A maintenance strategy for a multi-valve cryogenic distribution system

Jaroslaw FYDRYCH[1(*)], Guido CONSOGNO[2(*)]

[1]European Spallation Source ERIC, Box 176, 221 00 Lund, Sweden

[2] WEKA AG, Schuerlistrasse 8, CH-8344 Baeretswil, Switzerland

Introduction. Big scientific facilities that use cryogenic technologies usually need to transfer and distribute cooling power from a cryogenic plant to cryogenic users. This requires cryogenic distribution systems which include many valve boxes at the cryogenic users. Such systems consist of a number of components which can malfunction or get damaged in many ways leading to unwanted shut downs of the entire facility. In order to avoid problems or mitigate their consequences the cryogenic distribution system should be properly operated and maintained. This requires planning of maintenance works, storing spare parts and ordering some service works. The paper presents a maintenance strategy for a multi-valve cryogenic distribution system. Possible failures of the system components are identified and required maintenance and reparation works are described. The presented maintenance algorithm is intended to support decision-making on spare parts and service cost minimizations.

A mutli-valve cryogenic distribution system is a system intended for distributing cryogenic fluids to a number of users and regulating the cryogen flows to and from the users. A good example of such systems the ESS linac cryogenic distribution system, currently under construction at European Spallation Source ERIC in Lund, Sweden (Fig. 1). Its distribution line is 310 m long and comprises 43 valve boxes, each with 6 to 8 cryogenic and 2 warm control valves.

