Risk Assessment of a Urea Reactor V8, April 28, 2018 Assumptions: 316L UG liner and only tubes outside the insulation as leak detection system

No:	Hazard Scenario: Revision	Hazard Scenario: Hazard & Initiating Event	Hazard Scenario: Consequences	Project phase	Equipment part	Hazard reference information: Document Number & Revision	Risk Ranking before Prevention and Mitigation steps	Prevention steps (to reduce Likelihood)	Mitigation steps (to reduce Consequences)	Sponsor 1	Sponsor 2	Sponsor 3	Sponsor 4	Sponsor 5	Sponsor 6	Risk Ranking after Prevention and Mitigation steps
1	3 October 2017	Bad workmanship, e.g. wrong design details and/or wrong materials leading to defects in the protective layer. These defects typically show up during the first years of operation.	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Engineering	Protective layer	UreaKnowHow.com Urea Incident Database: Incidents 10-005, 05-001, 01-001, 95-001, 91-001, 79-001	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Make use of skillful and experienced designers and fabricators; perform expediting services by skillful and experienced persons. Note that regulatory inspectors only inspect pressure bearing part.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
2	3 October 2017	Bad workmanship, e.g. bad welding, wrong materials leading to defects in the protective layer. These defects typically show up during the first years of operation.	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Construction	Protective layer	UreaKnowHow.com Urea Incident Database: Incidents 10-005, 05-001, 01-001, 95-001, 91-001, 79-001	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Make use of skillful and experienced designers and fabricators; perform expediting services by skillful and experienced persons. Note that regulatory inspectors only inspect pressure bearing part.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
3	3 October 2017	Chloride contamination behind the liner leading to locally chloride stress corrosion cracking and possible cracks in the protective layer during operation due to ingress of marine atmosphere during transportation.	Cracks in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Construction	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Avoid any contamination behind the liner and in the leak detection tubes by closing all leak detection holes with temporary plugs during transportation.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
4	3 October 2017	During drilling the leak detection holes in the carbon steel the liner was also partly drilled leading to first a very small leak in the liner after years of liner thinning due to passive corrosion (this was and maybe is still practice in the fabrication process of certain vendors)	Defects in the liner lead that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Construction	Liner	Case discussed during UreaKnowHow.com 5-Day Urea Training Program	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Make use of qualified and experienced fabricators.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
5	8 March 2018	During preparing the fixed liner welds a 1-3 mm groove was made in the liner.	As this area was also the heat affected zone with higher corrosion rates, this area became a weak spot in the liner	Construction	Liner	UreaKnowHow.com Urea Incident Database: Incident 12-003 and 12-004	Catastrophic consequence X Unlikely likelyhood (10)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Make use of qualified and experienced fabricators.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
6	3 October 2017	Leak detection hole still closed during operation. Note: When the reactor arrives at site these holes are closed to avoid ingress of chlorides and fouling during transportation.	No leak detection available during operation. In case a defect in a liner occurs, ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel.	Commissioining	Leak Detection System	UreaKnowHow.com Urea Incident Database: Incident 98-003	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Assure proper connection and installation of an active leak detection system. Note: An active leak detection system focuses more attention to the risks associated with a urea reactor. Properly mark leak detection holes during fabrication of vessel as there are verious type of holes in high pressure equipment.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
7	3 October 2017	Chloride contamination on process side leading to locally chloride stress corrosion cracking and possible cracks in the protective layer for example by using chloride containing water during water run.	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Commissioining	Protective layer		Catastrophic consequence X Moderate likelyhood (12)		In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
8	3 October 2017	Buckling and damage of liner due to too high pressure behind liner from a pressurised leak detection system	Leak detection system will detect leak after start up of plant. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Commissioning	Liner		Major consequence X Moderate likelyhood (11)	Install a vacuum based active leak detection system to avoid reoccurance of this incident. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)
9	3 October 2017	Buckling of liner due to creating vacuum in reactor by condensing steam during for example temporary holding the heating up procedure of reactor	Leak detection system will detect leak after start up of plant. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Commissioning	Liner		Major consequence X Moderate likelyhood (11)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs. Add air during heating up procedure with steam and add pressure measurement with vacuum pressure range.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)
10	3 October 2017	Buckling of liner due to creating vacuum in reactor during draining	Leak detection system will detect leak after start up of plant. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Commissioning	Liner		Major consequence X Moderate likelyhood (11)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs. Add air during heating up procedure with steam and add pressure measurement with vacuum pressure range.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)
