RECOMMENDATION

General requirements on the measures for the prevention of impermissible radiolysis gas reactions, 10.07.2003

Request for drafting an RSK recommendation

Due to events related to radiolysis gas reactions, recently occurred repeatedly (last events: damages at the nuclear power plants Brunsbüttel and Hamaoka in Japan), it was to be checked according to the RSK to which extent the necessary precaution against events with radiolysis gas reactions can further be ensured with the measures taken so far and the safety philosophy pursued with it, or if, due to new findings, a new safety-related concept and approach under consideration of additional and further measures and analyses in the nuclear facilities concerned is regarded as necessary.

Consequently, the RSK established an ad-hoc working group on radiolysis gas at its 352nd meeting on 13.06.2002 which was to develop the procedure and assessment criteria for verifying that the necessary precaution has been taken. The RSK requested the ad-hoc working group to prepare the draft recommendation for the RSK and specified this request at its 353rd meeting on 11.07.2002.

At the 1st meeting of the ad-hoc working group on 08.08.2002, the representative of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) requested a recommendation from the RSK how it can be demonstrated that the necessary precaution against damages resulting from radiolysis gas reactions has been taken in accordance with the state of the art in science and technology.

Course of the consultation

On 08.08.2002, the ad-hoc working group RADIOLYSIS GAS had its first meeting, listened to reports and prepared the draft of a recommendation, as requested, which was presented to the RSK on its 354th meeting on 05.09.2002. The comments of the RSK were considered in the consultation on structure and contents of the recommendation on its 2nd and 3rd meeting (22.11.2002 and 21.01.2003, respectively).

Within the frame of the 3rd meeting of the ad-hoc working group RADIOLYSIS GAS on 21.01.2003, it was decided to first define the schematic proceeding on the control of radiolysis gas accumulations (see Fig. 1) and to list potential measures (see Table 1). These measures were discussed and agreed upon at the 361st meeting of the RSK on 10.04.2003. Furthermore, the elements of the explanatory text component of the statement were developed. At the 364th meeting of the RSK on 10.07.2003, this statement was adopted.

The proceeding defined in this statement has been developed for the analysis of BWR plants. The proceeding can be applied analogously to the conditions in systems of PWR plants as far as impermissible radiolysis gas reactions may occur at them.

General requirements

The RSK is of the opinion that protective measures against impermissible radiolysis gas reactions have to be implemented by the plant operators. This requires adequate preventive measures and, where appropriate, measures for limitation of the consequences. In this respect, distinction is to be made – dependent on the potential damage extent after radiolysis gas reactions – between four safety levels.

Until now, the German rules and regulations do not include any specific regulations on the protection against impermissible radiolysis gas reactions, although several requirements of the existing rules and regulations can be applied analogously to questions related to radiolysis gas reactions.

In principle, the defence-in-depth concept for nuclear installations, which is based upon the compliance with the four protection goals, is also applicable here:

- Reactivity control,
- cooling of the fuel elements,
- confinement of radioactive material, and
- limitation of radiation exposure.

The necessary precaution against damages is given if compliance with these protection goals – according to the different safety levels – is given with the required reliability.

Proceeding

A comprehensive analysis of the consequences of potential radiolysis gas reactions and possible countermeasures has to be performed to check whether the necessary precaution against damages is given:

- In a first part, those areas have to be identified where there is a potential for radiolysis gas accumulations. For this purpose, all areas of the plant have to be examined.

- In a second part, it is to be checked for each of the identified areas, which maximum effects might result from a radiolysis gas reaction.

- In a third part, preventive measures are to be defined for each identified area. The requirements on the quality of the measures for the prevention of a radiolysis gas reaction depend on the safety level according to which the potential event has to be classified.

Fig. 1 shows the necessary analysis steps in the form of a flow chart.