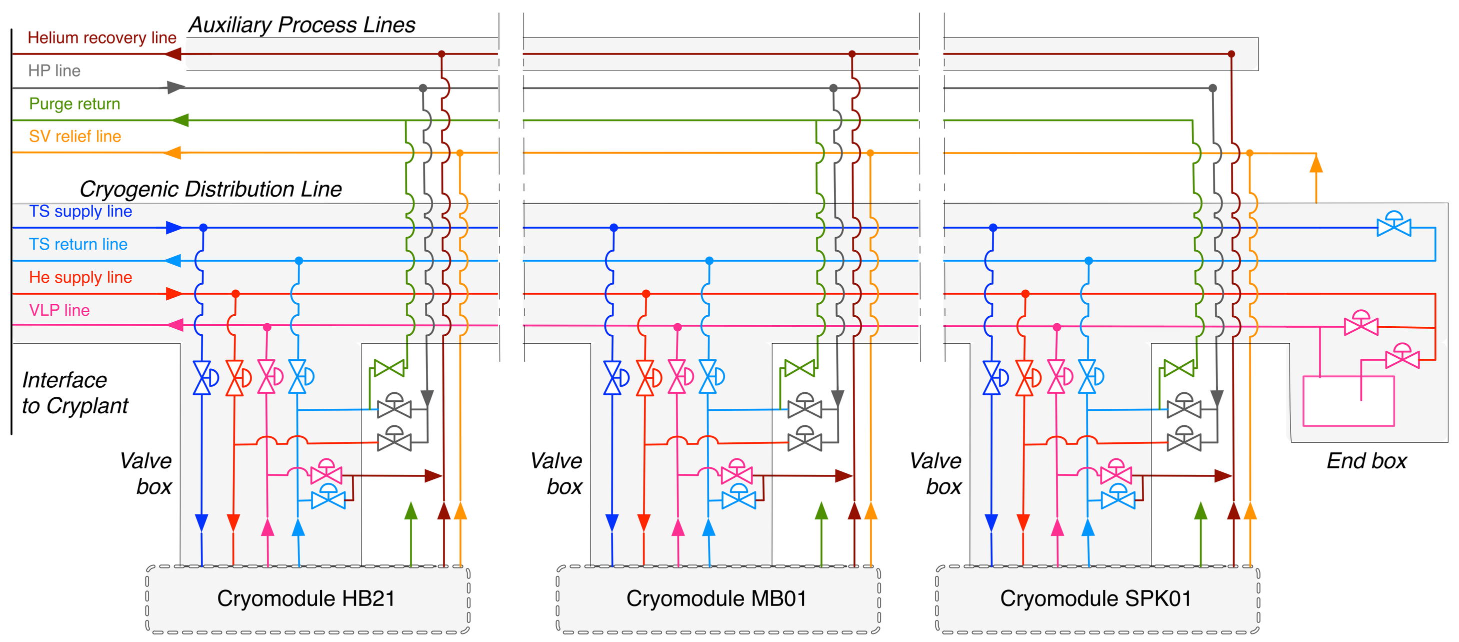

Figure 1. General flow scheme of the CDS for the ESS Linac

Maintenance strategy goals are to evaluate the required resources for all the typical maintenance activities related to the control valves and assess (and minimize) the costs of all reparations of malfunctioning or damaged components of the CDS control valves. Repair and maintenance work procedures need to include several activities. Figs 5 and 6 show example algorithms for maintenance and reparation works.

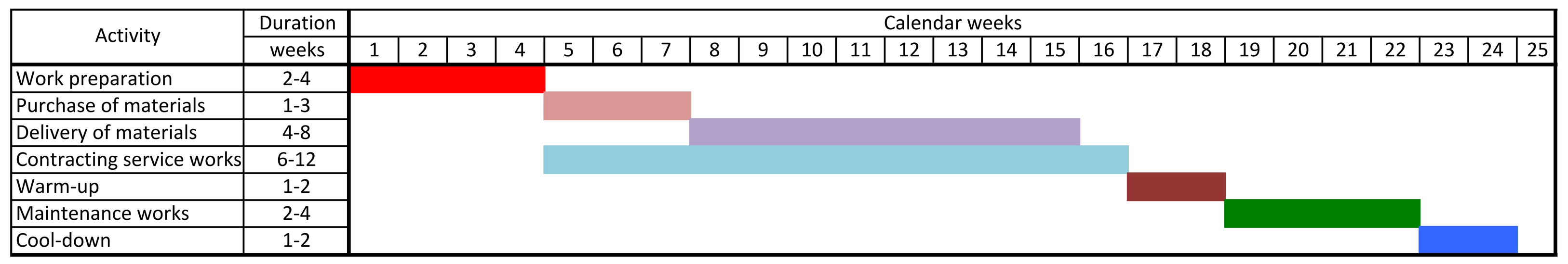

Figure 5. Example procedure for maintenance with outsourced service and purchased parts

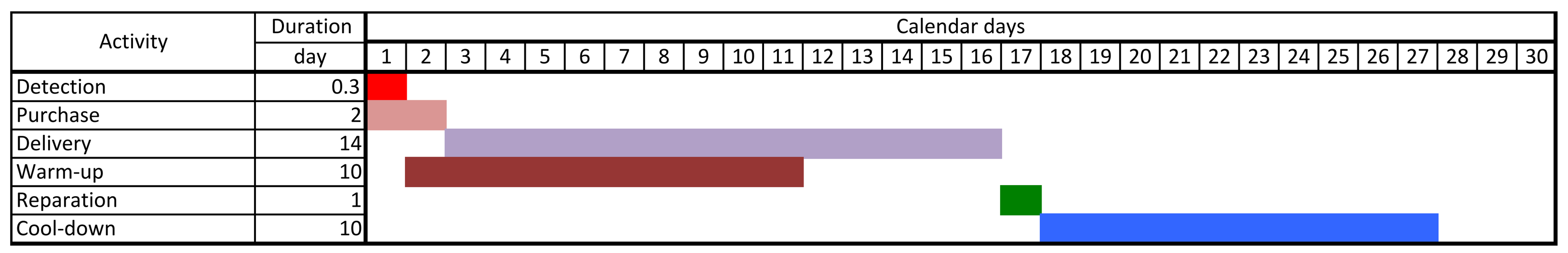

Figure 6. Example procedure for reparation of an insert

The presented **case study** is done for a CDS with 400 valves designed for 43 year operation. The assessments of the costs of spare parts and workforce are shown in table 1. It is assumed that all the parts are inspected but only a certain given fraction is exchanged. Estimations of the downtimes due to failures are shown in table 2. The lowest statistical downtime is for internal workforce and stored repair parts. Then the CDS availability may exceed 99.5%.