11	3 October 2017	Ammonium carbamate in contact with carbon steel can lead to bi-(carbonate) stress corrosion cracking in case water is present behind the liner.	Cracks in carbon steel, which are difficult or impossible to detect and which may compromise the integrity of the reactor. Note: The possibility to detect these cracks during inspection may be possible in case of a solid wall reactor, however the consequences of cracks are more severe in a solid wall.	Operational	Carbon Steel Wall	UreaKnowHow.com Urea Incident Database: Incidents 10-005, 05-001, 04-001, 96-001, 95-001	Major consequence X Moderate likelyhood (11)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Never flush behind the liner with steam, water or condensate. Remove old liner when a relining job is due, so one is able to assess the integrity of the carbon steel pressure bearing wall.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)
12	3 October 2017	Ammonium carbamate in contact with carbon steel may lead to hydrogen induced stress corrosion cracking in carbon steel due to low oxygen environment.	Cracks in carbon steel, which are difficult or impossible to detect and which may compromise the integrity of the reactor. Note: The possibility to detect these cracks during inspection may be possible in case of a solid wall reactor, however the consequences of cracks are more severe in a solid wall.	Operational	Carbon Steel Wall	UreaKnowHow.com Urea Incident Database: Incident 94-001	Major consequence X Moderate likelyhood (11)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Remove old liner when a relining job is due, so one is able to assess the integrity of the carbon steel pressure bearing wall.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)
13	8 March 2018	Ammonium carbamate in contact with carbon steel pressure bearing wall (outside) leading to bi-(carbonate) stress corrosion cracking in carbon steels due to leaking carbamate falling on reactor vessel	Cracks in carbon steel on outside, which can harm the mechanical integrity of the vessel	Operational	Carbon Steel Wall	UreaKnowHow.com Urea Incident Database: Incident 94-001	Major consequence X Moderate likelyhood (11)	Performing corrosion inspections by qualified and experienced inspectors also on outside of Urea Reactor. Focus on damaged insulation areas. Avoid that leaking ammonium carbamate can drip on high pressure urea equipment.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)

14	3 October 2017	Nitrate stress corrosion cracking to outside side of carbon steel wall due to e.g. bad support design and/or insulation. Note: nitrates can origin from local nitric acid or ammonium nitrate plant or even urea conversion by bacteria.	Cracks in carbon steel on outside side, which can threaten the mechanical integrity of the reactor.	Operational	Carbon Steel Wall	UreaKnowHow.com Urea Incident Database: Incidents XX-003, XX-004	Major consequence X Moderate likelyhood (11)	Performing corrosion inspections by qualified and experienced inspectors also on outside of Urea Reactor. Focus on damaged insulation areas. Assure and maintain proper insulation; Install shelter on top of reactor.	In case of a leak stop the plant								Major consequence X Rare likelyhood (5)
15	3 October 2017	Sulphur corrosion to outside side of carbon steel wall due to e.g. bad support design and/or insulation.	Pitting corrosion of carbon steel on outside side, which can threaten the mechanical integrity of the reactor.	Operational	Carbon Steel Wall		Major consequence X Moderate likelyhood (11)	Performing corrosion inspections by qualified and experienced inspectors also on outside of Urea Reactor. Focus on damaged insulation areas. Assure and maintain proper insulation; Install shelter on top of reactor.	In case of a leak stop the plant								Major consequence X Rare likelyhood (5)
16	3 October 2017	Flange leakage leading to crevice corrosion at flange connection of nozzle leading to damage of stainless steel and/or carbon steel parts of flange connection.	This may threaten the mechanical integrity of the flange connection	Operational	Flange connection		Major consequence X Moderate likelyhood (11)	Apply proper installation and tightening procedures for flange connections. Keep leaking flange connection free of solids in order that leak can be assessed and less risks can occur of corrosion of carbon and stainless steel parts of the flange connection, stop the plant and correct the situation.	In case of a leak stop the plant								Major consequence X Rare likelyhood (5)
17	3 October 2017	Flange leakage leading to crevice corrosion at flange connection of manway cover leading to damage of protective layer and/or stainless steel and/or carbon steel parts of flange connection.	This may threaten the mechanical integrity of the vessel	Operational	Flange connection		Major consequence X Moderate likelyhood (11)	Apply proper installation and tightening procedures for flange connections.	In case of a leak stop the plant								Major consequence X Rare likelyhood (5)
18	3 October 2017	Passive corrosion of trays leading to thinning. Normal part of design basis, typical lifetime of trays is 10-15 years as corrosion is from two sides. Corrosion rate is higher in top of reactor as temperatures are higher.	Somewhat less conversion to urea	Operational	Internals		Insignificant consequence X Likely likelyhood (5)	Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Measure wall thickness of trays.									Insignificant consequence X Rare likelyhood (1)
19	3 October 2017	(Erosion) Corrosion of downcomer leading to hole and process upset (more prone in bends and in Saipem reactors due to 2-phase flow regime and higher velocities)	Lower conversion figures in synthesis as reactor inlet liquid mixes with outlet liquid	Operational	Internals		Insignificant consequence X Likely likelyhood (5)	Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings, Measure wall thickness of downcomer.									Insignificant consequence X Rare likelyhood (1)
