Comparative Quantitative Risk Assessment (QRA) Approach ON large Scale Underground Pipelines

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The Buried gas pipelines can be safer and more efficient than vehicle transportations for material and energy transport in modern society. However, underground pipelines can be dangerous and have many safety issues because it is difficult to inspect and manage. If an accident occurs, it will incur property and personal injury due to sudden gas leak or explosion. In fact, The Kaohsiung gas explosion accident of 31 July 2014 had caused the deaths of 32 people and 321 people were injured. It caused by leaking 4 inches diameter propene buried pipeline due to poor management in risk assessment. Therefore, Buried gas pipeline risk assessment is needed to prevent any accident. This paper conducted a study on several possible underground pipeline routes of petrochemical complex in Ulsan, Korea. The methodology used in this Quantitative Risk Assessment (QRA) has focused on the risk comparison. During the QRA using risk analysis software packages as DNVGL PHAST. F-N curves for toxic, fire & explosion based on rupture scenarios were generated with rupture historical rupture frequency and consequence analysis. The main intention of this paper is comparing the relative risk of the buried pipeline and we have determined whether any route having hazardous substances such as hydrogen and ammonia would be unacceptable.

I. INTRODUCTION

Energy transportation pipelines are evaluated to be the most practical energy transportation system because they enable stable energy supply from production sites and their management costs are very low once the problem of initial installation costs has been solved. However, along with increases in pipeline lengths, cases of accidents due to pipe rupture have been increasing. In fact, in 2010, an explosion accident occurred due to damage to poor weld zones in natural gas pipelines in San Bruno, California, USA. Due to the accident, eight persons died and 58 persons were injured. [1][2] In the case of South Korea, a hydrogen gas leakage accident occurred in 2015 due to pipeline damage during drilling operations in Ulsan Petrochemical Complex. Although there was no damage for humans, this accident could lead to great damage if there was any ignition source in the vicinity. To minimize damage when an unexpected accident has occurred as such, the risk of underground pipeline networks should be appropriately assessed.

Methods of assessment and management of the risk of buried pipelines can be largely divided into three; risk based quantitative risk assessment, qualitative risk assessment, and probability theory based structural safety assessment. First, quantitative risk assessment is a method implemented to numerically quantify risks to assess the risks and reduce the assessed risks to below the level desired by us. Representative ones include Bevb Risk Assessment of RIVM in Netherlands and the PIR calculation method in IMP, a pipeline soundness management system in the USA. Second, qualitative risk assessment is a method of assessing risks more easily through material, inflammability, and toxicity indices and a representative one is the RIMAP (Risk-Based Inspection and Maintenance Procedures for European Industry) of Europe. [3] Finally, structural safety assessment is a method of assessing the reliability of pipelines by clearly assessing uncertainty and the PIRAMID (pipeline risk analysis for maintenance decision) of C-FER in Canada is known to be this method. In the present study a quantitative risk assessment (QRA) technique was proposed as an underground pipeline accident risk assessment technique that fit domestic circumstances and actually applied the technique to three sections of a hydrogen pipeline and three sections of an ammonia pipeline in a petrochemical complex. Using PHAST v6.7, the toxicity and fire risk of the pipelines were indicated as Societal Risks and the risks of the pipelines by section were compared and analyzed in two methods.

- Cumulative FN curve
- FN Curve per km

II. QRA Methodology

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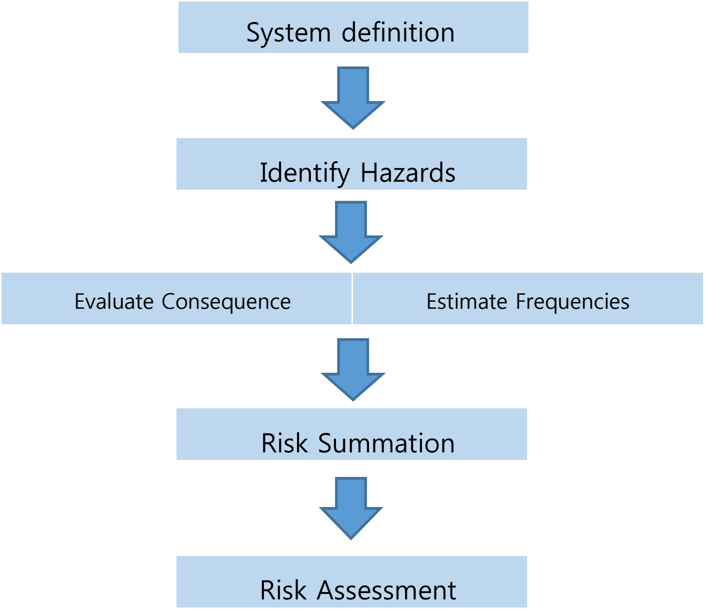

