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Title
RELIABILITY OF THE MOGLI GAS DETECTION SYSTEM FOR UNMANNED PLATFORMS

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ABSTRACT

The reliability and the availability of the MOGLI gas detection system to be used on unmanned platforms has been assessed. The assessment has been carried out on basis of a failure mode and effect analysis, followed by a quantification of the failure rate as can be found in literature and by expert judgement.

The failure frequency of the total system is estimated on once per year. Practical experience is necessary to obtain more substantial proof of the reliability of the system. The availability of the system can be 0.994, provided the check procedures by the computer system are effective.

TABLE OF CONTENTS

ABSTRACT 2

1. INTRODUCTION 4

2. FAILURE MODE AND EFFECT ANALYSIS 5
2.1 Analysis technique 5
2.2 System blocks 6
2.3 Effects on failure 6
2.4 Results of the FMEA 7

3. QUANTIFICATION 11

4. CONCLUSIONS 14

5. REFERENCES 15

6. AUTHENTICATION 16

Appendix 1 FMEA results

1. INTRODUCTION

The work in this report has been completed by TNO under the terms of the EEC contract for the development of new types of gas and fire detectors to be used on unmanned platforms.
One of the subprojects which is part of the development work is the assessment of the reliability of the gas detection system as designed by the project partner TECSA Srl Italy.
The assessment has been carried out by performing a FMEA (failure mode and effect analysis) and subsequently quantifying the failure probability of critical items. The quantification was done with failure data as can be found in literature and by expert judgement.

The results of the FMEA are presented in chapter 2. Chapter 3 contains the quantification part of the study. In chapter 4 conclusions and recommendations are given.

2. FAILURE MODE AND EFFECT ANALYSIS

2.1 Analysis technique

A failure mode and effect analysis (FMEA) is a commonly used technique to analyze the design of an equipment on possible undesired events, which might happen as a consequence of a technical or human failure. A FMEA is a bottom-up analysis, i.e. the failure modes of system components are defined and their effects upon the overall system investigated. A system to be analyzed is divided in functional blocks and parts. The function of each part is described and subsequently the possible modes of failures are investigated. For each failure mode, causes, effects and possible recommendations to improve the design are identified. Improvements can also be considered on basis of the expected failure frequency of critical parts and by practical experience. At the moment of analysis no practical experience was obtained with the system.

The FMEA on the gas detection system, known as MOGLI which stands for Measuring Organic Gases with Laser Infrared system has been carried out jointly by TNO and TECSA. The analysis is based on project documentation provided by Tecsa and on brochures from manufacturers of various items constituting the subsystems and the parts.
An important benefit obtained by carrying out the analysis is that a better insight can be gained in which failures have to be detected by the system.

2.2 System blocks

The MOGLI design has been divided in the following system blocks:

- cooling system of laser,
- laser system,
- collimation optical system,
- chopper,
- monochromator,
- calibration system,
- detection part,
- atmospheric analysis system,
- communication system,
- general parts.

An overview of the system blocks is presented in figure 1. A more detailed description of the MOGLI system itself and the functions of the subsystems are to be found in a future report by Tecsa.

2.3 Effects on failure

The following important system effects at failure of the gas detection system have been identified:

E1: no gasdetection

E2: the detection system gives a spurious alarm.

E3: the detection system signals the failure of a critical component, not detecting results in the unavailability of the system during a certain period of time, which depends on the time between calibrations or maintenance.

Occuring of E1, no gas detection as a result of a failure of a critical component, could imply a dangerous situation when at the same time a major escape of gas takes place. The time in which the system on a unmanned platform is unavailable should be as short as possible. Hence the probability of E3 should be as high as possible and consequently the aim of the design should be such that every failure of a critical component is detected by the system itself, although in practice this may result in excessive effort and expenditure being concentrated in a BITE system.

If the probability of correct selfdiagnosis is close to 1 or (P[E3]=1), the probability of E2 will tend to be zero (giving a spurious signal means the system is failing and is not available). Furthermore it has to be emphasized that occurring of E2 (a spurious platform shutdown) will result in significant economic consequences.