20	3 October 2017	(Condensation) Corrosion of internal pipe of radio-active source for level measurement.	Shut down required and possible radio-active contamination of reactor solution	Operational	Internals	UreaKnowHow.com Urea Incident Database: Incident 96-001	Major consequence X Moderate likelyhood (11)	Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings, Measure wall thickness of internal pipe. Apply higher alloy materials for this pipe. Switch to radar type level measurement.	In case of a leak stop the plant								Major consequence X Rare likelyhood (5)
21	3 October 2017	Leak detection hole still closed due to crystallisation of urea during leak	No leak detection available during operation. In case a defect in a liner occurs, ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel.	Operational	Leak Detection System	UreaKnowHow.com Urea Incident Database: Incident 13-002	Major consequence X Moderate likelyhood (11)	An active vacuum based leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Note: Only a vacuum system guarantees a direct monitoring of a maximum liner area. Apply tracing to leak detections tubing.	In case of a leak stop the plant							Major consequence X Rare likelyhood (5)
22	3 October 2017	Passive corrosion leading to opening of subsurface defects leading to active corrosion.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner	2015 Al-Siyabi Omifco Helium Leak Detection in High Pressure Urea Reactor (E-Library UreaKnowHow.com)	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Measure wall thickness of liner and overlay weld at same location at regular time intervals. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
23	3 October 2017	Weld defect (e.g. weld decay, knife line attack) in liner.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner	AICHE 2014 Yara paper	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Look for defects in liner welds. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
24	3 October 2017	Corrosion (e.g. weld decay, knife line attack) in Heat Affected Zone (HAZ) of weld of liner to carbon steel wall.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Pay attention to HAZ during corrosion inspections. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
25	3 October 2017	Defect (full penetration, pinhole, start-stop) in clip weld to liner.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner	AICHE 1995 Thielsch paper	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Look for defects in clip welds. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs. Assure full penetration and complete inspectable welds of clips (design phase).	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
26	3 October 2017	Condensation corrosion in gas phase part of reactor due to heat sinks like lifting lugs, bad tracing and insulation, supports of ladders or platforms.	Higher corrosion rates (AICHE 2014 Yara reports 0.2 mm/yr but this can vary) leading to shorter lifetimes and leaks in liner. Ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner	AICHE 2014 Yara paper	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Measure liner thickness at heat sinks. Assure and maintain proper tracing and insulation (temperature above condensation temperature of vapours); remove lifting lugs; avoid heat sinks. All these measures will increase lifetime of liner.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
27	3 October 2017	Higher corrosion rates in areas with high velocities or in gaps (e.g. between trays and protective layer) leading to defects in protective layer (erosion corrosion).	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Focus on gaps and in area between tray and protective layer. Avoid gaps between trays and protective layer during design and fabrication phase.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
28	3 October 2017	Fatal failure of high pressure piping leading to sudden de-pressurization of complete synthesis section and too fast cooling down of liner leading to cracks in the liner.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner	UreaKnowHow.com Urea Incident Database: Incidents 98-003, 00-001	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections of the high pressure piping system during turnarounds by qualified and experienced inspectors with a frequency depending on age of the plant and previous inspection findings. Make use of skillful and experienced designers and fabricators also for high pressure piping systems; perform expediting services by skillful and experienced persons. Never apply clamps on carbamate lines.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)

29	3 October 2017	Clogged area behind the liner due to an earlier leak without an active leak detection system in operation.	It is possible that parts of areas underneath the liner are not detected by circulating air (note there are two grooves in parallel and thus there can be flow while one groove is clogged). Leak may be detected too late. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel.	Operational	Liner		Catastrophic consequence X Moderate likelyhood (12)	A vacuum based active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Note: Only a vacuum system guarantees a direct monitoring of a maximum liner area also in case some parts are clogged.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
30	3 October 2017	Clogged leak detection hole and/or inter connecting tubing due to for example an earlier leak without an active leak detection system in operation.	No leak detection available. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel.	Operational	Liner		Catastrophic consequence X Moderate likelyhood (12)	A vacuum based active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Note: Only a vacuum system guarantees a direct monitoring of a maximum liner area also in case a leak detection holes is clogged or only one leak detection hole is available.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
