Assessment of the maximum possible number of victims of accidents at hazardous production facilities for insurance purposes

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Abstract In this article, we will familiarize with the currently used methods of assessing the maximum possible number of victims, their analysis and construction of algorithms, followed by a comparison of the results, on the basis of which the most optimal method of assessing the maximum possible number of victims will be chosen. An approach to assessing the maximum number of victims, based on the modeling of the territorial distribution of people within the zone of damaging factors. One of the complex and urgent tasks in the framework of the application of existing approaches to the assessment of the maximum possible number of victims for insurance purposes is the problem of modeling the density of the distribution of people within the zones of the affecting factors. The most adequate approach is based on the discretization of the density over the territory of the site by dividing it into areas, for example, by imposing a certain grid.

Keywords: assessment, insurance, victims, individual risk, algorithm, probability

1 Introduction

According to the current legislation in the field of civil liability insurance for damage caused during the operation of hazardous facilities, for the purposes of liability insurance for each scenario under consideration, it is recommended to calculate the maximum possible number of victims (MPNV), which is determined by the number of people caught in the zone of damaging factors [1,2].

To assess the possible losses in the EMERCOM system, the methodology developed by the Federal state University of GOCHS in 2007 is used. It consists of several stages.

At the first stage of assessing the number of victims, it is necessary to identify the object by the type of hazardous substance and the form of its use (storage, production, processing), followed by the allocation of a digital code corresponding to the substance and the method of its use.

In the second stage of the assessment, the class of exposure of the hazardous object is determined according to the code identifying the hazardous object and the volume of substance on it.

In the third stage of assessing the number of victims are determined by the affected area, consisting of:

Areas of irretrievable losses-all who were in this area during an emergency should be guaranteed to die, while outside this zone, the death of people does not occur.

Area of sanitary losses-it is believed that the health of all those trapped in the area will be caused one or another degree of damage, while outside the area of damage is completely absent.

The fourth step in assessing the number of victims is to determine the number of people caught in an emergency in the area of irretrievable and sanitary losses [3-7].
The shares of areas and the areas themselves can be taken approximately or calculated using traditional methods of planimetry with the application of templates to the map at an appropriate scale. Also, when determining the number of people caught in the area of impact factors should take into account the specifics of the emergency and its dependence, for example, weather conditions.

The fifth step is to determine the number of victims in the areas of sanitary and irretrievable losses, taking into account the correction factor for mitigating the consequences of the accident. This adjustment is necessary because the number of victims may be reduced by the possibility of rescue measures prior to the impact of the accident and the availability of personal protective equipment and shelters. These factors can significantly affect the total number of victims. Values of correction coefficient is determined on the basis of the digital code of the dangerous substance operating on the facility [8].

An approach to assessing the maximum number of victims, based on the modeling of the territorial distribution of people within the zone of damaging factors. One of the complex and urgent tasks in the framework of the application of existing approaches to the assessment of the maximum possible number of victims for insurance purposes is the problem of modeling the density of the distribution of people within the zones of the affecting factors. The most adequate approach is based on the discretization of the density over the territory of the site by dividing it into areas, for example, by imposing a certain grid. An alternative to this approach is the currently widely used approach based on a uniform distribution of people on the territory of the potential object.

According to the method [9-11], to assess the consequences of the i-th scenario of the accident under consideration, it is recommended to calculate the number of victims, determined by the number of people caught in the zone of the damaging factors. Deterministic criteria establish the values of the damaging factor, in which there is a particular level of damage (destruction). Deterministic criteria assign a certain value of the negative impact of the damaging factor a specific degree of damage to people, the destruction of buildings, engineering structures. In the case of deterministic criteria, the conditional probability of defeat is assumed to be 1 if the value of the damaging factor exceeds the maximum permissible level, and equal to 0 if the value of the maximum permissible level of defeat is not achieved. Probabilistic criteria show what the conditional probability of a level.

Individual risk for people in buildings is recommended to be determined taking into account the potential risk of destruction of the building during an explosion in accordance with Annex No. 3 to the Federal norms and rules in the field of industrial safety "General rules of explosion safety for explosive chemical, petrochemical and oil refineries" in such a way that the vulnerability factor in the implementation of scenarios with an explosion is 0 if the building does not fall into the zone of destruction in the explosion, and is 1 if it falls. In this case, the conditional probability of death in the building is taken depending on the degree of destruction of buildings. The coefficient of vulnerability in the implementation of the damaging factors associated with thermal and toxic damage, it is recommended to determine based on the ability of the shelter. In the absence of information about the protective properties of the shelter should take the vulnerability coefficient equal to one.