Identification of the system areas with potential for radiolysis gas accumulations

The partial step "Identification of system areas affected" is performed to ensure a systematic identification of all areas of the plant with a potential for radiolysis gas accumulations. The identification is performed irrespective of whether measures for the prevention of radiolysis gas reactions have already been implemented. This is necessary, on the one hand, to ensure a complete listing of all system areas affected. On the other hand, the listing is required for later plant modifications in order to be able to systematically check the absence of impacts of modification measures on the control of impermissible radiolysis gas reactions.

The flow chart to be adhered to in this partial step is presented in the first part of Fig. 1.

In a first step, the potentially affected system areas in the plant are identified. These are those where a primary steam admission may occur during operating modes and plant operation states that are possible according to the instruction manual or shift instructions (full load, partial load, abnormal operation, maintenance). In addition, leakages at system isolating valves or at heat exchangers are to be postulated in the analysis. For the identification, the accumulation of radiolysis gas at deep locations, the stratification of steam and radiolysis gas, the entry of water into steam-carrying systems and the entry of steam into water-carrying systems also have to be considered.

In a second step, the identified system or system section has to be checked for "stagnant" medium. Since in systems with slow flows, areas with radiolysis gas accumulations cannot be excluded completely, it is determined conservatively that radiolysis gas accumulations can safely be excluded only if there are turbulent flows. Therefore, a flow coefficient $R_e < Re_{crit}$ is to be applied as criterion for "stagnant" medium.

In a third step, it is checked for the identified system sections whether a radiolysis gas accumulation may be caused by condensation of primary steam. As far as other accumulation mechanisms for radiolysis gas in the system or system section affected are possible, these also have to be considered.

Identification of the maximum effects of a radiolysis gas reaction

For the identified systems and system sections, the maximum possible effects have to be determined. For this determination it is generally to be postulated that there is an ignition mechanism which can take effect. This is due to the manifold possibilities for ignition mechanisms in case of hydrogenous gas mixtures which are the reason that the absence of ignition mechanisms cannot be verified with sufficient reliability. The analysis is to be performed independent of the available and planned measures because it also has to be checked in a later step of the analysis whether the available and planned measures are in accordance with the identified safety levels.

In the analysis, a radiolysis gas reaction is to be postulated for a system section completely filled with radiolysis gas, thus at a maximum possible radiolysis gas concentration. The reaction pressure of this postulated reaction (detonation or alternatively deflagration in case of justified exclusion of the physical boundary conditions necessary for a detonation) and the impacts on the plant, the system and neighbouring components by fragments and blast waves as well as by loss of coolant, blow-down forces, activity release, reaction forces, temperature, humidity are to be determined. Here, it is to be considered that due to the specific energetic conditions during a radiolysis gas reaction the mechanical impacts may be stronger than in other cases within the design basis that are to be postulated.

The possible maximum effects determined in the analysis are to be classified according to Safety Levels 1 to 4 by means of the left column of the second part of Fig. 1. Safety Levels 1 and 2 can be considered together in this case. For the classification according to the respective safety level, the maximum possible effects under conservative assumptions (e. g. regarding the failure of safety systems or regarding the impacts of fragments) are to be postulated, which is common practice in safety analyses.

Definition of the preventive measures

In dependence on the safety level, according to which the maximum possible effects determined have to be classified, there are different requirements on type and reliability of the measures for the prevention of radiolysis gas reactions. In general, the requirement on the measures to be fulfilled, in addition to the necessary precaution at each safety level, is that they must have the effect that there will be no dominant contribution to the damage frequency due to radiolysis gas reactions at the respective safety levels under consideration of the design spectrum.

Another requirement on the prevention of impermissible radiolysis gas accumulation is given with regard to the plant operating procedures, the operating instructions, the diligent performance of work, the inspection and documentation of activities in the areas concerned during maintenance processes and other interventions at the plant.

The same applies to the recurrent inspections required to verify the maintenance of effectiveness of the measures for the prevention and monitoring of impermissible radiolysis gas accumulation. Scope and type of the recurrent inspections have to be laid down in the respective test manuals. The respective specifications have to be updated on the basis of operating experience.