For electronic components three failure modes can be distinguished: (see ESA [3]): short, open and drift. A short or an open signal is in most cases easy to detect. A drifting signal by failure of the electronic component, however, is difficult to distinguish from a really changing signal. This could result in effect E2 or even E1. To detect drifting signals a test procedure with known input and output signals is needed. The degrading of non-electronic components and by this a weaker output signal has to be taken in consideration.

2.4 Results of the FMEA

The results of the FMEA are presented in tables in Appendix 1 of this report. As a general finding it can be stated that the consequence of a failure of the majority of components of the detection system results in no detection of gas, which is caused by the fact of limited redundancy. In later discussions on failure probabilities it is recommended to include more redundancy in the system especially for the vacuum system.
Although the failure of many parts results in a failure of the total detection system, it is checked for the possible failing parts that the design of the software system will be such that each foreseeable failure will be detected either directly or in an indirect way.
Below the summarized results are given as obtained per system block.

Cooling system of laser

The cooling system consists of a compressor and a temperature meter. The temperature of the laser should be kept in a narrow range.

Failure of the temperature alarm itself (failure of the sensor or failure of the amplifier, for example a drifting signal) can result in a temperature alarm or in a wrong temperature for the laserdiode and consequently in a wrong emitting frequency of the laserdiode.

Laser system

The laser system is the key element in the total detection system. The manufacturer of the system has provided the system with four laser diodes.

A failure of a laserdiode leads automatically to an exchange of the failed diode into another diode which is done, on command of the computer system, by the x-positioner. The redundancy of the laser system depends on the functioning of the x-positioner. A regular test of the positioner and diodes is therefore recommendable.

Another possibility of not getting the benefit of a fourfold redundancy of the laser system is a failure of the pressure and temperature indicators. A too high temperature not indicated by the sensors leads to a failure of the diode. Hence the diode will be changed automatically and the next new diode will also fail because of the incorrect temperature. This possibility has to be adressed in the software routines in the computer system.

Collimation optical system

The collimation system consists of a mirror and lenses which should be free of dust and moisture. The functioning of these components depends therefore on the correct functioning of the air conditioning system.

A failure of the airconditioning system, results in diminuation of precision of the gas detection. The consequences of this are not quite clear; it seems possible that E2 or even E1 can occur. To avoid this, the proportion I/I(zero) should be controlled periodically, with an alarm when this proportion is too low.

Chopper

The chopper is to split the beam into a reference and a detection signal.

A failure of the chopper is detected by both line-in-amplifiers LIA1 and LIA2.

Monochromator

The monochromator is to select a specific frequency of light. The monochromator is adjusted during installation. The correct functioning of the monochromator is almost entirely dependent of the correct functioning of the air conditioning system.

Wave length locking system

The wave length locking system consists of a low pressure (L.P.) cell and a vacuum pump and a reference gas supply. The system is needed to stabilize the laser wave length at the centre of the absorption sector for the measurement.

A drifting signal could occur on failure of the detectors D1 and D2, the amplifiers of the detector-signals and in the line-in-amplifiers LIA1 and LIA2. The possibility of a drifting signal should be recognized by the test procedures of the computer.

On discussion of the reliability of the wave length locking system, it is decided to replace the L.P. cell with valves, pump and p-sensor by a gas tight cell, this by its simplicity should be much more reliable.

Detection part

The detection part consists of the detection cells coupled to fibercombs with yz-postioners and a check cell. The postioners have at least two levels: a first level to divide the detection cells in groups and a second level to divide the signal between specific cells. The check cell is needed to compare a standard signal to the signal as measured in the platform environment.

Failure of the first-level yz-positioners will effect the functioning of the complete gas detection system whereas a failure of the second-level yz-positioners only effects the functioning of a group of gas detection cells.

Failure of other components in the detection part means that only in one cell no gasdetection is possible. With the check-cell the functioning of the whole gasdetection system is controlled, except parts of other de-

tection-cells, like the airflush and the retro-reflector. (An extra check of the good functionning of the detection part could be obtained by an additional HeNe laser system, which is needed for the initial installation of the detection part.)

Moisturing of the fibercomb can, on the long term, have consequences for the detection possibilities, which mainly depends on the air conditioning system.