2 Development of an algorithm to assess the maximum possible number of victims.
Description of mathematical model.

We will analyze the components of the formula for calculating the number of deaths in the area of the striking factors

\[
N^i_{epicmp} = \sum_{i=1}^{\mu_i(x,y)} \int_{\Omega_i} \mu_i(x,y) q(x,y) dxdy \Omega_i = \bigcup_{j=1}^{\mu_j (x,y)} \Omega_j
\]

(1)

\[
v_{j,y}(x,y) \cdot \tilde{P}_{def}^j (x,y) \geq 0.01
\]

(2)
\( v^{ij}_{\text{str}}(x, y) \) - the coefficient of vulnerability of a person located at the point of the territory with coordinates \((x, y)\) from the \(j\)-th damaging factor, which can be realized during the \(i\)-th scenario of the accident, and depends on the protective properties of the room, shelter, which can be a person at the time of the accident, and changing from 0 (the person is invulnerable) to 1 (the person is not protected because of minor protective properties of shelter), or exceed 1 in case of death in the collapse of buildings; we will consider its values in three possible scenarios of the accident in the building and beyond:

2.1. The coefficient of vulnerability for the different accident scenarios

2.1.1. Values of vulnerability coefficient for the staff members who are in the room.

2.1.1.1. The coefficient of vulnerability to fire Strait in the case of a person in the building.

\[
v^{ij}_{\text{str}}(x, y) = \begin{cases} 
1 \\ 0 
\end{cases}
\]

(3)

2.1- if \( r < R_{\text{str}} \), 0- if \( r > R_{\text{str}} \). And as it can be seen from the function, this value always takes the value 1, if the radius of action of the damaging factors, which in this case is equal to the area of the fuel spill, is superimposed on the area of the building for which the assessment is made.

2.1.1.2. Vulnerability factor in the explosion of fuel-air mixture in the case of a person in the building.

\[
v^{ij}_{\text{exp}}(x, y) = \begin{cases} 
1 \\ 0 
\end{cases}
\]

(4)

1 - if \( r < R_{\text{exp}} \), 0- if \( r > R_{\text{exp}} \). The values of this indicator are similar to the Strait fire-the vulnerability of staff members is assumed to be 0, in the case where the radius of action of the damaging factors does not affect the territory of the building for which the analysis is carried out.

2.1.1.3. The coefficient of vulnerability in the fire-flash in the case of a person staying in the building.

\[
v^{ij}_{\text{fl}}(x, y) = 0
\]

(5)

The value of this coefficient for the fire-flash will always be 0, as it is believed that the damaging factors of this emergency that occurred outside the building, are not able to cause damage to staff members in the building.

2.1.2. Values of the vulnerability coefficient for staff members in the open area.

The coefficient of vulnerability in the open area will always be equal to one, since there are no shelters with sufficient protective properties to neutralize the damaging properties of the emergency.

\( p^{ij}_{\text{op}}(x, y) \) - conditional probability of death of an unprotected person in the open space at the point of the territory with coordinates \((x, y)\) from the \(j\)-th damaging factor in the implementation of the \(i\)-th accident scenario.

Also, as in the case of the previous indicator, consider the dependence of its values on the type of emergency and the location of the staff at the time of a negative event.

2.2. The probability of death of staff members for the different scenarios accident.
2.2.1. The probability of death for staff members in the room.

2.2.1.1. The probability of death of staff members in the building, the fire spillage.

\[ P_{zub}^{ij}(x, y) = \begin{cases} 1 & \text{if } r < R_{up}, \\ 0 & \text{if } r > R_{up}. \end{cases} \]  

(6)

The probability of death in a building in a fire spill is taken to be 1, if the area of action of the damaging factors includes the area of the building and is considered to be zero when it is less than this area.