Fig. 1. Schematic QRA step

III. Case Study

III.A. System Definition

- Pipeline Condition
- Pipeline Route
- Surrounding Environment (Population density, weather condition)

First, we have assumed two different underground pipeline transportation carrying a representative flammable substance, hydrogen in gas phase as pipeline A and a representative toxic substance, ammonia in gas phase as pipeline B. well for the case study. As shown in Table I, the starting and destination points are the same for all pipelines but the routes are different as #1, #2 and #3 respectively. Also different population densities are assumed around the routes and they are designated as A, B, C, and D. The process conditions in the pipelines and lengths are described in Table I and II. Table III shows the population densities around the routes and Table IV describes the most likely weather conditions of the location based on the guideline of Offsite Risk Assessment for Korean Risk Management Program.[4]

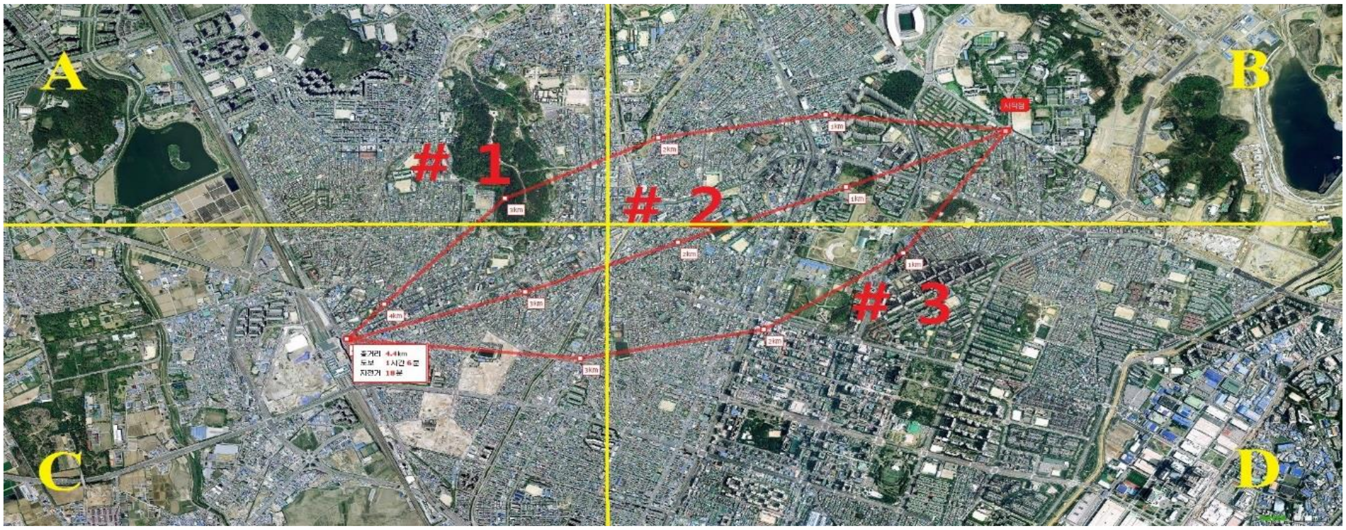

Fig. 2. Pipeline Route and Population density [6]

TABLE I. Pipeline Condition

Parameter	pipeline A	pipeline B
Material	Hydrogen	Ammonia
Pipe Diameter	100 mm	100 mm
Pipe wall thickness	0.0457 mm	0.0457 mm
Pressure	70 bar	70 bar
Temperature	15 ℃	15 ℃

TABLE II. Pipeline Route

Parameter	Route # 1	Route # 2	Route # 3
Pipeline length	4.3 km	4 km	4.4 km

TABLE III. Population Density

Parameter	Area A	Area B	Area C	Area D
Population Density	10,000 km2	15,000 km2	7,000 km2	10,000 km2

