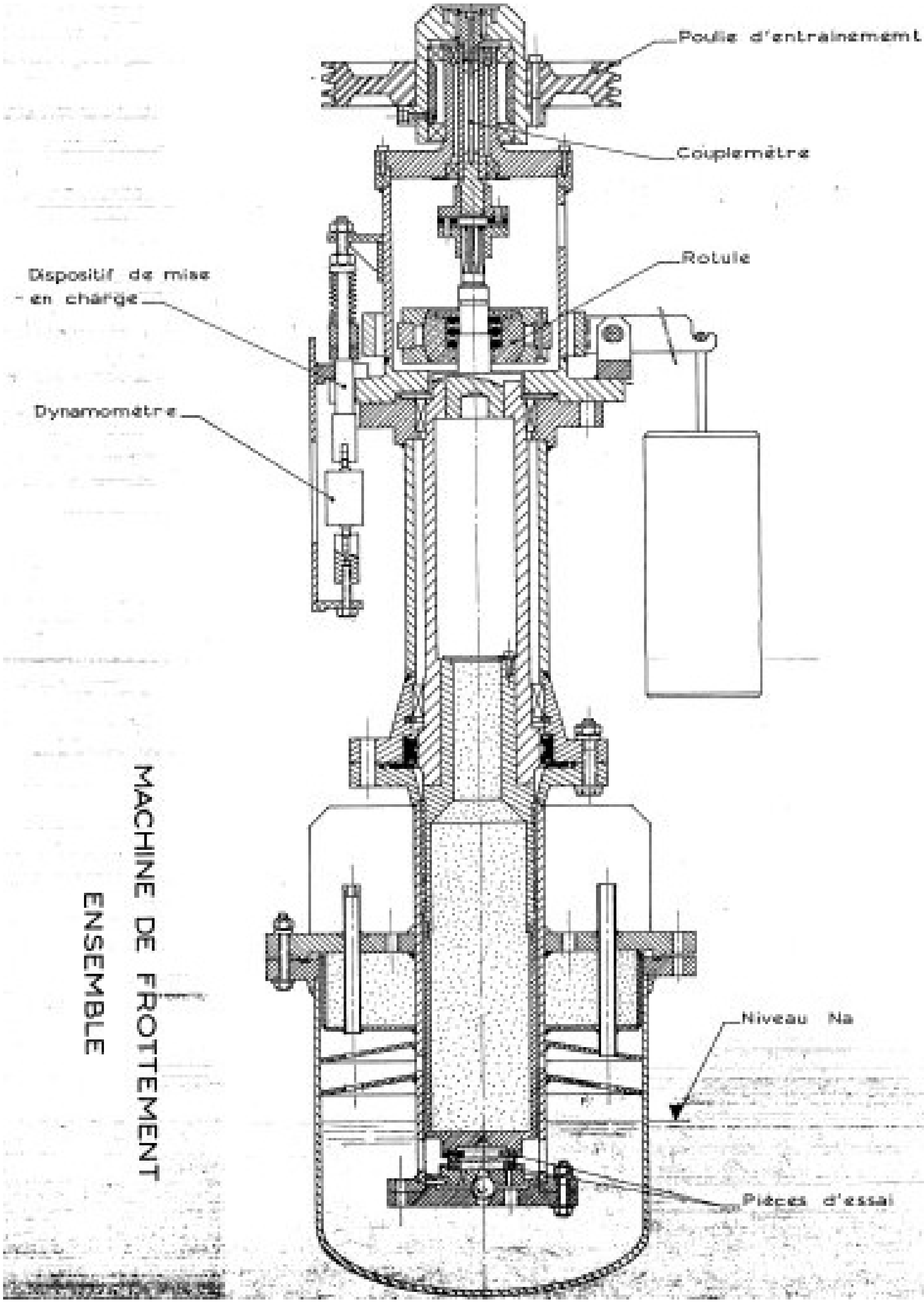

Fig.1

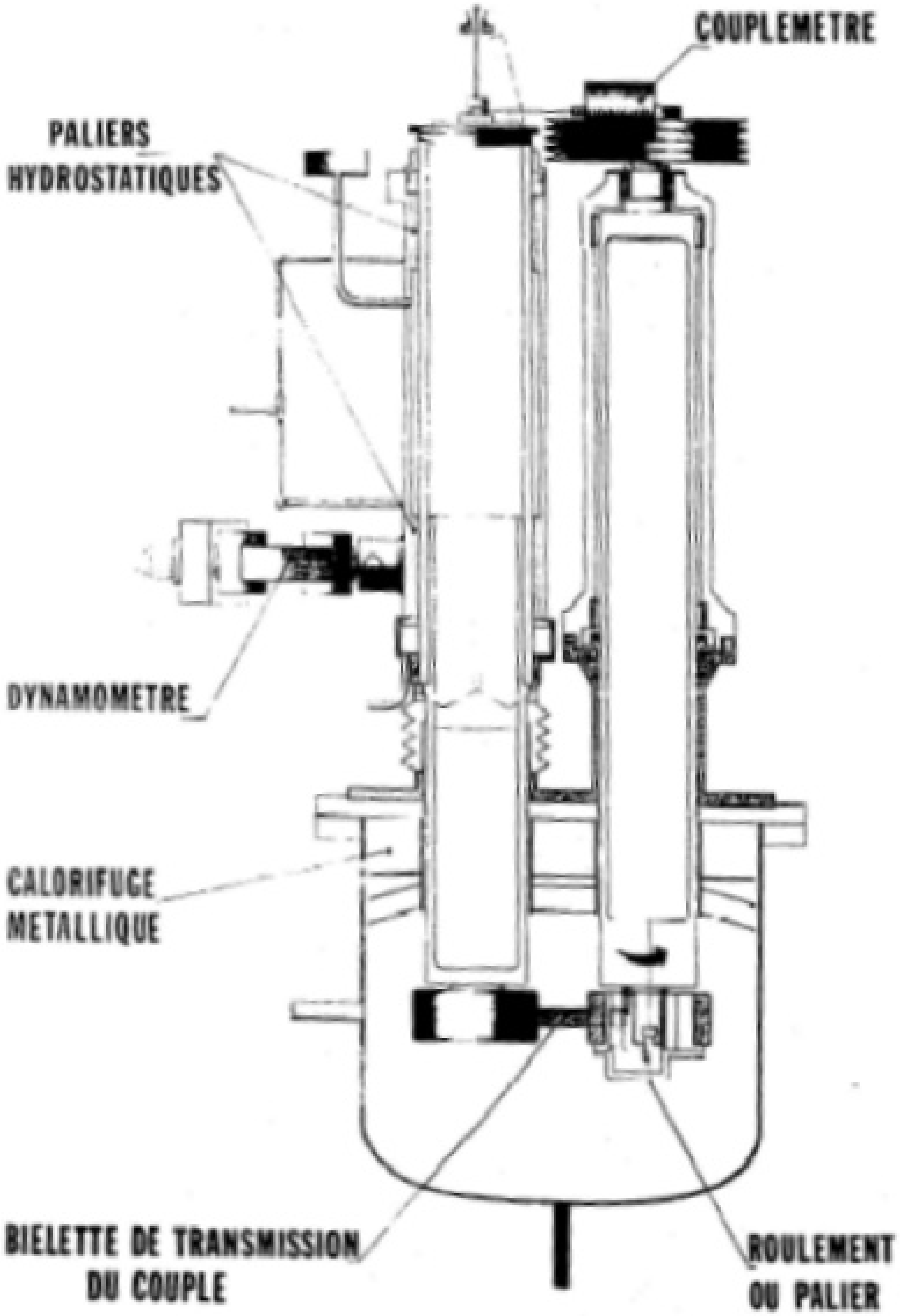
COUPLEMETRE
PALIERS
HYDROSTATIQUES
DYNAMOMETRE
CALORIFUGE
METALLIQUE
BIELETTE DE TRANSMISSION
DU COUPLE
ROULEMENT
OU PALIER

fig.2

FICHE DE VÉRIFICATION DU DOCUMENT

TITRE DU DOCUMENT :

HTRE – Deliverable 37 of WP5
Review of tribological problems on former HTRs and on FBR technology

Rédacteur : L. CACHON

Domaines* de la Vérification	**Résultats ****		
1) Vérification de la forme : respect de la PR1 G1 du MQ DER	Conformité		
Modèle de NT	C	NC	
Contenu des « cartouches » : page 1, page 2 et page courante	C	NC	
Plan du document et Pagination	C	NC	
Clarté de la mise en forme (traitement de texte)	C	NC	
Respect de l'orthographe et de la grammaire françaises	C	NC	
Formules, Figures, Tableaux, … (titres, unités, échelles, légendes, …)	C	NC	SO
2) Vérification scientifique			
Les documents de références et les documents applicables sont-ils mentionnés ?	Oui	Non	SO
L'étude s'appuie-t-elle sur une analyse de l'état de l'art ?	Oui	Non	SO
Le problème est-il clairement posé ?	Oui	Non	SO
Les hypothèses sont-elles clairement définies ?	Oui	Non	SO
Les données sont-elles appropriées et validées ?	Oui	Non	SO
Les méthodes employées sont-elles justifiées et validées ?	Oui	Non	SO
Les ordres de grandeur sont-ils cohérents ?	Oui	Non	SO
Les conclusions sont-elles justifiées ?	Oui	Non	SO