Athmospheric analysis system

The atmospheric analysis system consists of detector D3, an amplifier and two line-in-amplifiers.

The previous comments on the detectors, amplifiers, line-in-amplifiers, air conditioning system, do also apply for these system parts.

Communication system

The gas detection system will be coupled to a communication system to on-shore. A failure of the communication system means that from on-shore no action can be taken in case of an undesired event. However this does not impair the safety of the platform, as the protection system does not require shore information, but would result in an urgent maintenance visit from shore.

General failures

The functioning of the gas detection system is also dependent of the power supply as available on the platform. We have assumed that the redundancy of the power supply is such that it will not effect the reliability of the gas detection system. The gas detection system is expected to be supplied from the emergency switchboard, the availability of which is extremely high and if this switchboard looses power the platform will shut down in any case.

Furthermore, interfaces and cable connections are of relevance in this respect.

3. QUANTIFICATION

The quantification of the failure frequency of the gas detection system has been carried out by consulting literature data and by expert judgement. The expert judgement has been done by an expert of TECSA and by an expert of TNO.

Literature data

For the critical components as found by means of the FMEA failure rates have been assessed. Sources for these failure rates were (see also section 5 references):

* databanks
* handbooks
* data of the supplier
* educated guess.

The failure rates thought to be applicable are included in the tables of the FMEA (Appendix 1).

The total failure frequency of the gas detection system has been calculated starting from the following assumptions:

* The main effect to be considered is no gas detection. The possibility of a spurious alarm and unsufficient selfdiagnosis should be recognized by computer check procedures, which is dependent of the reliability of the software and the total test time spent on checking the software. At the moment no validated methodology is available to assess the reliability of certain computer programmes. In order to get a more reliable computersystem, a second opinion on the correctness of the structure and consistency of the programme routines is recommendable.
* Failure frequencies are constant. This implies that degradation processes as wear out and ageing are not considered. This also implies maintainance (inspection, repair, renewal) will be carried out properly.
* No gas detection on the long term is equivalent to no gas detection in general.
* Failures of components, which are only relevant during installation of the gas detection system, are neglected.

The total failure rate of the gasdetection system has been calculated by summing up all failure rates. In table 1 the calculated failure rates per year for the different subsystems and for the total system are given.

Table 1 Failure rates of subsystems and of total system

Subsystem	Failure rate [-/year]
cooling system of laser	2.9E-1
laser system	2.7E-2
collimation optical system	8.8E-3
chopper	8.8E-2
monochromator	1.8E-4
wave length locking system	3.2E-1
detection part	3.3E+0
atmospheric analysis system	1.8E-1
communication system	3.7E-1
general parts	8.8E-3
total system	4.6E+0
total system without fibers and communication s.	1.0E+0

On average 4.6 times a year the system fails on such a way that in one or more cells no gasdetection is possible. From this on average 1.0 times a year the gasdetection system will fail such a way that no gasdetection at all is possible.
The calculated value must be seen as an indication only, because of lack of practical experience the estimated failure rates are uncertain.

If it is assumed that at each failure of the system is detected (P[E3]=1) and that a repair will take on average two days, the availability of the system is approximately 363/365=0.994. The availability of the system in which all cells should function is with an estimate of 4.6 failures per year 356/365=0.97.

Expert judgement

The experts have been asked to give an opinion about their thoughts with regard to the expected reliability of the critical parts of the gas detection system. The rating was low, medium and high reliability. As a rule of thumb high reliability equals to a failure rate of 1.10^{-6} per hour and another next category has a 10 fold higher or lower failure rate. The ratings as given by the experts are listed in tables of the FMEA.

In general the expert ratings agree rather well to each other and to the failure frequencies as found in literature. According to one expert special care should be taken to the correct electronic coupling of the various system parts, which can be done by adequate measures according to the second expert.

From the discussions about the reliability of the system it is concluded that the vacuum pump should have redundancy and that the low pressure cell should be a gas tight cell, although the total reliablity will not be affected drastically by these design changes.

The reliability of the fibers has been given a rather low rating, following some bad experience in the past. It is expected the fiber coupling can be improved. Practical tests will give the necessary insight in the functioning of the fibers.