TABLE IV. Weather Condition

Weather Name	Weather 1.	Weather 2.
Wind Speed	3 m/s	1.5 m/s
Pasquill Stability	D	F
Atmospheric Temperature	25 ℃	25 ℃
Surface Roughness	Urban	Urban
Surface Temperature	15 ℃	15 ℃

III.B. Hazard Identification

This hazard identification process is very crucial to accurately analysis the risk for underground pipelines. There could be small, medium, large leak scenarios due to corrosion but they are excluded based on the assumption that protecting system works fine and coatings are well maintained. However, as seen in the most recent incidents with underground pipelines as in Table V, excavation damage has been selected for the scenario by external construction since the location is urban to super-urban which has a lot of possible digging construction. Excavation damages usually cause total ruptures of pipelines rather than small leaks. Thus in this paper, rupture scenario frequencies and its corresponding consequences are investigated. For pipeline A (hydrogen), jet fire is likely to occur with immediate ignition because the minimum ignition energy of hydrogen is very low (0.011 mJ). For pipeline B (ammonia), toxic hazard is only considered though ammonia is both toxic and flammable since its toxic hazard can reach further than flammable hazards and it is difficult to ignite ammonia. Summarization of consequences in each pipeline is given in Table VI.

TABLE V. Underground pipeline Accident in Korea

Date	Cause	Release Amount
2014.01	Excavation Damage	LPG 40 ton
2014.02	Excavation Damage	Xylene 30 m^3
2016.04	Excavation Damage	Nitrogen 60,000 m^3

TABLE VI. Event Tree Rupture Pipeline

Material	Direct Ignition	Delayed Ignition	No Ignition
Pipeline A (Hydrogen)	Jet Fire	n/a	n/a
Pipeline B (Ammonia)	n/a	n/a	Toxic Vapor Cloud

III.C. Consequence and Frequency Estimate

A widely-used program in petrochemical industry for process hazard analysis, PHAST v6.7 is employed for consequence analysis in the paper. Majority of underground pipelines are less than 5 km in S. Korea and line rupture scenario was selected instead of long pipeline rupture scenario in the program for maximizing discharge rates assuming locations of rupture are adjacent to source points. Input values for PHAST are shown in Table VII. The historical rupture frequencies are used in RIVM report and the same value, 3.7 x 10^{-5}/(km·year) is selected for this paper. Hypothetical ruptures are assumed to occur at every kilo-meter.

TABLE VII. Major Input Value in PHAST v6.7

Parameter	Input Value
Scenario Type	Line Rupture
Release Elevation	0 m (Minimum Data)
Release Direction	45 deg

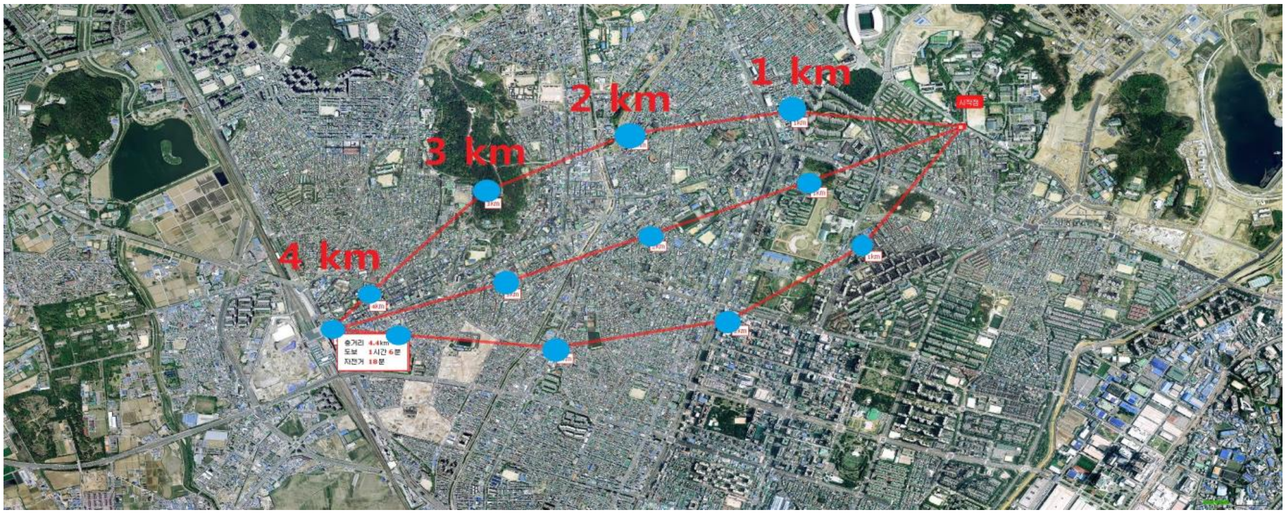

Fig. 3. Hypothetical rupture locations for three pipelines (per km)