In addition to the specified evaluation criteria and the provision on intervention derived from them, the temperature transducers installed in the vulnerable areas are also to be evaluated regularly with regard to potential radiolysis gas reactions not leading to a direct failure of integrity or function. If by this relevant temperature drops are observed, which are not directly related to operating processes, and if there are implausible changes of the data or other implausible indications, an analysis of an unidentified radiolysis gas reaction has to be initiated conservatively. In order to exclude the risk from the consequences of a pre-damage for further operation as far as possible, the area affected are preferably to be inspected immediately for damages. Further measures for the identification of such processes may be, e. g., special loose parts monitoring systems and motion detectors.

The right column of the second part of Fig. 1 presents the measures or the requirements on the measures, respectively, which have to be provided for the prevention of radiolysis gas reactions with impacts on the respective safety level. Examples for measures to be taken and their classification according to the safety levels are present in Table 1. The examples in Table 1 also establish the necessary level of he measures in case of impacts according to the different safety levels.

For the prevention of radiolysis gas reactions with consequences at Safety Level 3, continuous and reliable monitoring measures are required. In addition to the requirement that all measures have to be of a high performance quality, comparable to that for the protection in case of similar risks, these comprise, e. g. in case of failure, self-signalling and redundant monitoring measures. Redundancy may only be dispensed with if the detection of the failure and the associated statement on the condition in the area affected is ensured in any case on the basis of the provisions made in a multi-stage system and measures are taken immediately for the restoration of monitoring. The time periods required and specified for it have to be so short that no relevant radiolysis gas concentrations can accumulate, under conservative assumptions, in the monitored system areas affected. How to proceed after signalling of a failure and within which time period the monitored condition has to be restored has to be specified in the instruction manual (safety specifications).

For the prevention of radiolysis gas reactions with consequences according to Safety Level 4, continuous and high-level monitoring measures (redundancy, diversity or failure monitoring) are required. According to the larger potential damage, there has to be a higher-level monitoring compared to the monitoring for system areas with maximum possible effects to be classified as Safety Level 3.

At Safety Levels 3 and 4, passive measures are of particular importance. Deviations from this requirement are only permissible if none of the corresponding passive measures can be realised, and they have to be justified. With the measures to be taken in such a case a similar level has to be reached as is the case when employing passive measures.

For all measures at Safety Levels 3 and 4, the instruction manual (safety specifications) also has to specify criteria and measures in case of deviations from target specifications, so that in case of disturbances and failures clear instructions can be given for the further proceeding up to the instruction to shut down the plant if the effectiveness of a measure cannot be restored in time.