31	3 October 2017	Strain induced stress corrosion cracking of 316L UG liner in area liquid - gas interface leading to possible leaks.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur. Note: These cracks in liner which grow with slow rates.	Operational	Liner		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Look for cracks at liquid - gas interface. Minimize stops & starts and quick cooling down & heating up procedures.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
32	3 October 2017	Many stops & starts and quick cooling down and heating up leads to more stresses in liner or higher risks for cracks in liner.	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner	AICHE 1995 Thielsch paper	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Minimize stops & starts and quick cooling down & heating up procedures. Minimize the distance between the liner and the carbon steel.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
33	3 October 2017	Subsurface defects open up due to passive corrosion.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. A defect in an overlay weld exposes only a limited area of the carbon steel to ammonium carbamate. Leak before break is a more likely scenario.	Operational	Overlay welding Failure		Minor consequence X Moderate likelyhood (6)	Perform corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. These defects lead to pinholes in overlay welding. Note in case one finds one pinhole it is likely more will be / become present. Operator outside should inspect for possible leaks through insulation during rounds and shut down the plant in case of a leak.	In case of a leak stop the plant							Minor consequence X Rare likelyhood (2)
34	3 October 2017	Weld decay in overlay welding due to too high heat input	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. A defect in an overlay weld exposes only a limited area of the carbon steel to ammonium carbamate. Leak before break is a more likely scenario.	Operational	Overlay welding Failure		Minor consequence X Moderate likelyhood (6)	Perform corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. These defects lead to pinholes in overlay welding. Note in case one finds one pinhole it is likely more will be / become present. Operator outside should inspect for possible leaks through insulation during rounds and shut down the plant in case of a leak.	In case of a leak stop the plant							Minor consequence X Rare likelyhood (2)
35	3 October 2017	Too high pressure in reactor caused by several possible process upset conditions	Pressure safety valve blows off, carbamate crystals will erode seat area, pressure safety valve needs service and unexpected down time of some days. Further large amount of ammonia and CO2 are emitted to an assumed safe location. Insignificant safety consequence but environmental and financial issue.	Operational	Process		Insignificant consequence X Likely likelyhood (5)		Apply LESER flush safety valves, which do not require servicing after blowing off. Double check safe location at blow off side of reactor safety valves.								Insignificant consequence X Likely likelyhood (5)
36	3 October 2017	Loss of oxygen or too less oxygen for proper passivation leading to active corrosion with higher corrosion rates and possible defects in protective layer	Loss of passive Cr2O3 layer in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Process		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Take daily Nickel analysis in final product plus keep track of colour of final product.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
37	8 March 2018	Chloride contamination on process side leading to locally defects in passive Cr2O3 layer and accelerated rates of strain induced stress corrosion cracking	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Process	https://www.ureaknowhow.com/ukh2/round-table/viewtopic.php?f=33&t=16444&p=8203#p8203	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Avoid any chloride contamination on the process side and perform analysis at regular time intervals.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
38	3 October 2017	Sulphur contamination on process side leading to locally defects in passive Cr2O3 layer and accelerated rates of strain induced stress corrosion cracking	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Process	http://www.ureaknowhow.com/ukh2/round-table/viewtopic.php?p=431#p431	Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Minimize any sulphur contamination on the process side, otherwise increase oxygen level for passivation (valid within limites).	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
39	3 October 2017	Blocking in too long, active corrosion starts.	Detoriation of the protective layer increases the risk that hidden defects show up. This leads that ammonium carbamate will be in contact with carbon steel pressure bearing wall. Ammonium carbamate in contact with carbon steel leads to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Limit blocking in events and duration as recommended by licensor. Note A consequence of blocking in can be discoloration of the end product. In case the discoloration disappears, no active corrosion has been taken place. And in case it does NOT disappear active corrosion has occured and one should stop the plant, drain, inspect and re-passivate.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
40	3 October 2017	CO2 leaks into the synthesis / reactor leading to higher temperatures during blocking in leading to risks of active corrosion with higher corrosion rates	Detoriation of the protective layer increases the risk that hidden defects show up. This leads that ammonium carbamate will be in contact with carbon steel pressure bearing wall. Ammonium carbamate in contact with carbon steel leads to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Check temperature trends in reactor during blocking in.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
41	3 October 2017	A too high steam pressure on stripper shell leads to strip gas formation leaking into the reactor. This leads to a stripping effect of the oxygen in the liquid during blocking in leading to risks of active corrosion with higher corrosion rates	Detoriation of the protective layer increases the risk that hidden defects show up. This leads that ammonium carbamate will be in contact with carbon steel pressure bearing wall. Ammonium carbamate in contact with carbon steel leads to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Avoid/limit blocking in of reactor.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