2.2.1.2. The probability of death of staff members in the building, the explosion of fuel-air mixture.

\[ P_{zub}^{ij}(x, y) = \begin{cases} P_{paz}^{ij} \bigwedge P_{j} & \text{insignificant} \\ P_{paz}^{ij} \bigwedge P_{j} & \text{medium} \\ P_{paz}^{ij} \bigwedge P_{j} & \text{heavy} \\ P_{paz}^{ij} \bigwedge P_{j} & \text{full} \end{cases}. \]  

(7)

The probability of death of staff members suffering from the effects of the explosion of TVs in the building, depends on the probability of destruction of the building as a result of their exposure, so in this case, the probability of death takes the form of a function

\[ P_{zub}^{ij} = f \left[ P_{paz}^{ij} \bigwedge P_{j} \right] \]  

(8)

2.2.1.3. The probability of death of staff members in the building, in a outbreak-fire

\[ P_{zub}^{ij}(x, y) = 0 \]  

(9)

As in the case of the vulnerability coefficient, the value of this coefficient for the fire-outbreak will always be zero, as it is believed that the damaging factors of the emergency that occurred outside the building are not able to cause damage to staff members in the building.

2.2.2. The probability of death of staff members located in the open area.

2.2.2.1. Probability of death of the staff members who are on the open platform at the fire-spill.

\[ P_{zub}^{ij}(x, y) = \begin{cases} 1 & \text{if } r < R_{up}, \\ \int_{-\infty}^{\infty} e^{-\frac{r^2}{2}} dr & \text{if } r > R_{up}. \end{cases} \]  

(11)

The probability of injury to staff members in an open fire-spill is considered to be equal to 1, if the staff members falls into the fire zone, and punched-function, taking different values, in the opposite case.
2.2.2.2. Probability of death of the staff members who are on the open platform at explosion of fuel-air mixture

\[
P_{\text{inj}}^{ij}(x, y) = \int_{-\infty}^{0} e^{\frac{-r^2}{2}} dt.
\]  

The probability of death in the explosion of the fuel-air mixture always takes the member's value of the probit- function that characterizes the probability of damage to staff.

2.2.2.3. The probability of death of staff members in the open area, in an outbreak-fire.

\[
P_{\text{out}}^{ij}(x, y) = \begin{cases} 
1 & \text{if } r < R_{\text{top}} \\
0 & \text{if } r > R_{\text{top}}
\end{cases}
\]  

1. if \( r < R_{\text{top}} \). 0- if \( r > R_{\text{top}} \). This value, in contrast to the vulnerability factor, can take a different value depending on where the person is at the time of the accident.

3 Algorithm development

List of basic data needed to determine the maximum possible number of victims:

\( l = 1 \ldots L \) – distribution of staff members on the site, depending on various factors: day or night work shift, the occurrence of an emergency situation at the facility or the appearance of a large number of people near the facility – in the case of inspection or other activities.

\( m = 1 \ldots M \) – functional groups of staff performing different functions and working independently of each other. This indicator is important to determine the number of people who can be within the range of damaging factors at the time of implementation of the accident scenario.

\( q_{ix, iy} \) – the proportion of time people stay at the point \( x, y \). In this case, this indicator is considered to be equal to the length of the work shift.

\( ix, iy \) – coordinates of the zone within which the probability of human injury is assessed. The introduction of this indicator is due to the division of the object of assessment into separate zones, in each of which the calculation of the necessary indicators is carried out separately.

\( z = 1 \ldots Z \) – an additional group of zones within which there is a building with the possibility of finding staff in it.

\( SZ \) – the number of separation grid squares falling within the \( z \)-zone. The process of constructing the algorithm should begin with the development of the basic algorithm for assessing the maximum possible number of victims.
Step 1: define \( l=1 \ldots L \) - distribution of staff members on the site, depending on various factors: day or night work shift, the occurrence of an emergency at the facility or the appearance of a large number of people near the facility in the case of inspection or other activities.

Step 2: \( j \) - th damaging factor that can be realized during the \( i \) - th scenario of the accident and depends on the protective properties of the room, shelter, which can be a person at the time of the accident, and changing from 0 (the person is invulnerable) to 1 (the person is not protected because of the minor protective properties of the shelter).

Step 3-4: \( i_x,j_y \) – coordinates of the zone within which the probability of human injury is assessed. The introduction of this indicator is due to the division of the object of assessment into separate zones, in each of which the calculation of the necessary indicators is carried out separately.