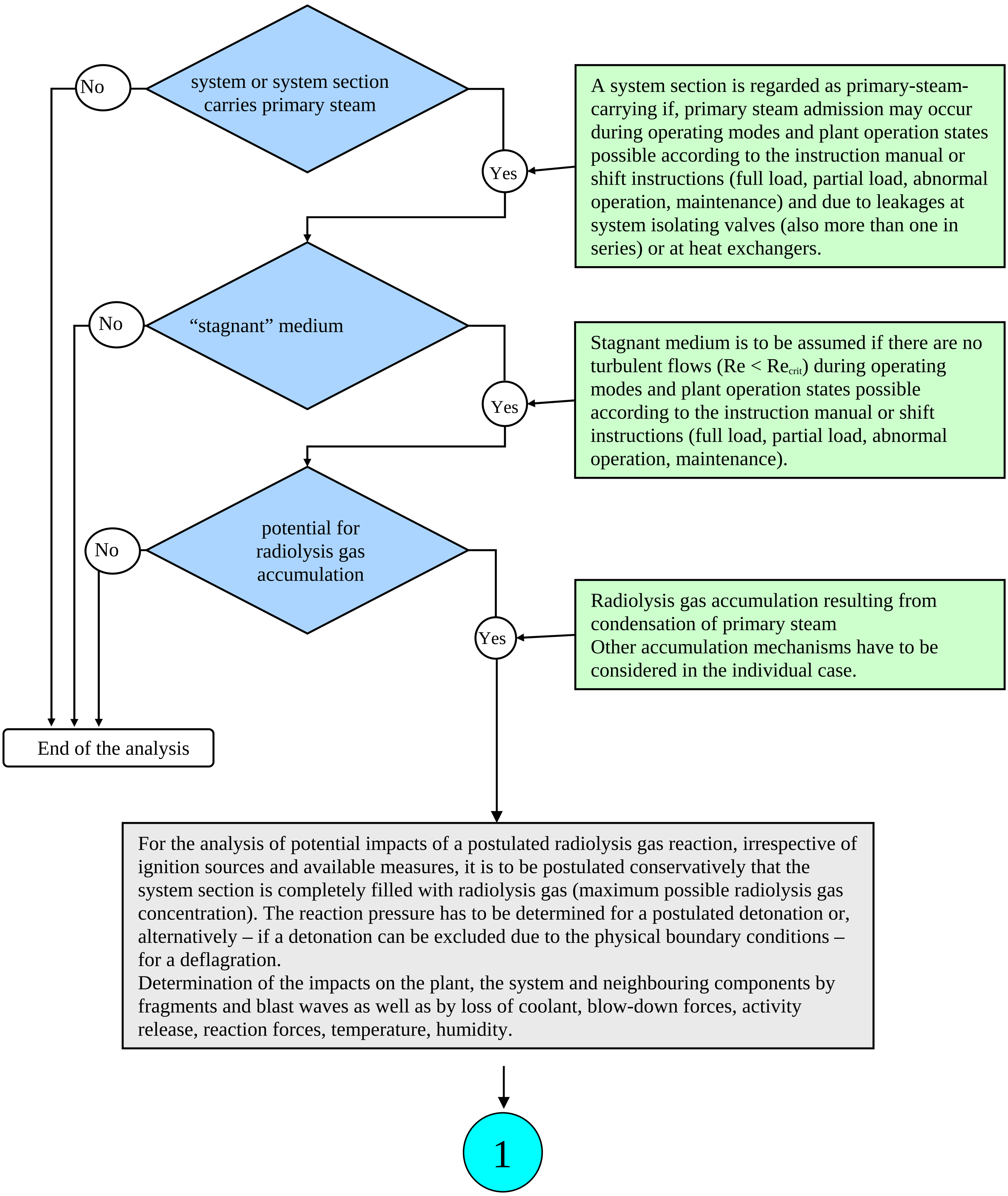

Fig. 1: Schematic proceeding on the analysis of the consequences of potential radiolysis gas reactions

Fig. 1 (continued):

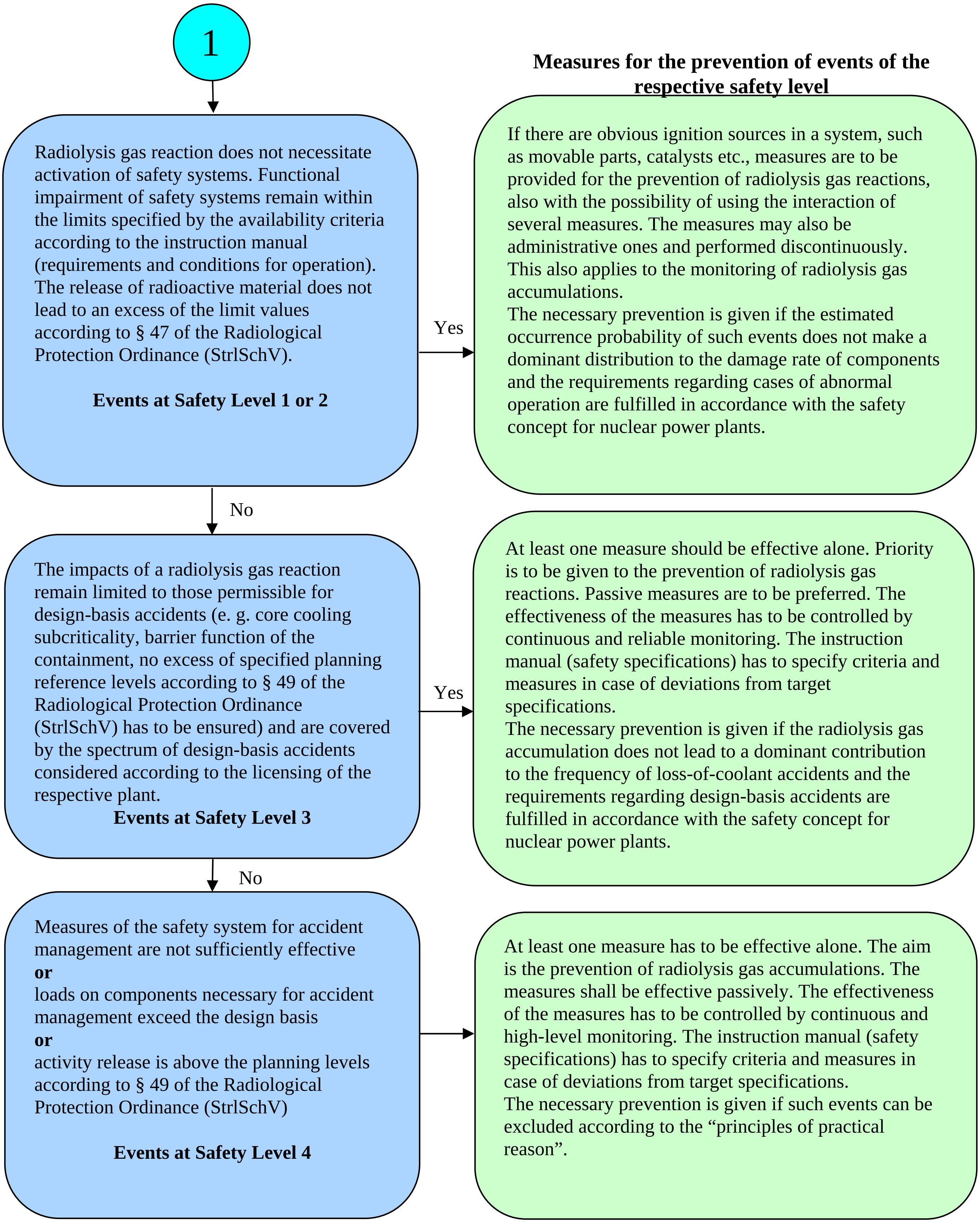

Table 1: Examples for measures for the prevention or control of radiolysis gas reactions

Measure	For prevention of events at safety level
Cyclic flushing by manual actions; effectiveness monitoring by continuous temperature measurement with signalling in case of excess of limit value or failure.	1/2
Catalyst or thermal-control ventilators; effectiveness monitoring by discontinuous measurement permissible.	1/2
Flush line with valve interlock in valve-open position; position control before start up; effectiveness test during start up by measurement.	1/2
Catalyst; effectiveness monitoring by continuous temperature measurement with signalling in case of excess of limit value or failure.	3
Verification by operational measurements that accumulation can be prevented by physical effects (convection, diffusion, gas transport in the condensate); effectiveness monitoring by continuous temperature measurement with signalling in case of excess of limit value or failure.	3
Flush line with valves; valve interlock in valve-open position; position control before start up and effectiveness test by continuous measurement during operation.	3
Structural protection measures limiting the reduction of the consequences to a lower safety level.	3/4
Secured flow-through, verified on the basis of physical principles with continuous high-level monitoring. This can be realised, e. g., in form of a blush bore or line without valves, having to exclude an impermissible impairment of the effectiveness by operational influences.	4