III.D. Risk Summation Result

III.D.1. Societal Risk using Cumulative FN curve

Cumulative FN curves are made calculated to show FN curves integrating 5 different risk points which are set per km (start point at 0 km,1 km, 2km, 3 km, 4 km). For both pipeline 1,2, it appeared that the cumulative risk of #1 route is higher than the others, and the risk of #2 is higher than that of #3 as shown in Fig 4. On the other hand, the cumulative risk of ammonia pipelines in Fig. 5 are higher than hydrogen pipeline risk in Fig 4.

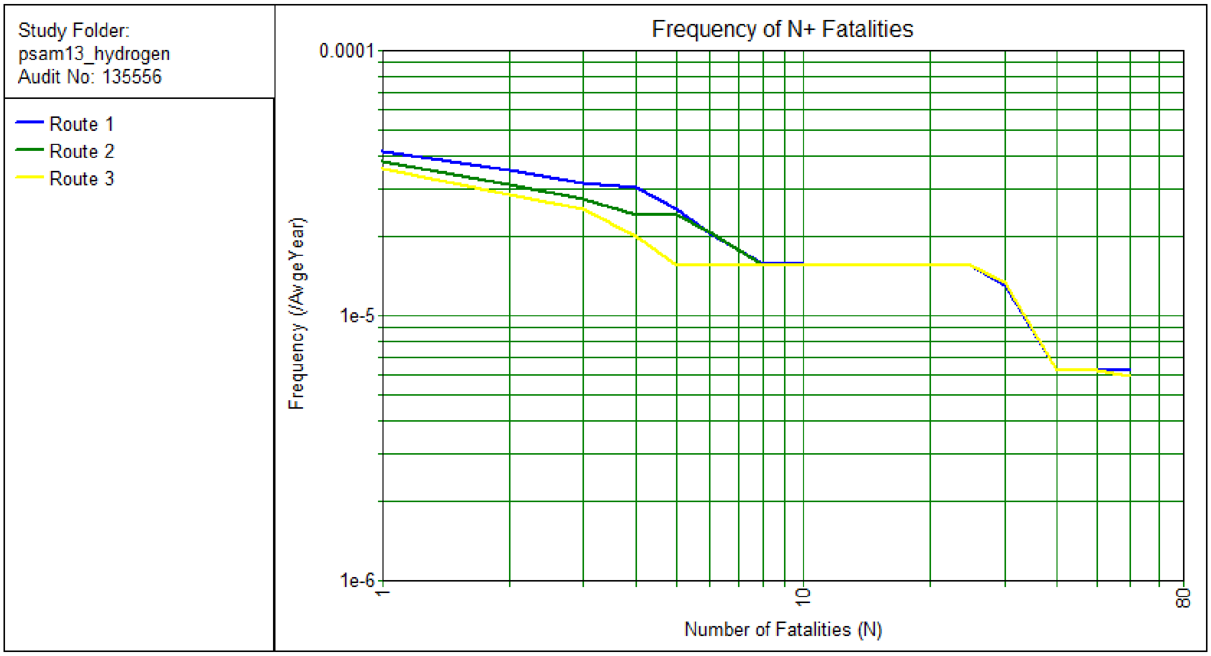

Fig. 4. Pipeline A (Hydrogen) Societal Risk using Cumulative FN curve