A typical cryogenic control valve for application in cold helium installations is presented in figure 2. The inlet and outlet are welded to a process lines, whilst at its top there is a flange that is welded to the vacuum jacket of a valve box. The fluid room is separated from the vacuum by a continuous metallic barrier and from the external environment by static and backup seals. The cryogenic valve contains moving parts for controlling the opening between the flow plug and the seat. The movements of the plug is driven by a pneumatic actuator and transmitted by a stem located inside the insert. The valve is built in such a way, that the internal parts, down to the seal and the plug can be extracted from the upper side. After unscrewing and removing the valve head the valve insert with the bellows and flow plug can be pulled up out of the valve body (Fig. 3). The sealing system from the atmosphere contains bellows connecting the moving part of the stem with a ring, which is fixed to the body of the valve and sealed by o-rings (Fig. 4). The failures of cryogenic valves are generally due to fatigue, accumulation of impurities and aging of materials. Typical maintenance operations are replacements of used o-rings, seat seals and metallic bellows. They can also include the exchange of some components of the control units, such as the diaphragm and compressed air gasket of the actuator as well as the compressed air solenoid valves of the positioner. Since a number of parts that need to be exchange are located in the internal and intermediate rooms, the maintenance work can require warming up and depressurisation of the process line. Usage times, review periods and failure rates for main components of cryogenic valves are shown in Tabs 1 and 2.

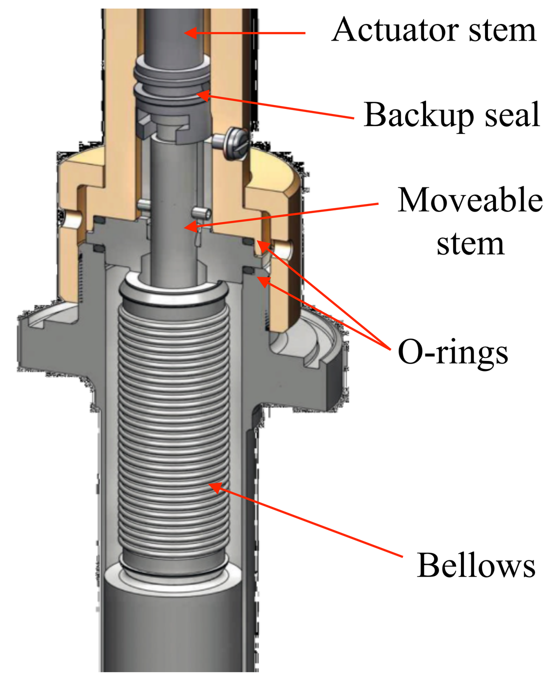

Figure 4. Sealing system from the atmosphere

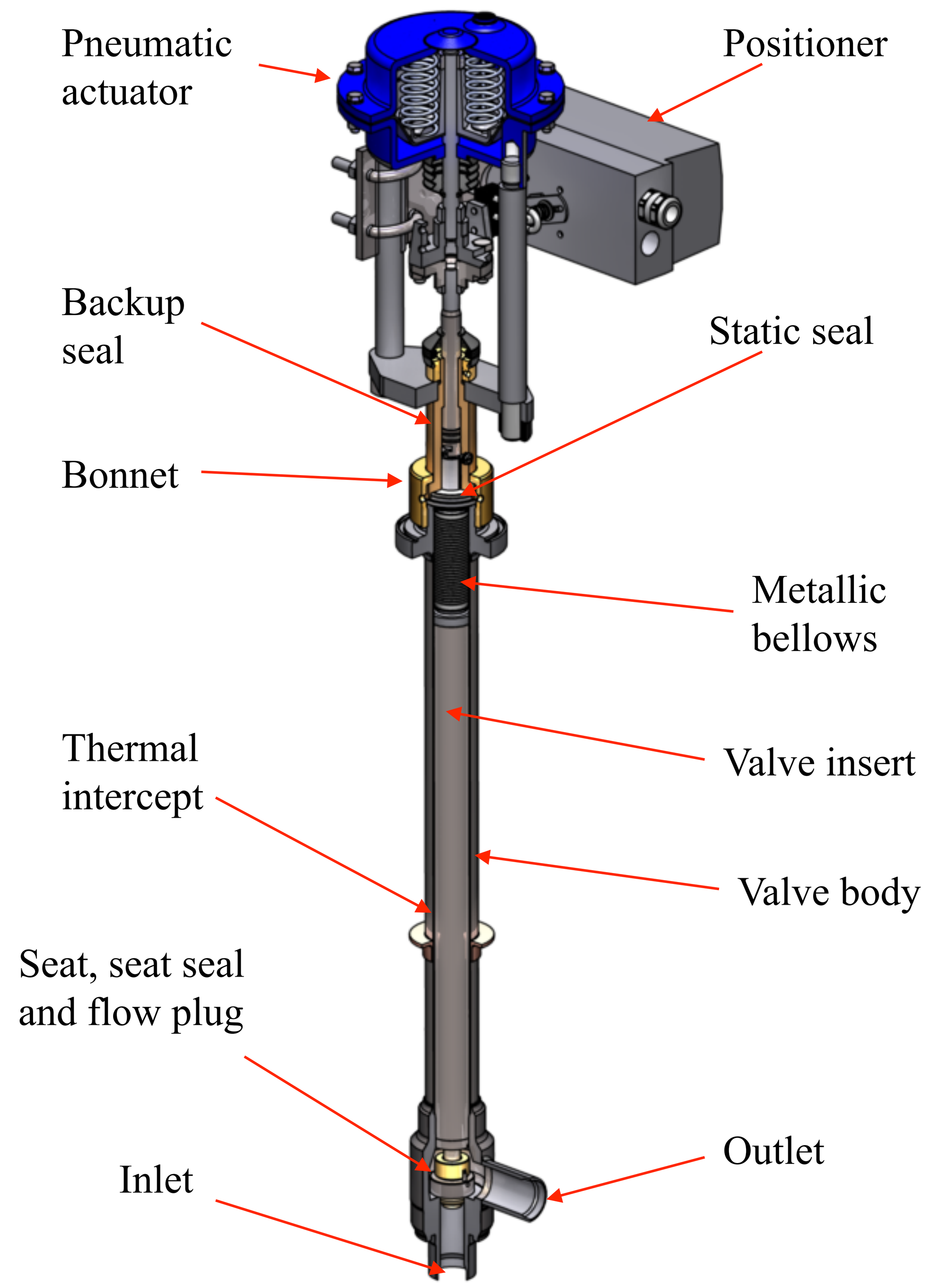

Figure 2. Main components of a cryogenic valve for cold helium installations

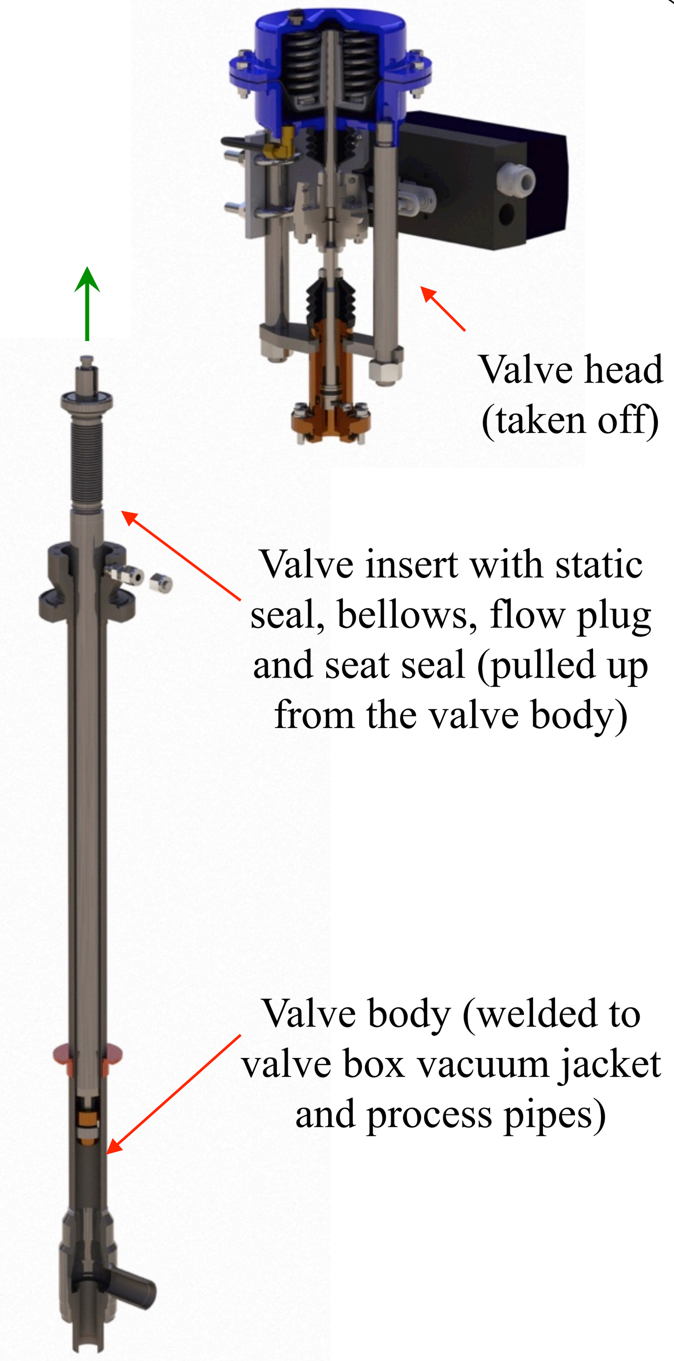

Figure 3. Dismantling of a cryogenic valve

Table 1. Estimations of required costs of the maintenance of CDS control valves

Control valve components	Usage time / review period [year]	Quantity per system [-]	Maintenance work time per component [hour]	Minimum required number of workmen [-]	Required personnel resources [man-hour]	Total cost of personnel resources [EUR]	Fraction for replace [%]	Unit cost of spare parts [EUR]	Total cost of spare parts [EUR]	Total cost of maintenance [EUR]
Gaskets	5-7	800	1/8	1	100	6000	100%	50	40000	46000
Seat seal	5-7	400	1/4	1	100	6000	50%	100	20000	26000
Bellows	20-25	400	1/2	1	200	12000	20%	1300	104000	116000
Actuator	5-7	400	3/4	2	600	36000	10%	500	20000	56000
Air valve	15-25	800	1/4	1	200	12000	10%	300	24000	36000
Air gauge	15-25	400	1/4	1	100	6000	10%	300	12000	18000

Table 2. Estimations of statistical downtimes caused by failures of valve components (I, O – internal and outsourced workforce, P, S – purchased and stored repair parts)

Control valve components	Failure rate [1/year]	Quantity per system [-]	Cumulative failure rate [1/year]	Downtime for incident [day]				Statistical downtime per year [day]			
				I/P	I/S	O/P	O/S	I/P	I/S	O/P	O/S
Gaskets at warm end	5.0E-06	800	4.0E-03	27	22	27	22	0.108	0.088	0.108	0.088
Seat seal	5.0E-05	400	2.0E-02	27	22	27	22	0.54	0.44	0.54	0.44
Insert bellows	5.0E-05	400	2.0E-02	27	22	27	22	0.54	0.44	0.54	0.44
Actuator	5.0E-07	400	4.0E-04	17	2	17	6	0.0034	0.0004	0.0034	0.0012
Air solenoid valve	5.0E-05	800	4.0E-02	17	2	17	6	0.68	0.08	0.68	0.24
Air gauge	5.0E-06	400	2.0E-02	17	2	17	6	0.34	0.04	0.34	0.12
							Total:	2.21	1.09	2.21	1.33