Step 5: \( \mu_i(x,y) \) - function describing the territorial distribution of people within the zone of action of the damaging factors (density of distribution of people, people/m2) accounting changes in the distribution of people depending on the change of staff members, carrying out emergency (routine) repair or construction works on the territory of the OPO, periodic occurrence of mass congestion of people near the OPO and the influence of organizational and technical measures aimed at the early evacuation of people.

Step 6: the calculation of the number of deaths in the area of impact.

Step 7-8: \( i_x,j_y \) – coordinates of the zone within which the probability of human injury is assessed. The introduction of this indicator is due to the division of the object of assessment into separate zones, in each of which the calculation of the necessary indicators is carried out separately.

Step 9: \( i_x, j_y \) – coordinates of the zone within which the probability of human injury is assessed. The introduction of this indicator is due to the division of the object of assessment into separate zones, in each of which the calculation of the necessary indicators is carried out separately.

Step 10: The probability of death of staff members for different accident scenarios (\( P \)) taking into account the value of the vulnerability coefficient for different accident scenarios, if this indicator takes the value \( \geq 0.01 \), then we proceed to the calculation of the calculation of the number of deaths in the area of the damaging factors, otherwise we carry out an additional account: the \( j \) - th damaging factor, which can be realized during the \( i \) - th accident scenario and depends on the protective properties of the room, shelter, in which a person may be at the time of the accident. This varies from 0 (the person is invulnerable) to 1 (the person is not protected due to the minor protective properties of the shelter) and
as soon as the parameter becomes ≥ 0.01. Also we pass to calculation of calculation of number of the dead who appeared in a zone of action of the striking factors.

Step 11: Again imposed on the obtained values of $ix,jy$ are the coordinates of the zone within which the assessment of the probability of destruction of people. The introduction of this indicator is due to the division of the object of assessment into separate zones, in each of which the calculation of the necessary indicators is carried out separately.

Step 12. Next, consider $m=1...M$ - functional groups of staff members performing various functions and working independently of each other.

This algorithm performs a search of different scenarios in accordance with the available source data and the specified parameters determined by the characteristics of the object of evaluation. But to use it requires building multiple approach determining parameters:

$\mu_{ix,jy}$ - territorial distribution of people depending on various factors;

$V_x,y_{ix,jy,i,j}$ - vulnerabilities of staff members located at a certain point at the time of the accident

$P_{zub,l,i,j}$ - the probability of death of staff members located at a certain point at the time of the accident

The next sub-algorithm actually allows us to determine the distribution of people on the site in accordance with the indicator $z$ - location of the areas of people, often coinciding with the location of buildings. If the functional group of staff members does not fall into these coordinates, the presence of people on it is not considered, respectively, the number of people in coordinates $ix, jy$ is taken to be 0. Otherwise, the number of people who are in the evaluation area is calculated by the formula given in the sub-algorithm and describes the distribution of staff members on a certain area taken as the area of the zone.

Let us consider in detail sub-algorithm describing the territorial distribution of people in buildings at the site of the test object $\mu_{ix,jy}$, where

Step 1: listing of all possible zones $z$ – from 1 to $Z$

Step 2: next, consider $m=1...M$ - functional groups of staff members performing various functions and working independently of each other

Step 3: designated $ix,jy$ are the coordinates of the zone within which the assessment of the probability of destruction of people. In each of the zones, the calculation of the necessary indicators is carried out separately. If there is no staff in the area under consideration, that is, the values $ix, jy$ do not fall within $Z$, then

Step 4: consider $m=1...M$ - functional groups of staff members, and further on all possible zones $z$ from 1 to $Z$. Otherwise,

$$\mu_{ix,jy} = \frac{N_{z,m,l}}{S^2} + \mu_{ix,jy}$$

and do Step 4, for the obtained data.

Step 5: determine

Finally, consider the sub-algorithm describing the dependence of the probability of death and vulnerability of staff members from various factors. In this sub-algorithm shows the probability of staff members affecting factors of the accident while people are in the building and outside in all areas of the subject property. The values of these indicators have been discussed in detail in section 2.1, so we will not consider them in this subsection.

To determine the parameters $\mu_{ix}, jy$ and $j$ in the framework of this algorithm is carried out for all possible zones $z$ from 1 to $Z$.