3) Vérification de la clarté et de la cohérence d'ensemble			
Le Titre est-il explicite et pertinent ?	Oui	Non	
Le Résumé est-il autoporteur, clair et conclusif ?	Oui	Non	
Le Résumé est-il cohérent avec l'Introduction et la Conclusion ?	Oui	Non	
Les Mots Clés sont-ils pertinents et exhaustifs ?	Oui	Non	
L'Introduction indique-t-elle suffisamment : les objectifs contractuels, le contexte technique, les objectifs précis, les enjeux, …	Oui	Non	
L'Introduction présente-t-elle l'articulation de la présentation ?	Oui	Non	
L'enchaînement des étapes de la présentation est-il compréhensible ?	Oui	Non	
La Conclusion précise-t-elle clairement le degré d'atteinte des objectifs contractuels ?	Oui	Non	
La Conclusion ouvre-t-elle des perspectives ?	Oui	Non	SO

Bilan de la Vérification			
Les modifications demandées ont toutes été prises en compte par le Rédacteur	Oui	Non	SO
Les modifications listées en PJ n'ont pas été suffisamment prises en compte par le Rédacteur et nécessitent l'arbitrage de l'Approbateur	Oui	Non	SO

**	C et Oui	Jugé Satisfaisant par le Vérificateur
**	NC et Non	Jugé Non Satisfaisant par le Vérificateur : modifications demandées au Rédacteur
**	S.O.	Jugé Sans Objet par le Vérificateur (la rubrique ne s'applique pas)

Vérificateur* :	**Domaines* : 1, 2 et 3**	**Date :**	**Visa :**

* S'il y a plusieurs vérificateurs, chacun remplit une Fiche en précisant les domaines qu'il a vérifiés