42	3 October 2017	Active corrosion due to blocking in again shortly after a previous blocking in period (unsufficient refreshment of liquid with enough oxygen content)	Detoriation of the protective layer increases the risk that hidden defects show up. This leads that ammonium carbamate will be in contact with carbon steel pressure bearing wall. Ammonium carbamate in contact with carbon steel leads to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. With repeating blocking in periods, limit total blocking in period as recommended by the licensor unless content of reactor has been refreshed sufficiencty.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
43	3 October 2017	Crevice corrosion at seat area of safety valves increases area and lower pop up pressure	Pressure safety valve pops up too early, carbamate crystals will erode seat area, pressure safety valve needs service and unexpected down time of some days. Further large amount of ammonia and CO2 are emitted to an assumed safe location.	Operational	Safety valve	Nitrogen & Syngas 2013 LESER paper	Insignificant consequence X Likely likelyhood (5)	Apply LESER flush safety valves, which guarantee an open discharge during operation, no erosion during discharging and closes again wihtout servicing.									Insignificant consequence X Rare likelyhood (1)

44	3 October 2017	Too high pressure in reactor caused by several possible process upset conditions plus a malfunctioning pressure safety valve (for example clogged outlet line)	Pressures higher than design pressure can cause risks for the mechanical integrity depending on level of pressure reached (it is assumed pressure will remain below test pressure)	Operational	Safety valve		Insignificant consequence X Likely likelyhood (5)	Apply LESER flush safety valves, which guarantee an open discharge during operation, no erosion during discharging and closes again wihtout servicing.								Insignificant consequence X Rare likelyhood (1)
45	3 October 2017	Fatigue cracks in liner sleeve in nozzle due to thermal stresses.	Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Liner		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. A vacuum based leak detection system detects more quickly a leak. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Focus on nozzles during fabrication and inspections. Install two leak detection holes in each liner compartment. Make use of experienced and high quality vendors.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
46	3 October 2017	Too fast and often cooling down of the reactor leads to mechanical fatigue stresses on the protective layer leading to cracks	Defects in the protective layer lead that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical integrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Operational	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Never use extra cooling media to cool down the reactor.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
47	3 October 2017	Flushing the leak detection system with water can cause contamination between the carbon steel layers in case there is no protecting tube in the leak detection holes present leading to cracks in the carbon steel (nitrates or (bi-)carbonates).	Cracks in the carbon steel can threaten the mechanical integrity of the vessel.	Operational	Leak Detection System		Catastrophic consequence X Moderate likelyhood (12)	Never flush behind the liner with steam, water or condensate. Install protective tubes in the leak detection holes. Make use of qualified and experienced fabricators.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
48	3 October 2017	A leak in the liner can cause contamination between the carbon steel layers in case there is no protective tube in the leak detection holes present leading to riks for (bi)carbonate stress corrosion cracks in the carbon steel.	Cracks in the carbon steel can threaten the mechanical integrity of the vessel.	Operational	Leak Detection System		Catastrophic consequence X Moderate likelyhood (12)	Install protective tubes in the leak detection holes. Make use of qualified and experienced fabricators.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
49	3 October 2017	Bad workmanship during repair, e.g. bad or too much welding, wrong materials leading to defects in the protective layer. Note: welding gives heat input which can reduce the corrosion resistance of the protective layer.	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Maintenance	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)
50	3 October 2017	Use of chloride containing marker leading to chloride stress corrosion cracking	Defects in the protective layer leads that ammonium carbamate can get into contact with carbon steel pressure bearing wall. Ammonium carbamate will be in contact with carbon steel pressure bearing wall leading to potentially high corrosion rates (1000 mm/year). This can threaten the mechanical inegrity of the vessel. As leaking liquid in a urea reactor contains also urea, clogging of the leak detection tubes is likely to occur.	Maintenance	Protective layer		Catastrophic consequence X Moderate likelyhood (12)	An active leak detection system with a reliable and accurate ammonia detector, which is in operation since the first start up, minimizes time that ammonium carbamate is in contact with carbon steel and minimizes the risk of clogging of the leak detection tubes. Performing corrosion inspections during turnarounds by qualified and experienced inspectors with a frequency depending on age of reactor and previous inspection findings. Make use of qualified and experienced fabricators and welders for repair jobs. Minimize welding as repair procedure. If welding is required make use of 25-22-2 welding material during repair jobs. Never use chloride containing markers.	In case of a leak stop the plant							Catastrophic consequence X Rare likelyhood (7)