4. CONCLUSIONS

The calculated reliability of the MOGLI system indicates a failure frequency of one per year. No gas detection by one specific cell could happen 4.6 times per year. Since more cells can detect an escape of gas the overall reliability of measurement per cell can be better. Practical tests will be necessary to give these figures a more solid basis.

The availability of the system is highly dependent of the capability of correct selfchecking of the system. If the self checking procedures are optimal, the system will have a high availablity and a low spurious signal rate. The availability of the total system, with a repair duration of two days and a failure frequency of one per year, is estimated on 0.994.

5. REFERENCES

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Appendix 1 RESULTS FMEA

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
I	COOLING SYSTEM OF LASER								
1.1	compressor	compress He	electrical mechanical	loss of cooling, no gasd	temp alarm failure rate Compi not directly applicable	3,0E-05	C	L	L
1.2	temperature sensor	measure T	electronic	T(measured) < T(real) laser not enough cooled, loss of cooling, no gasd		1,0E-06	C	HH	H
1.3	sensor amplifier		electronic	loss of cooling, no gasd			in 1.2	H	H
1.4	pipes		leak, rupture	loss of cooling, no gasd		1,0E-08	C	HH	HH
1.5	cooler	cool laser	leak	loss of cooling, no gasd	Gifford-Mcmahon or Stirling - maintenance free for 1 year (data manufacturer)	1,0E-06 0,0E+00	C, E	HH	HH
1.6	heater (resistance)	fine tuning T	damage	loss of cooling, no gasd	negligible	1,0E-08	E	HH	HH
1.7	heater controller		electronic	loss of cooling, no gasd		1,0E-06	E	H	H
1.8	connection between heater and controller		bad connection	loss of cooling, no gasd		1,0E-08	N	M	-
1.9	connection between heat controller and PC		bad connection		alarm	1,0E-08	N	M	-
	subtotal					3,3E-05			

FREQUENCY [-/hr]
C = Compi
GB = Green & Bourne
N = Negligable
E = Estimation
R = Redundancy

EXP1 = Expert 1 (TNO)
EXP2 = Expert 2 (TECSA)

L = Estimated component reliability low (failure frequency 1E-04)
M = Estimated component reliability medium (failure frequency 1E-05)
H = Estimated component reliability high (failure frequency 1E-06)

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
II	LASER SYSTEM								
2.1	lasercase/gaskets	protection	leakage		negligible	1,0E-08	N	HH	HH
2.2	laserdiode (4x)	emission	rupture of bounding by thermic. stress	automatic change of diode wwith X postioner see 3.2	mtbf = ■ 1 year (Mutek, Spectral Physics)	1,0E-08	R	H	H
2.3	laser current control		electronic	no gas detection		1,0E-06	E	H	M
2.4	connection between laser current control and LIA2		bad connection	degradation, no gas detection		1,0E-08	N	H	-
2.5	turbomolecular + back press. pump	maintain vacuum near diode	mechanic electric	no gas detection	alarm is given	1,0E-06	C, E	M	H(r)
2.6	electr. control sys. of pump		electronic	no gas detection			in 2.5		
2.7	pipe between pump and laser		rupture, leak	air leaks in no gas detection	alarm from vacuum system (p-sensor)	1,0E-08	C	M	M
2.8	valve in pipe		valve closed	no gas detection		1,0E-08	N	L	H
2.9	connection between laser current control and PC		bad connection	no control	alarm; after period possible stop gasdetection	1,0E-08	N	M	-
2.10	p-sensor	control p	electronic	depends on software		1,0E-06	C, E	H	H
	subtotal					3,1E-06			