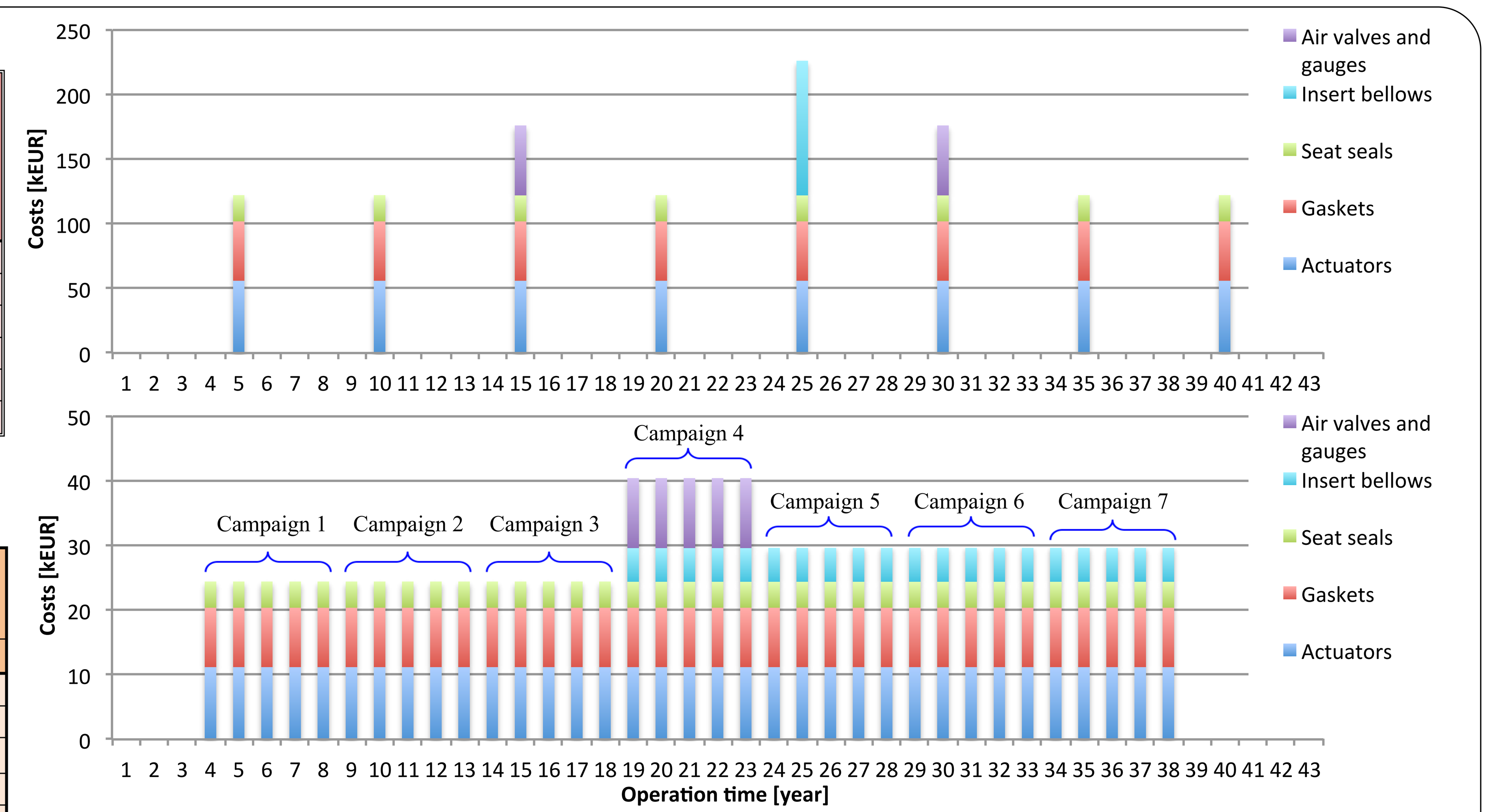

Figure 7. General plans for maintenance works a) scheduled for one shut down at a time and b) distributed for several consecutive shut downs

Conclusions. The presented maintenance strategy for a multi-valve cryogenic distribution system shows that in a long run (43 years) the cost of spare parts may exceed 1.6 kEUR per valve. To perform appropriate and thorough maintenance works there is a need for 15 man-hours per valve. Proper planning and scheduling maintenance activities may help to lower to a certain extent the total cost of the maintenance works. If all the works are planned to be done in one turn for all the valves at the end of recommended review periods it results in severe irregularities in needs for financial and personnel recourses. Planning the maintenance activities in long-term campaigns (of several years) may help to definitely allocate required resources. Figure 7b shows that the yearly cost of maintenance work can vary from 60 to 100 EUR per valve.

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