Step 1: We carry out search on $ix, jy$ – coordinates of a zone within which the assessment of probability of defeat of people is carried out. In each of the zones, the calculation of the necessary indicators is carried out separately.

$$r = \sqrt{(x-x_0)^2 + (y-y_0)^2}$$

Step 2: If the square $ix, jy$, within which the probability of hitting people in the building
If it’s a fire-spill, and R<Rnop, then \( v_{ix,jy} = 1 \), \( P_{uix,jy} = 1 \) and conduct recount on ix,jy – coordinates of the zone within which the probability of human injury is assessed.

If it’s a fire-spill, and R>Rnop, then \( v_{ix,jy} = 0 \), \( P_{uix,jy} = 0 \) and conduct recount on ix,jy – coordinates of the zone within which the probability of human injury is assessed.

If there was an explosion of the fuel-air mixture, and R<Rnop, then \( v_{ix,jy} = 1 \), \( P_{uix,jy} = P_{xy} \Delta P \) and conduct recount on ix,jy – coordinates of the zone within which the probability of human injury is assessed.

If there was an explosion of the fuel-air mixture, and R>Rnop, then \( v_{ix,jy} = 0 \), \( P_{uix,jy} = P_{xy} \Delta P \) and conduct recount on ix,jy – coordinates of the zone within which the probability of human injury is assessed.

If there was a fire flash, then \( v_{ix,jy} = 0 \), \( P_{uix,jy} = 0 \) and conduct recount on ix,jy – coordinates of the zone within which the probability of human injury is assessed.

In other cases, \( P_{uix,jy} = 0 \) and conduct recount on ix,jy – coordinates of the zone within which the probability of human injury is assessed.

Step 4: If the square ix, jy –, within which the assessment of probability of defeat of people not in the building is carried out, \( v_{ix,jy} = 1 \).

If it’s a fire-spill: and if R<Rnop, then \( P_{uix,jy} = 1 \) and conduct recount on no ix, jy – coordinates of the zone within which the probability of human injury is assessed.

\[
P_{uix,jy} = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-\frac{r^2}{2}} dt
\]

If it’s a fire-spill, and if R>Rnop, then \( P_{uix,jy} = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-\frac{r^2}{2}} dt \) and conduct recount on ix, jy – coordinates of the zone within which the probability of human injury is assessed.

If there was an explosion of the fuel-air mixture: and conduct recount on ix, jy – coordinates of the zone within which the probability of human injury is assessed.

If there was a fire flash: and if R<Rnop, then \( P_{uix,jy} = 1 \) and conduct recount on ix, jy – coordinates of the zone within which the probability of human injury is assessed.

If there was a fire flash: and if R>Rnop, then \( P_{uix,jy} = 0 \) and conduct recount on ix, jy – coordinates of the zone within which the probability of human injury is assessed.

4 Conclusion

Based on the results, we can draw a number of conclusions characterizing the advantages and disadvantages of each of the methods used:

The methodology used by the Ministry of emergency situations allows for a relatively quick and simple analysis of the possible number of victims, without requiring a large amount of data. This is due to the binding of the data used in this technique to only a few indicators: the type of substance, its quantity and the role played in the technological process, all other data are tabular, which greatly simplifies the calculations. However, the disadvantages of this technique is a fairly low accuracy of the results associated with the relativity of the data used, and the inability to take into account in the calculations of the actual number of staff members staying at the facility depending on the work shift. However, this technique is justified in cases where it is required to estimate the number of people who are able for one reason or another to be in the area of action, which can be critical when working in the field during the liquidation of the consequences of the accident. [12-17]
The methodology presented by federal Budgetary Institution scientific and engineering centre ‘Power Safety’ requires a significant amount of data, such as: territorial distribution, changing the location of staff depending on the work shift, changing the distribution of people in emergency situations and knowledge of the exact location of the staff. Also, the use of this technique is accompanied by a large number of calculations for each possible scenario under all possible conditions, which makes it problematic to use it without the appropriate software. However, instead, it offers a sufficiently accurate data about the defeat of the people, given the flow of time, allowing you to fully assess the damage and to carry out the identification of funds required for liquidation of consequences of the accident. This determines its use in the system of insurance of dangerous objects, established by the Federal law №225 "The low about compulsory insurance of civil liability of the owner of a dangerous object for causing harm as a result of an accident at a dangerous object" from 27.07.2010. [1]

The described algorithm of application of the technique based on modeling of distribution of people on the territory of potential object can allow to carry out an adequate assessment of the maximum possible number of victims in the conditions of unsteadiness of workplaces or conditions of heterogeneity of stay of people in the territory or near potentially dangerous object. It should be noted that the currently available approaches of this indicator are based on a priori approach, which indicates the impossibility of accurate prediction of the results of future negative phenomena. However, the proposed algorithm makes it possible to improve the accuracy of estimates of the maximum possible number of victims in terms of a wider range of used source data and discrete modeling of the distribution of people.

