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11

Asbestos Hazards Analysis in Construction Projects With the Fault Tree Analysis and the Failure Mode and Effect Analysis

KEYWORDS: HEALTH AND SAFETY AT WORK, RISK ANALYSIS, ASBESTOS RISK, FAULT TREE ANALYSIS, FAILURE MODE AND EFFECT ANALYSIS.

The Italian construction sector suffered more than the other industrial sector the negative effects of the world economic crisis. A consequence has been a change in its organization concerning labour and managent on the health and safety issues. Evidence of this can be found in an increase of fatal accidents and occupational diseases. In particular occupational diseases became a health concern in construction. The aim of the presented research work is to assess the hazard of asbestos fibres inhalation due to decommissing of old industrial promises with roofing of asbestos. The developed approach starts from a probabilistic assessment of the risk, using the Risk Analysis tools, the Fault Tree Analysis (FTA) and the Failure Mode and Effect Analysis (FMEA). Risk assessment through the FTA is based on a backward approach: it starts from the malfunction of the system, called Top Event, in order to look for the triggering causes (events); on the contrary, the FMEA analysis is based on a forward approach: they start from a set of events and go on in order to analyse what kind of malfunctioning these can generate in the system. Both the FTA and the FMEA are applied to three approved decontamination techniques (encapsulation, confinement and removal), and for each of them operational phases, equipment, building products and PPE (Personal Protective Equipment) are evaluated highlighting the procedures needed to operate in complete safety.
With this approach the main factors that contribute to the increase of the risk of asbestos fibres inhalation are detected: preliminary analysis and assessment of the state of building decay, the use and maintence of PPE and machinery, and the supervision during main working phases.

INTRODUCTION

The construction sector has suffered more than the others from the negative effects of the economic crisis, ISTAT data (ISTAT, 2017) show that since 2008 a total of 800.000 job positions have been lost. In recent years, the building site has changed profoundly and as a result the organization of work within it has changed.

After some years of reduction of both accidents and fatal accidents, we are witnessing a worrying increase in occupational diseases because of less safety at work. In the five-year period 2013 - 2017, according to the INAIL observatory data, (INAIL, 2013 - 2017) an increase of 20% of the diseases of suspected professional nature is found. The occupational diseases caused by exposure to asbestos is the aim of this research work. The fifth RENAM (National registry of mesotheliomas) report published by INAIL reports the data related to Mesothelioma cases detected by the Regional Operative Centers. From the data examined and related only to those affected by professional causes, the sector most affected by this dramatic record is that of construction with 15.2% of cases. About occupational cancers, construction workers are the most exposed to lung cancer; precisely, they are 50% more likely to develop lung cancer than all other workers.

The widespread presence of Asbestos Cement Materials (MCA) in the construction industry determines a risk of exposure to asbestos, especially for those who carry out building renovations, even if decontamination is normally carried out by specialists with dedicated training. The decontamination and removal of slabs of cement - asbestos used in buildings for the roofing is a typical case of building intervention where laborers exposed to asbestos. Building operation involves a specific risk of falling, with or without breaking the slabs, and dispersion of asbestos fibers, for these reasons suitable temporary works must be created to protect against the risk of falling and workers must be provided with suitable means of protection of respiratory tract and protective clothing. The aim of the present study consists in the analysis and assessment of risks in the remediation operations of a cement-asbestos roof, specifically the risk of inhalation of asbestos fibers. We intend to proceed with a probabilistic risk assessment, using the tools of FTA - Fault Tree Analysis, based on a backward approach, and the FMEA - Failure Mode and Effect Analysis, based on a forward-type approach, which represent systems of innovative analysis for the building sector, but already proven in other areas, for example in the aerospace missions of NASA, in the robotics, chemical and automobile industries. The analysis is carried out on the three techniques of remediation (encapsulation, confinement and removal) analyzing for each the operations to be performed, the materials and the products to be used, the individual protection devices to wear carefully assessing what needs to be done to operate in complete safety.