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
III	COLLIMATION OPTICAL SYSTEM								
3.1	mirrors and lens		moistured; out of position	diminuation of precision in detection	check by system alarm by proportion I/I(zero) too low	1,0E-08	N	HH	HH
3.2	X positioner electrical motor	optimate laserbeam direction	mechanical electronic electric	no correct position no gas detection	detection of failure by check of output of detectors 1 & 2 and by encoder	1,0E-06	E	H	H
3.3	connection between XYZ and PC		bad connection	no change in possition possible, see also 3.2	complete handshake	1,0E-08	N	M	H
	subtotal					1,0E-06			
IV	CHOPPER	bacground noise calculation							
4.1	electric motor	turn chopper	electric	no gas detection		1,0E-07	C	H	H
4.2	frequency counter (infrared fotocell)	read frequency for LIA 1 and 3	electronic	no gas detection		1,0E-05	GB	H	H
4.3	disc		mechanical		negligible	1,0E-08	N	HH	HH
4.4	connection between chopper and LIA 3		bad connection	no gasdetection possible	see remark at 4.2	1,0E-08	N	M	H
4.5	connection between chopper and LIA 1		bad connection	no gasdetection possible	see remark at 4.2	1,0E-08	N	M	H
	subtotal					1,0E-05			
V	MONOCHROMATOR	cancel out side modes							
5.1	stepping motor		electronic electrical	no installation possible	only used before operation to install	1,0E-08	N	-	-
5.2	electr. contr. sys.		electronic	no installation possible	see 5.1				
5.3	connection between stepping motor and PC		bad connection	no installation possible	se 5.1	1,0E-08	N	-	-
5.4	optics		see 3.1	see 3.1	see 3.1	1,0E-08	see 3.1	HH	HH
	subtotal					2,0E-08			

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
VI	WAVE LENGTH LOCKING SYSTEM								
6.1	low pressure cell	contain ref. gas	leak	air flows into system & no gasdetection possible	pressure alarm; how is quality ref. gas in LP cell controlled?	1,0E-07	E	H	H
6.2	valves		leak	no change of ref. gas results on long term in incorrect gas detection	continous gasflushing?	1,0E-06	C, E	-	-
6.3a	pump	maintain p low in LP cell	mechanical electrical electronic	pressure to high, see also 6.2	test pump before really needed	1,0E-06	C	-	-
6.3b	p-sensor	see 2.10				1,0E-06	C, E	-	-
6.4	splitters 2 diffraction optics	split up beam	see 3.1	see 3.1	see 3.1	1,0E-08	see 3.1	H	H
6.5	detector D1 diode	transduce into current	electronic	proportion U/U2 cannot be calculated	system down	1,0E-07	C	H	H
6.6	4-stage thermoelectric cooler (Peltier)	cool detector	electrical	proportion U/U2 cannot be calculated	see 6.5	1,0E-05	C, E	HH	H
6.7	electr. tempcontr. of cooler		electronic	proportion U/U2 cannot be calculated	see 6.5	1,0E-06	see 1.7	M	M
6.8	detector D2	see 6.5 - 6.7				1,0E-07	C	HH	H
6.9	amplifiers 1 & 2	amplify detector-signals	electronic electrical	no gas detection	software routine required to test amplificators;	2,0E-06	GB, E	H	H
6.10	contacts between detectors and LIA's		bad contact	proportion U/U2 cannot be calculated		1,0E-08	M	M	-
6.11	power supply of amplifiers transformer converter	supply power to amplificators	electrical	no gas detection		1,0E-06	GB	H	-

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
6.12	LIA 1	takes frequency of chopper and laser calculates 1st Fourier der. of frequency laser	disturbing noises; electronic	proportion U/U2 cannot be calculated	software check of LIA needed	1,0E-05	GB, E	M-H	M-H
6.13	LIA 2	takes reference frequency; calc. 1st Fourier der.	disturbing noises; electronic	proportion U/U2 cannot be calculated	software check of LIA needed	1,0E-05	GB, E	M-H	M-H
6.14	connections between LIA's and PC		bad connection	on long term no gasdetection possible		1,0E-08	N	M	-
	subtotal					3,7E-05			

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
VII	DETECTION PART								
7.1	fibercomb	direct beam to different cells	humidity absorbtion	moisturing of fiber ends on the long term no gas detection	check periodically test: control proportion input- and outputintensity of detection part needed	1,0E-07	E	-	-
7.2	XYZ postioners 2 electr. motors (2x3=6)	direct laserbeam to different fibers	electrical electronic mechanical	detection in all cells not possible	identification of failure is no problem; synchronity between pairs of positioners	1,0E-06	C, E	H	H
7.3	connections between positioners and PC		bad connection	detection only at one cell	alarm	1,0E-08	N	M	-
7.4	fibres	transmit beam to different cells	files bend to much rupture	no detection at the cell in consideration	fibres could be placed in tu 36 fibres, 100 m length human error	3,6E-04	E: 1E-8/M	LL	LL
7.5	cell	place where detection finds place	beam obstructed	no detection possible in the cell in consideration	alarm on different levels possible, depending on duration of obstruction	1,0E-08	N	HH	HH
7.6	mirror	reflect beam into two directions	negligible?			1,0E-07	E, N	??	??
7.7	airflushing at mirror and diffraction optic	keep clean optics	no flush or not enough	moisture, see 3.1	no control available of local airflush; alarm as in 7.1 is needed	1,0E-06	E	??	??
7.8	retroreflector	reflect beam	moistured	see 3.1	identification of failure by alarm as mentioned in 7.1	1,0E-06	E	??	??
7.9	coupling optics (2x)	collimate beam to fiber comb	moisture	see 3.1	see 3.1	2,0E-08	see 3.1	HH	HH
	subtotal					3,8E-04			

remark about detection part: a checkcell controls the functionning of the system; there is also an extra control of the functioning of the fibers and cells by a HeNe laser system.

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
VIII	ATMOSPHERIC ANALYSIS SYSTEM								
8.2	detector D3	see 6.5 & 6.8	see 6.5 & 6.8	no gas detection if tempsensor fails by indicating T too low, fals alarm is possible		1,0E-07	see 6.5	HH	H
8.3	amplificator 3	see 6.9	see 6.9	no gas detection	see 6.9	1,0E-06	see 6.9	H	H
8.4	LIA 3	calculates 1st Fourier der. of beam freq.	electrical electronic	no gas detection		1,0E-05	see 6.12	M-H	M-H
8.5	LIA 4	calculates 2nd Fourier der. of beam freq.	electrical electronic	no gas detection		1,0E-05	see 6.12	M-H	M-H
8.6	connection between LIA 4 and current control		bad contact	no gas detection		1,0E-08	N	M	-
8.7	connection between PC and LIA's 3 & 4		bad contact	no gas detection		1,0E-08	N		
	subtotal					2,1E-05			

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
IX	COMMUNICATION SYSTEM								
9.1	PC		hardware software		hardware: negligible on platform because of 3 parallel computers; software: human error?	1,0E-06	E	L	L
9.2	radiolink	transmit information from PC to "on shore"	electronic	no relay of information to onshore about situation on platform		3,0E-05	TNO/PTT 0.25-0.30/year	L	-
9.3	alarm front-end		electronic	no action taken	on shore control must take action in such a situation	1,0E-06	E	H	
9.4	analog data interface		electronic	?		1,0E-06	E	H	
9.5	trip system		mechanic electronic hydrolic	no action taken ?		1,0E-05	E	L	
	subtotal					4,2E-05			
X	GENERAL FAILURES								
10.1	PC	see 9.1		no gas detection	see 9.1		see 9.1		
10.2	Interface	connection between PC and different components	electronic	no gas detection		1,0E-06	E		
10.3	Power supply		no current	no gas detection		1,0E-08	N		
	subtotal					1,0E-06			

NR	COMPONENT	FUNCTION	FAILURE MODE	EFFECTS	REMARKS	FREQUENCY	SOURCE	EXP1	EXP2
	COOLING SYSTEM OF LASER					3,3E-05			
	LASER SYSTEM					3,1E-06			
	COLLIMATION OPTICAL SYSTEM					1,0E-06			
	CHOPPER					1,0E-05			
	MONOCHROMATOR					2,0E-08			
	WAVE LENGTH LOCKING SYSTEM					3,7E-05			
	DETECTION PART					3,8E-04			
	ATMOSPHERIC ANALYSIS SYSTEM					2,1E-05			
	COMMUNICATION SYSTEM					4,2E-05			
	GENERAL FAILURES					1,0E-06			
	TOTAL					5,3E-04	[-/hr]		
						4,6E+00	[-/yr]		
	Total without fibers					1,4E+00	[-/yr]		