References
[1] Federal law of 27.07.2010 №225-FL «About obligatory insurance of civil liability of the owner of dangerous object for causing harm as a result of accident on dangerous object». – 2014, 17 p.
[2] Federal law of 21 July 1997. N 116-FL «About industrial safety of hazardous production facilities»
[3] The determination of the amount of damage in the event of accidents at hazardous facilities. URL: http://riskprom.ru/_ld/2/268...pdf.
[4] «Life safety. Safety in natural and man-made emergencies". Textbook. – 2012, 592 p.
[5] Oltyan I Y, Vostokov V Y, Korovin A I " Method of estimating the maximum number of victims of emergencies caused by fires, explosions and emissions of toxic substances"
[6] Akimov V A, Bykov A A, Vostokov V Y, Lyakhovets T L, Malyshev V P Guidelines for determining the number of victims in emergency situations of man-made / Akimov V. A., Bykov A. A., Vostokov V. Yu., Lyakhovets T. L. // Независимая оценка риска. – p. 347-367.
[7] Byzov A P, Efremov S V Methodological approaches to the assessment of individual and collective risks for site explosive objects /
[8] Inapshba N U, Byzov A P. Assessment of the maximum possible number of victims of accidents at hazardous production facilities. //Science week of SPbSPU: proceedings of the scientific forum with international participation. Institute of military technical education and security. – SPb.: Publishing house of Polytechnical Institute, 2015. – p. 181-183.
[9] «Methodological foundations for conducting hazard analysis and risk assessment of accidents at hazardous production facilities". Safety guide. Approved by order No. 144 of the Federal service for environmental, technological and nuclear supervision of April 11, 2016 – 2016.
[10] Federal law from 21.06.1997 №117-ФЗ «About the safety of hydraulic structures». – 2015, 14 p.
[11] Byzov A P Methodical apparatus of assessment of technogenic risk in explosions and fires at the objects of fuel and energy complex. Thesis for the degree of candidate of technical Sciences. SPb.: Publishing house of Polytechnical Institute, 2011.
[12] Burlov V, Andreev A, Gomazov F. Mathematical model of human decision - A methodological basis for the realization of the human factor in safety management (2018) Procedia Computer Science
[13] Chalovskaya E K, Klochihin I O & Kaverzneva T T 2018 Algorithm of assessing working conditions at waste processing plants. Paper presented at the Proceedings of the 2018 IEEE International Conference "Management of Municipal Waste as an Important Factor of Sustainable Urban Development", WASTE 2018, 3-6. doi:10.1109/WASTE.2018.8554133

[14] Kovalenko I I, Sokolitsyn A S & Semenov V P 2018 Industrial injuries in the socio-economic aspect. Paper presented at the Proceedings of the 3rd International Conference Ergo-2018: Human Factors in Complex Technical Systems and Environments, Ergo 2018, 205-208. doi:10.1109/ERGO.2018.8443868

[15] Shevchenko N, Manucharyan R, Gravit M & Geraskin Y 2017 Programs for calculating the explosion resistance of buildings and structures. Paper presented at the IOP Conference Series: Earth and Environmental Science, 90(1) doi:10.1088/1755-1315/90/1/012192

[16] Braila N V, Khazieva K L & Staritcyna A A. 2017 Results of technical inspection monitoring of the operation object. Magazine of Civil Engineering, 74(6), 70-77. doi:10.18720/MCE.74.7

[17] Volkov M, Kibkalo A, Vodolagina A & Murgul V 2016 Existing models residual life assessment of structures and their comparative analysis. Paper presented at the Procedia Engineering, 165 1801-1805. doi:10.1016/j.proeng.2016.11.925