ASBESTOS HAZARDS

Asbestos is a natural mineral with a microcrystalline structure and a fibrous appearance. The fibrous structure gives the asbestos a remarkable mechanical resistance and a high degree of flexibility; it resists very well to fire, heat, the action of chemical and biological agents, abrasion and thermal and mechanical wear, it also has sound-absorbing and heat-insulating properties and easily binds with building materials (lime, gypsum) and cement) and some polymers (rubber, PVC). The characteristics of the material and the low cost have favored a wide use in the sectors of industry, construction and transport. If, on the one hand, the fibrous structure has brought asbestos to have "positive" characteristics in its flexibility of use, on the other hand these fibers of which it is composed have the characteristic to divide longitudinally, whereby the material maintains the fibrous appearance up to the size of a few hundredths of a micron and for this reason it is so dangerous because, if inhaled, it can penetrate deep into the pulmonary alveoli and be carcinogenic.
With the issue of law n. 257/1992 - which prohibits the extraction, importation, exportation, marketing and production of asbestos - has started an important remediation work. The importance of planning and implementing the removal of materials containing asbestos was also recognized through the establishment of incentives by the Government.
Law 257 of 27 March 1992 is considered the Framework Law on asbestos as it was intended to regulate the process of asbestos disposal by defining precise criteria. It provides for the issuance of a series of decrees by the Ministry of health of a technical nature through which the intervention criteria have been established, the operating procedures to be adopted for the handling of materials containing asbestos, the methods for assessing the risk and safety procedures to be taken in materials removal work.
The first of these ministerial decrees is D. M. 6 September 1994 "Regulations and technical methods of application of art. 6, paragraph 3, and of the art. 12, paragraph 2, of the law March 27, 1992, n. 257, concerning the cessation of the use of asbestos ". The decree dictates the safety measures to be followed during the remediation interventions, the criteria and the limit values for the restoration of the environments after the remediation and describes the technical methods of custody of the materials and the operational procedures for the remediation of the same.
For the removal and maintenance of materials containing asbestos, the specific provisions relating to temporary or mobile construction sites provided for by Title IV of Legislative Decree 81/2008, in addition to those laid down by Chapter III of Title IX, concerning the " Protection of risks related to asbestos exposure ".
Remediation can be achieved by three techniques:

- encapsulation - treatment of the plates with products that cover the material preventing the release of the fibers;
- confinement - installation of a new roof over the existing one in cement - asbestos;
- removal-elimination and consequent disposal of the material containing asbestos.

Each of these methods of remediation, if not carried out correctly and without the appropriate protection devices, can pose serious risks to the health of workers.
Legislative Decree 81/2008 provides for an official communication to the Local Health Authority responsible for the territory in case of any activity concerning materials containing asbestos:

- notification in case of encapsulation or confinement - art. 250 of Legislative Decree 81/08
- in case of removal, a work plan is required - art. 256 of Legislative Decree 81/08

These mandatory communications are preventive, ie they concern activities that have not yet been carried out.
To arrive at an assessment on the need and urgency of remediation operations for asbestos-cement roofing (CA), algorithms have been developed over time to obtain objective and reproducible results. Examples of algorithms currently in use are the following:

- Index EPA
- Index FERRIS
- Index VERSAR
- AMLETO – Model for the assessment of the state of the CA roofing of the Emilia Romagna / Tuscany / Lombardy / Abruzzo Regions.

AMLETO is an algorithm based on a two-dimensional model that has the purpose of providing an operative tool to obtain indications on the actions that must be taken towards cement materials containing "exposed" asbestos.
The indicators considered refer to two parameter families:

- The context in which the building is inserted
- The state of conservation of the material

The calculation is made by adding the scores assigned to the parameters that describe the context in which the coverage is located, of which the total is shown on the abscissa axis of the graph, and the scores attributed to the parameters that describe the state of conservation of the coverage, taking account of the score on the worst side, whose total is shown on the axis of the chart's ordinates. The pair of values thus obtained identifies a point on the Cartesian plane included in one of the four areas in which the graph is subdivided and to which the different actions to be undertaken correspond.

METHODS PROPOSED FOR ANALYSIS AND RISKS ASSESSMENT

An effective management of health and safety in the workplace arises from a preventive and accurate analysis, assessment and subsequent risk management. Hence the need to have methodologies and support tools that, through the acquisition and management of data, allow the recognition and characterization of the risks that we intend to analyze, evaluate and manage in scenarios and operational contexts. With this in mind, INAIL, the National Institute for Workplace Accident Insurance, through the Department of Technological Innovations and Safety of Plants, Products and Anthropic Settlements, is committed to analyze the risk assessment process, to provide models of simplified and standardized risk analysis and management and organizational models dedicated to small business types where the risk underestimation could be greater, identifying the weakest phases (materials, procedures, organization), and developing subsidized procedures derived from risk analysis methods, FMEA and FTA, already used in reality of significant size and characterized by greater risks. The research activity is oriented to the development of experimental procedures to verify the structural integrity and reliability of components or elements of pressure equipment and lifting systems, based on failure analysis and fracture mechanics. With this study we intend to proceed with a probabilistic risk assessment, using the Risk Analysis tools.
To evaluate the risk of a system two approaches can be used:

- Forward analysis: we start from a set of events and we proceed forward to analyze what kind of malfunctioning they can generate in the system. It is therefore a preventive study aimed at eliminating critical system issues before the incident occurs. The analysis methods of this type are as follows:
  - IDEF - Integration Definition Language
  - SHELL - Software (norme), Hardware (strumenti), Environment (ambiente), Livewire (persona in attività)
  - FMEA – Failure Mode and Effect Analysis

- Backward analysis: it starts from the malfunctioning of the system and we go to look for the possible triggering causes (events). The analysis methods of this type are as follows:
  - IR – Incident Reporting
  - RCA – Root Causes Analysis
  - FTA – