Technical University of Denmark

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Aage Jensen, Jens Rasmussen and P. Timmermann

The Danish Atomic Energy Commission
Research Establishment Risö
Electronics Department

Abstract

A failure reporting system for electronic equipment is described, and fault data for selected electronic reactor instruments and research equipment are presented. Some average figures are suggested for rough predictions of failures in larger instrument systems.

CONTENTS

1. Introduction

Owing to the increasing importance and complexity of electronic equipment, reliability problems play a more and more significant part. Both in reactor instruments and in large, expensive experimental set-ups the consequences of failure have to be examined already at the design stage and must, especially in the case of safety systems, be followed carefully throughout the life of the equipment.

To improve the reliability and guarantee the safe operation of reactor instruments, radiation monitors and other vital instruments, a failure registration system is indispensable. Failure causes and consequences are, however, a complex function of component quality, circuit design, system planning, environment, operation, and maintenance, and a clear picture of the instrumentation is often difficult to obtain.

This report discusses some of the main problems in a registration system and some of the data collected during a two-year period by the Electronics Department at Risö. The registration started in 1960 and covers the reactor instruments at DR 2 and DR 3, together with all the research instruments constructed by the department.

It should be borne in mind that the failure rates quoted are biased by environment, repair policy and type of work. Comparison with other similar examinations is difficult and the use of other data for prediction therefore very approximate.

2. Application of Results

There is such a variety of influencing factors connected with failure that reporting of all relevant information is almost impossible and also too heavy a load on the maintenance personnel. It is therefore important to clarify what information it is desirable to extract from the data and to plan the reporting system so that only necessary questions are put to the service staff. It is essential to give careful instructions and explanation of the reasons for reporting failures in order to maintain interest. The largest single factor of error is probably insufficient reporting.

From the beginning the reporting system should establish a feed-back of reliability information from the service group to the instrument designer so that systematic design faults and component defects maybe corrected. This is important because of the extensive use of novel circuits and techniques in connection with the limited time available for prototype testing.

Examination of repeated failures under the same conditions will serve this purpose, and a quarterly summary will give the designer an indication of abnormal conditions.

Control of the quality of components and apparatus and collection of material for prediction of failures is also intended. Owing to the statistical nature of failures and the rather limited number of similar instruments working under the same conditions, it is difficult to test whether statistical control exists and to show any possible trends in the data.

The main sources of deviation from a simple failure pattern are to be found in use outside the specifications, such as occurs in the variety of applications of laboratory instruments. Also the different maintenance intervals for different instrument types impose a statistical variation which is considered important.

No preventive maintenance measures are taken for the research instruments, and their performance is only judged by the user. Then the service group is called in for correction of faults, a general check on performance is made, and other possible faults are corrected. When the service group is called in frequently owing to systematic failures, a higher rate of non-systematic failures will be observed. In the reactor instrument systems regular preventive maintenance takes place, but, for reasons of operational convenience, not at strictly equal intervals.

Another source of uncertainty is the estimation of operation time. Owing to the technical and administrative burden of furnishing the instruments with time indicators this solution is abandoned, and the operation time can range from "laboratory storage" to non-stop operation without any indication. Only for reactor instruments, which operate day and night, can the operation time be ascertained with certainty. These factors must be considered if the data are used for more detailed analysis. Up till now it has only been possible to deduce some more or less uncertain averages. It is planned, however, by test sampling to obtain an estimate of the operation time and moreover some information on maintenance.

3. Collection of Failure Data

The primary data concerning individual failures are noted on a repair form by the service technicians. As repair and service are centralized, only a small number of technicians have to be instructed. Data concerning instrument duty time are taken from a central file.

The data are coded in order to facilitate later examinations. The coding permits a punch-card system to be introduced later. It has been considered whether an advanced technical examination and coding of the repair form could be saved, but in our experience, coinciding with that of others, up to 80 % of the incoming reports have minor errors.

To facilitate later detailed analysis all replaced components are stored.

Repair form

Fig. 1 shows a translated repair form which has been used for registration. The collected data will be discussed later in the report, but as the conditions for collection are important for the evaluation of the data, a summary of the headings is given.

The repair form is completed immediately after repair by the service technicians. The statistical value of the data will to some extent depend on skill, especially in the diagnosis of failures. It is important to attain a uniform treatment of faults by the service staff in different service shops.

The repair number allows a simple storage of replaced components so that a more detailed examination may take place. This is valuable in the search for the causes of systematic failures and for the evaluation of the rates of different modes of failure, which are very important in the safety evaluation.

Type, manufacture, AEK No. This information identifies both the type and the individual instrument. Most reactor instrumentation consists of commercial apparatus, for which type and make should be filled in. The instruments designed by the Electronics Department have been subjected to comprehensive standardization, which to some extent allows a further division into sub-chassis such as standard power supplies built into different instruments.

Repair date. This gives a time distribution of failures, which may, especially for continuously operating instruments, provide information of initial performance and wear-out failures.

The location may give an indication of environmental stresses. A general analysis of the effect of different environments is not intended, but reference is made to general laboratory conditions. In some cases special results may be found in extreme environmental conditions and will thus be excluded from the general statistics.

Time integrator. The operation time is one of the most important parameters. Unfortunately, the measurement of integrated working time gives rise to administrative and economic problems. For the reactor instrumentation the working time is assumed to be 24 hours per day. This estimate is fairly good, as the repair time for individual instruments is comparatively short. For laboratory instruments, mainly designed by the Electronics Department, the date of delivery from store is the only well-known parameter. Replacements and non-duty during night hours make the actual operation time very uncertain. In order to compare different groups of instruments, the duty time for laboratory instruments is assumed to be 20% of the time out of store.

Installation of individual (electrolytic) time integrators in a large number of instruments has been considered. Such devices are built for 500-10,000 hours' operation. Electromechanical time integrators common for all instruments in a system are in use, but replacement of faulty instruments makes the figures uncertain.

AEK - RISØ
Elektronik afd.

REPARATIONSJOURNAL REP. № 6305

TYPE:	Chassis: ved AEK-typer	FABRIKAT:	AEK-NR. I mangel heraf fab.nr.	DATO:

Tilhører afd.:	TIMETÆLLERAFLÆSN.:	REPARATIONSTID:

Fejlen har vist sig UNDER DRIFT ☐, ved EFTERSYN EFTER REP. ☐, ved ANDET EFTERSYN ☐

Instrumentet udsat for OVERLAST: MEKANISK ☐ ELEKTRISK ☐ FUGT ☐ VARME ☐

Fejlen er rettet ved REPARATION ☐, ved MODIFIKATION ☐, ved JUSTERING ☐ af dertil bestemte variable komponenter. Justering efter reparation medtages ikke. Kun justeringer, der er nødvendige for at bringe instrumentet indenfor sine specifikationer, må medtages.

Fejlen er PERIODISK og IKKE LOKALISERET ☐.

Fejlen skyldes UDSLIDTE ELEKTRONRØR. Herved forstås kun rør, hvis eneste fejl er emission eller stejlhed mindre end 50 % af specificerede, målt på rørprøver. Diagram-kode og -nr. samt type anføres:

Rør, der opføres her, må ikke medtages i de følgende komponent rubrikker.

Fejlen skyldes EGENTLIG KOMPONENTFEJL. Kun den primære fejl anføres her. **Ved flere primære (uafhængige) fejl udfyldes et kort for hver fejl.** Komponentfejl, der skyldes overbelastning på grund af anden komponentfejl, medtages altså ikke. For komponentfejl skal også nedenstående rubrikker om fejlens karakter udfyldes.

Fejlende komponent	Diagram-kode og -nr.	Fejlende komponent	Diagram-kode og -nr.
Elektronrør type anføres		Modstand, fast	
Halvlederdiode »		Modstand, variabel	
Transistor »		Relæ	
Spole el. trafo m. lammelkerne		Omskifter o. l. mek. komp.	
Spole el. trafo af anden type		Stik eller sokkelforbindelse	
Kondensator, fast		Lodning eller ledningsføring	
Anden komponent, arten anføres:			

Komponentfejl er AFBRYDELSE ☐ KORTSLUTNING ☐ ÆNDRING AF DATA ☐ MEK. DEFEKT ☐

Den primære komponentfejl skyldes overbelastning ☐

BEMÆRKNINGER:

Denne rubrik må kun anvendes, når fejlen ikke kan specificeres i ovenstående.
Bemærkninger om reparationens udførelse føres i nedenstående rubrik.

Fejlen ytrer sig ved:	Fejlen rettet ved:

Udfyldes kortfattet, selv om oplysningerne fremgår af andre rubrikker. Sign.:

AEK Risö

Repair No.

Electronics Department

REPAIR FORM

Type:	Chassis (only for AEK types):	Manufacture:	AEK No.	Date:

Location:	Time integrator:	Repair time:

Fault discovered during operation ☐ during maintenance ☐

Instrument exposed to mechanical stress ☐ humidity ☐
electrical " ☐ heat ☐

Fault corrected by repair ☐, adjustment of variable components ☐

Adjustment after repair should not be included. Only adjustments necessary to bring the instrument in accordance with specifications should be included.

Fault spurious and not located ☐

Failure due to wear in valves. Includes cases where the only fault is a fall in emission or transconductance to less than 50 % of nominal value. Measurements with valve tester. Diagram code and No. and type should be stated.

Faults stated here should not be included below.

Failure due to real component faults. Only primary faults should be stated. Two or more independent faults should be stated on separate forms. Failures originating from overloading due to other failures should be excluded. For component failures the spaces dealing with modes of failure should be filled in.

Faulty component	Diagram code and No.	Faulty component	Diagram code and No.
Thermionic valve		Resistor, fixed	
Semiconductor diode		- , variable	
Transistor		Relay	
Coil or transformer with iron core		Switch or similar mech. comp.	
Coil or transformer, other type		Connector	
Capacitor, fixed		Wiring or soldering	

Other components:

Mode of failure. Short ☐, open ☐, change in value ☐, mechanical defect ☐. Primary failure due to overloading ☐.

Remarks:

This space should only be completed when the fault cannot be specified above. Remarks concerning details of repair should be filled in below.

Influence of fault on performance of instrument:	Fault corrected by:

Information give in the last two spaces will be transferred to an instrument card to aid future trouble shooting.

The reactor instruments work continuously, while the laboratory instruments are switched on and off several times a day. The on-off operation may influence the reliability, and a single switching may be equivalent to a certain operation time. This matter is being examined in our analogue computer, in which one half of the amplifiers are running continuously and the others are switched off at night.

Repair time. An analysis of the repair time may give some information on repair expenses and the possibilities of trouble shooting in the given design. The repair time is a useful parameter when the necessary number of spares has to be estimated.

Failure discovered during operation or maintenance

A considerable number of the instruments are checked and serviced regularly, and an analysis of failures found during maintenance is important in the assessment of the repair policy applied.

Reactor safety instrumentation is liable to two types of failure: safe failures, which release a trip signal from the instrument, and unsafe failures, which impede any trip signal. The latter will only be discovered during checks or maintenance. Classification of these failures cannot be performed by the maintenance staff, but must be carried out later on the basis of the information in this space and the later space dealing with modes of failure.

Mechanical or electrical stress. Environmental conditions have a great influence on the reliability, and an indication of special stresses is important for a correct conclusion from the failure data.

Repair, adjustment, spurious faults. A repair form should be used if an instrument has been taken out of service because of failure, or a check shows that the instrument is outside its specifications. The form is filled in even if the cause of the trouble is not found.

Adjustment should only be stated if the specifications are exceeded and normal function can be re-established by the use of semi-variable components intended for this purpose. Adjustment connected with repair or replacement should not be stated.

Wear in valves. Valves particularly are liable to fail through wear, and a special emission check is carried out. The space is completed when emission or transconductance for a valve has fallen to 50 % of the specified value. The valve test does not take place regularly, but usually when the instrument is being repaired for other reasons. All valves are then tested in a special valve tester, and those failing at the 50 % test are rejected, even when their performance is satisfactory.

If a valve is the primary cause of an instrument failure, and it is not classified as a worn-out valve, the failure is registered as due to a defective valve. This is not always correct; the circuit may be responsible, as failure may occur even when the emission is only decreased by 10 %. Since all replaced valves are stored, this can be examined later.

In special cases where reliability is vital, the emission is tested regularly. A comparison of valve failures for all instruments is not directly applicable owing to the different repair policies.

The replacement criterion applied so far is of questionable value, as the demands on emission or transconductance differ in the various circuits. Furthermore, since the rate of change of properties in older valves is probably lower than in new ones, it is contemplated to introduce a replacement criterion which is more dependent on the actual circuit, so that a more economical replacement policy can be applied without affecting the reliability. Too frequent replacement, and especially overall replacement, may decrease the reliability because of the higher rate of initial failures.

True component faults. In the repair form a rough division is made into component groups. The registration of diagram code and number allows a more detailed analysis of the dependence on type, load and special conditions. It is important to find the primary component that has failed so that all components which are overloaded on account of the failure can be excluded from the analysis.

The mode of failure is important for the analysis of reactor safety and is therefore also noted on the repair form.

Remarks

This space contains information which cannot be entered in the preceding spaces, and remarks which can facilitate later maintenance work. The last spaces are not used for fault analysis.

4. Fault Analysis

The data are divided into three groups comprising (1) research instruments, (2) DR 2-reactor instrumentation and (3) DR 3-reactor instrumentation. For the first group no preventive maintenance is provided, and the operation time is uncertain. A correction of calendar time by a factor of five is suggested. For the two other groups preventive maintenance is carried out regularly. Calendar time and operation time are equivalent when the component population is set equal to the installed equipment, but spares are excluded from the population, which is permissible so long as individual instrument lifetimes are not considered.

4.1. Research Instruments

All the registered instruments are constructed on a normal modular basis. Each instrument panel (P-number) consists of several sub-chassis (C-number). The same types of sub-chassis may occur in different instrument types; for example C75a, a DC stabilizer, is part of many DC supplies, pulse amplifiers, DC-amplifiers, etc. One instrument panel may contain several identical chassis, such as P25, an operational amplifier consisting of four single amplifiers (C38), while P61 consists of two similar amplifiers (C38). A survey of the registered research instruments is given in table 1.

Table 1

Instruments Designed by the Electronics Department

Type		x) Total working time in 1000 h	Components per instrument						
			Valves	Diodes	Transistors	Fixed resistors	" Var.	Fixed condens-ers	Relays
P 14a	Power supply	163	8			25		10	
P 17a	- -	534	8			18		10	
P 17b	- -	454	8	2		32		18	
P 20a	- -	283	8			20		10	
P 20b	- -	202	8	2		32		18	
P 15	- -	54	8			20		10	
P 18	- -	54	8			32		18	
P 2c	High-voltage supply	202	14	2		87	2	26	
P 16a	- - -	212	14			67		18	
P 16b	- - -	286	14			79	2	26	
P 48a	- - -	79	28			51		79	
P 82a	Pulse amplifier	353	16	8		128	2	79	
P 85a	- -	121	13	8		96	2	62	
P 96a	- -	361	16			126		72	
P 84, -88	Detector preamplifier	266	5			17		16	
P 25a, b	Operational amplifier	429	18			140		96	
P 61a, b	- -	17	17	4		100	4	51	
P 87a	1 channel analyser	369	15	16		110	4	71	
P 80a	Count-rate meter	89	17	2		95	8	25	
P 80b, c	- - -	387	17	2		95	8	25	
P 45	Scaler	455	21	8		299	2	63	7
P 53	-	17	21	21		181		54	8
P 69	-	17	14	4		101		34	2
P 71	-	403	17			179		54	
		5807							

x) Working time includes non-operation. It is actually the calendar time from the time of delivery of an instrument from the central store.

It is of interest, with a view to later analysis, to separate systematic and random failures. Systematic failures include failures the causes of which are easily explained and expected to disappear after modification of the instrument. The rate of random failures thus provides a good control of equipment performance and a fair prediction of future performance.

Systematic faults are classified as follows:

(a) Construction faults such as faulty connections.

(b) Secondary faults, which means faults arising from overstress due to primary faults. An example is an anode-resistor breakdown (secondary fault) due to a short circuit in the adjacent valve (primary fault).

(c) Modifications. All changes in component values and circuitry, mainly a result of reliability-improvement studies.

(d) Electrical or mechanical overstress due to faulty operation, transportation, accidents, etc.

(e) The operation has, at an early stage, revealed some frequent faults; the causes are not quite explained, but partly remedied. These faults are therefore also classified as systematic:

(a) broken glass envelope in EL81 in stabilizers;

(b) delay lines in P96 pulse amplifiers;

(c) some resistors and condensers in P25 operational amplifiers.

The scalers and count-rate meters (P80) are not included in part of the analysis on account of design faults, mainly connected with narrow circuit tolerances. It has not been possible with certainty to separate these systematic faults from random faults.

Table 2 shows the failures distributed on components and divided into systematic and random failures.

Table 2

Distribution of Failures on Components (scaler failures included)

Component	Random f.	Systematic f.	Total	In %
Valves in P80	163	15	178	
EL81 in stabilizers x)	41	95	136	
Other valves	144	6	150	
Valves, total	348	116	464	58
Fixed resistors	22	35	57	7
Var. resistors	3	0	3	0.3
Condensers	22	10	32	4
Diodes	7	3	10	1
Connectors	19	3	22	3
Wiring	35	27	62	8
Transformers, relays	18	33	51	7
Other components	100	5	105	12
	574	232	806	100

x) The distribution on systematic and random failures is uncertain as some random faults may be broken glass envelopes.

It is seen that valves account for 58 % of the faults, resistors for 7 % and capacitors for 4 %. A considerable improvement in reliability can already be expected by correction of systematic faults.

For the research instruments no preventive maintenance takes place during operation. Repairs are made at the request of the user, and his interpretation of "inadequate performance" is conclusive. After repair the instrument is brought back to the specified performance, and faults which were unknown to the user, or which were of no importance to him, are thus corrected and registered. The ratio between the total numbers of failures and service calls gives an indication of field performance. A high figure may indicate extensive preventive maintenance which saves the user from several operational troubles. But it may also indicate that the user often relies on a faulty instrument without being aware of it. Extension of information on this important point has been decided upon. Table 3 gives the rough result, separated into power supplies and real measuring chassis.

Table 3

Failures (Including Systematic Failures) and Service Calls

	Power supply	Instrument circuit
Service calls	150	240
Failures, total	244	562

In table 4 the failure rates are calculated on the basis of instrument operation time and component population.

Table 4

Component Failure Rates in per cent. per 1000 h

	Operation time x) in 10^6 h	Random failures	Systematic failures	Total
All valves	60	0.58	0.19	0.77
Valves excl. P80	52	0.35	0.12	0.47
Diodes	13	0.054	0.023	0.077
Fixed resistors	359	0.0061	0.0097	0.016
Var. -	7	0.043	-	0.043
Capacitors	188	0.012	0.0053	0.017

x) Operation time is equal to calendar time corrected for the time in which the instrument is in store. Detailed information on the actual operating time is only available for reactor instrumentation which operates continuously. Laboratory instruments are used much less than indicated in table 4. In later comparisons a correction factor of five will be used.

Approximately one half of the random faults of valves are replacements according to the criterion that emission has fallen below 50 % of the nominal value. These replacements are seldom due to functional failures, but more often to preventive maintenance carried out in connection with periodical inspection or repair of faults. The department is considering whether a more economical replacement policy, dependent on tolerance requirements in the actual circuits, can be adapted.

Tables 4 and 5, which give the failure rates for components and instruments, will later be compared with the reactor instruments and commented upon in detail.

Table 5

		Number of Failures		Failures in per cent. per 1000 h			
		Random	Systematic	Random	Systematic	Total	Per valve circuit
P 14a	Power supply	18	8	11.0	4.9	15.9	2.0
P 17a	- -	20	10	3.8	1.9	5.7	0.71
P 17b	- -	16	5	3.5	1.1	4.6	0.57
P 20a	- -	3	19	1.1	6.7	7.8	0.97
P 20b	- -	1	0	0.5	0	0.5	0.06
P 15	- -	1	2	1.9	3.8	5.7	0.71
P 18	- -	2	1	3.8	1.9	5.7	0.71
P 2c	High-voltage supply	11	3	5.4	1.5	6.9	0.49
P 16a	- - -	10	5	4.7	2.4	7.1	0.51
P 16b	- - -	22	11	7.7	3.9	11.6	0.84
P 48a	- - -	3	2	3.8	2.5	6.3	0.45
P 82a	Pulse amplifier	26	7	7.4	2.0	9.4	0.59
P 85a	- -	16	1	13	0.8	14	1.1
P 96a	- -	61	34	17	9.4	26	1.6
P84, P88	Detector preamplifier	13	8	4.9	3.0	7.9	1.6
P 25a, b	Operational amplifier	85	43	20	10	30	1.7
P 61a, b	- -	20	8	118	46	164	9.6
P 87a	1 channel analyser	30	4	8.4	1.1	9.4	0.63
P 80 a	Count-rate meter	60	10	67	11	78	4.6
P 80b, c	- - -	171	36	44	9.3	51	3.0
P 45	Scaler	27		5.9			
P 53, P 69	-	2		5.9			
P 71	-	26		6.4			

The absolute number of failures is given in order to indicate how much confidence can be placed in the failure rates.

The figures quoted for the scalers are probably too low as several faulty decatron valves are not registered.

The rate of random failures is calculated per valve circuit in an attempt to derive a figure which is independent of the number of components per instrument. Within groups of similar type the figures are reasonably constant and, as expected, increase with increasing complexity of function.

A comparison with failure rates for similar equipment at Harwell shows a fair agreement.

4.2. Reactor Instrumentation at DR 2

The instrument population at DR 2 is very small, and therefore little confidence can be placed in the failure figures. The operation time can be stated very accurately for the instruments in the console. The spare instruments are not included in the instrument and component population; which is correct so long as exponential lifetime distribution is assumed. The reactor instruments are very closely controlled, both by the service group, who carry out a preventive maintenance service, and by the operators, who make weekly, monthly and start-up tests of instruments on site. Failures found during operation will often originate from these tests. The repair reports give no information on this point, but it is contemplated to correlate the failure registration with the operational log kept by the reactor group. This is especially important at DR 3, where redundant measuring channels are extensively used.

The instrument population is given in table 6.

Table 6

The DR 2 Instrument Population

			Number of components					
	Number of instruments	Operation time x 10^3 h	Valves	Diodes	Fixed resistors	var. resistors	Condenser	Relay
Preamplifier	2	32	4		17		8	
Linear amplifier	2	30	17		62	2	3	
Power supply	2	29	9		20		6	1
Rate-meter	2	32	15		56	4	17	
Log. amplifier	1	15	10	4	36	3	10	
Scaler	1	15	28	2	184	7	75	1
Composite safety amplifier	4	58	17	2	101	7	6	5
Magnet amplifier	1	15	13		47	2	5	
Radiation-monitor power supply	1	18	4					
Radiation monitor	8	138	1					
Recorder		34	3					
Recorder		53	4					
Servo unit		15	4					

The failures are distributed as shown in table 7. Operation includes tests made by operators.

Table 7

Distribution of Failures Found During Operation and Maintenance

	Operation	Maintenance	Total
Preamplifier	1	0	1
Linear amplifier	3	22	25
Power supply	0	2	2
Rate-meter	9	17	26
Log. amplifier	7	7	14
Scaler	1	10	11
Composite safety amplifier	28	35	63
Magnet amplifier	7	5	12
	56	98	154

The failure rates are given in table 8. The figures are reduced to failure rate per valve circuit for intercomparison. Only three systematic failures have been registered, and these are omitted.

Table 8

Rate of Failure per Instrument Type

	Failure in % per 1000 h	% per 1000 h per valve circuit
Preamplifier	3	0.8
Linear amplifier	80	4.7
Power supply	7	7.8
Rate-meter	81	5.4
Log. amplifier	93	9.3
Scaler	73	2.6
Composite safety amplifier	110	8.5
Magnet amplifier	80	6.2
Radiation-monitor power supply	44	11
Radiation monitor	4.3	4.3
Recorder	50	17
Recorder	66	16
Servo unit	47	12

The valves are responsible for 74 % of the failures, resistors for 11 % and capacitors for 1 %. A replacement policy has been used for valves whereby they are replaced when the emission falls to 50 % of the nominal value. This policy will be reconsidered, partly because the emission is not the critical parameter in all circuits.

The component failure rates are given in table 9 and will be considered later.

Table 9

	Number of failures	In %	Operation time x 10^6 h	Failure rate % per 1000 h
Valves	114	74	3.1	3.7
Resistors, fixed	16	11	14.6	0.11
- , var.			0.8	-
Condensers	2	1	2.8	0.07
Diodes	8	5	0.2	4
Connectors	5	3		-
Wiring				-
Transformers, relays			0.3	-
Other components	9	6		-
	154			

4.3. Reactor instrumentation at DR 3

Table 10

DR 3 Instrument Population (Selected)

	Number of instruments	Operation time x 10^3 h	Number of components: Valves	Transistors	Diodes	Fixed resistors	Var. resistors	Condenser	Relay	Number of instruments incl. spare instruments
γ-monitor	20	394	13		2	69	6	9	3	25
γ-head	20	394	1			16	2	1		25
Rate-meter	9	155	23			148	17	49	1	12
Fast neutron head	6	103	2			23		9		8
Scintillation head	3	52	2			16		2		4
Temp. trip. amplifier	6	103		19	35	116	10	26	2	12
- - -	3	52		13	28	78	7	17	1	4
- - -	3	52		13	38	78	7	17	1	4
Shut-down amplifier	6	103	12		2	69	7	13	3	8
Power error meter	2	34	21		11	121	7	27	3	3
Period-meter	3	52	15		4	76	10	12	3	4
Leak detector	3	52	10		4	43		22	20	4
Misalignment amplifier	7	120	13		11	44	13	19	6	8

The evaluation follows the same lines as for DR 2, and the same remarks are valid. There are several systematic failures which are not included in the following tables.

Table 11

	Operation	Maintenance	Total	Failure rate, % per 1000 h	Failure rate, % per valve circuit or transistor
Y-monitor	82	118	200	51	3.9
Y-head					
Rate-meter	25	92	117	76	3.3
Fast-neutron head					
Scintillation head					
Temp. trip. amplifier	4	5	9	8.7	0.46
- - -	6	7	13	25	1.9
- - -	8	4	12	23	1.8
Shut-down amplifier	13	23	36	35	2.9
Power error meter	0	12	12	35	1.7
Period-meter	1	7	8	15	1.0
Leak detector	0	13	13	25	2.5
Misalignment amplifier	3	20	23	19	1.5

Table 12

Components	Number of failures	In %	Operation time x 10^6 h	Failure rate, % per 1000h
Valves	330	74	13.5	2.5
Resistors, fixed	33	7	92.9	0.036
- , var.	3	1	9.8	0.034
Condensers	32	7	21.9	0.15
Diodes	1		10.1	0.01
Transistors	4	1	3.1	0.13
Connectors	2			
Wiring	2			
Transformers, relays	24	5	4.0	0.6
Other components	13	5		

5. Comparison of Component Failure Rates

The failure rates derived from the three groups are compared in table 13. In this case the figures for research instruments are multiplied by 5 to obtain a more realistic operation time. This figure is of course rather arbitrary and weakens the comparison. The figures by Dummer have been taken from his book on reliability[1], and the Harwell figures (1956) are given in ref. 2).

Table 13

Component Failure Rates. Failures in % per 1000 h

	Relays	Valves, total	" , excl. P80	Resistors, fixed	" , var.	Condensers	Transistors	Diodes
Electronics Department, all failures		4	2	0.08	0.2	0.08		0.4
Electronics Department, only systematic		3	2	0.03	0.2	0.06		0.3
DR 2		4		0.1	0.8	0.07		4
DR 3	0.6	3		0.04	0.03	0.2	0.1	0.01
Dummer	1.5	2		0.2	0.5	0.1	0.1	0.1
Harwell, 1956		1		0.05				

6. Conclusion

The purpose of this report has been to present a failure registration system and some results obtained for nucleonic instruments.

The value of the statistics will only appear when the instruments have been studied for several years and a number of problems concerning failure classification, time measurement and the influence of maintenance policy have been solved.

As regards prediction, the figures indicate that the following average values can be used for laboratory instruments:

high-voltage supply	0.4 %	per 1000 h per valve circuit
power supply	0.4 %	- - - - - -
amplifiers	1 %	- - - - - -
scalers	0.8 %	- - - - - -

These figures are based on calendar time. A correction factor of five is suggested for continuous operation.

References

1) G. W. A. Dummer and N. Griffin Electronic Equipment Reliability (Wiley, New York, 1960).

2) L. A. Kilbey, Reliability as a Design Parameter. Nuclear Engineering 2, 177-181 (1957)