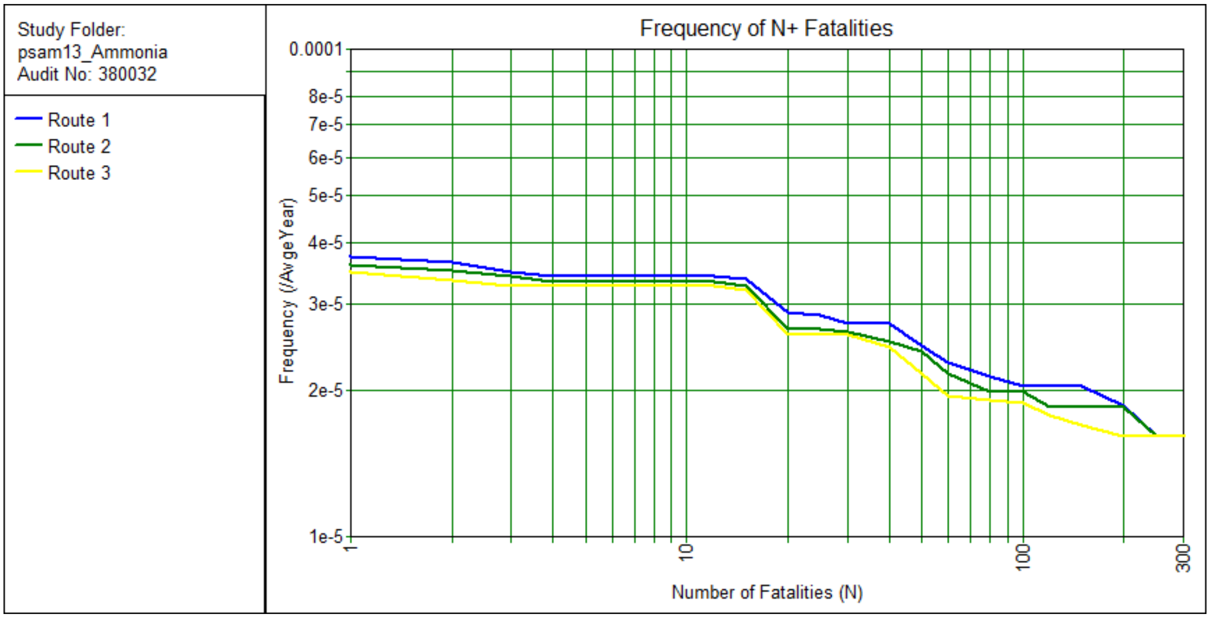

Fig. 5. Pipeline B (Ammonia) Societal Risk using Cumulative FN curve

III.D.2. Societal Risk using FN curve per km (only pipeline A, Hydrogen)

“FN curve per km” method is performed by calculating the risk at each hypothetical point at every km. Thus the risks of starting points of route 1,2,3 are all the same shown in Fig 6 because all routes share the same starting place of the pipelines. But the risks at 2 km point of route 1,2,3 shows the different result as Route 1 > Route 2 = Route 3 in Fig. 7 since the populations around them are different.

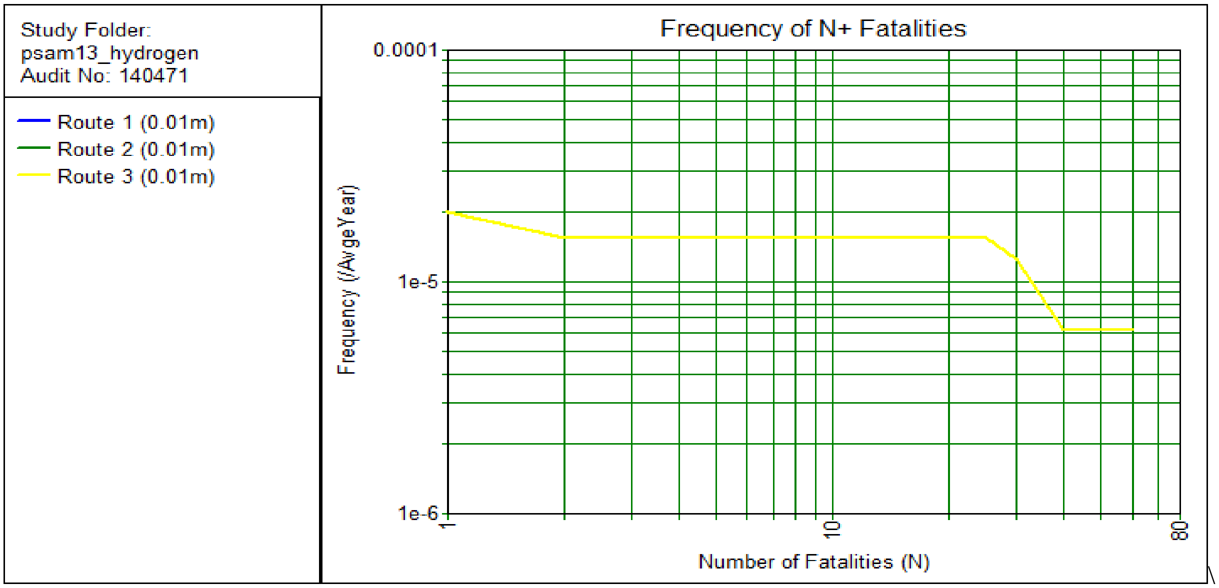

Fig. 6. Pipeline A (Hydrogen) 0.01 m Societal Risk using FN curve

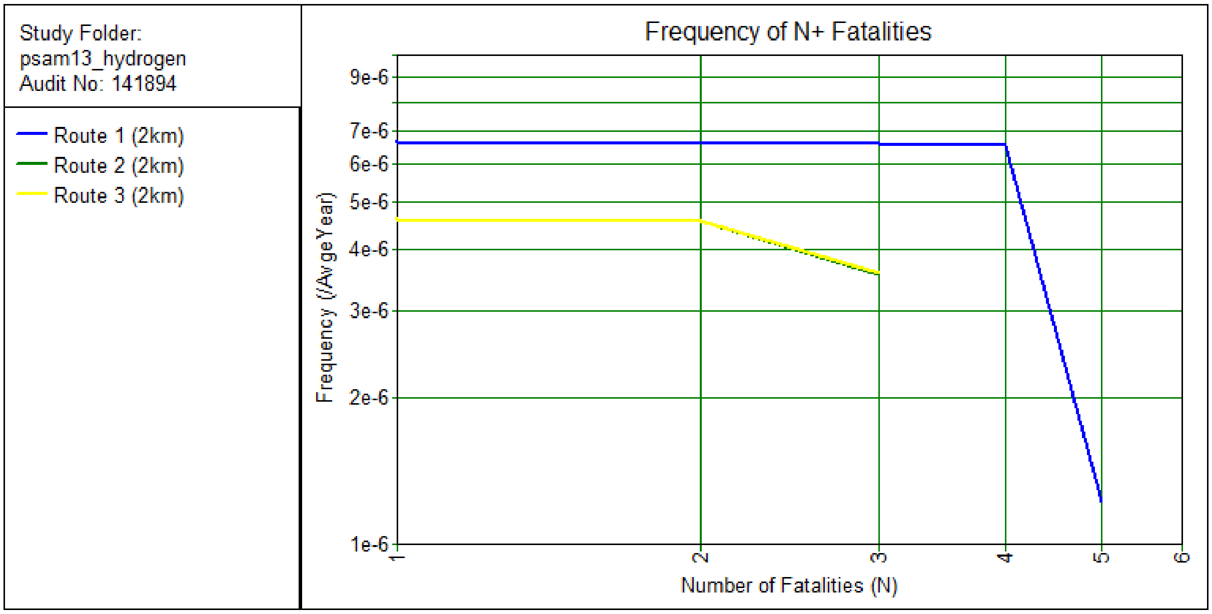

Fig. 7. Pipeline A (Hydrogen) 2 km Societal Risk using FN curve

IV. CONCLUSIONS

This paper has shown how to compare risks for three possible underground pipeline routes having two different materials (hydrogen, ammonia) using FN curve. Overall, route 3 has the lowest risk among three possible pipeline routes for both materials so that it would be better to make a final decision on select the route unless there is any other reason not to build it in there. “Cumulative FN curve” method shows the risk of route 1 > 2 > 3 in Fig 4. The reason is different population density as in TABLE III, B> A= D. Route 1 passes relatively dense populated area (Area A and Area B). Therefore, the risk of route 1 is larger than other routes. In addition, this paper shows the societal risk of ammonia pipeline is greater than hydrogen pipeline. It is because hazardous concentration by the toxicity of ammonia can reach a lot further than hazardous heat radiation by hydrogen. The risk of each route can be also compared by drawing them in one figure for each km. Fig. 7 shows route 1 is more dangerous than other routes(route 1> route 2= route 3). “Cumulative FN curve” is more effective when we make a final decision on what route should be selected since it can shows overall risk at glace.

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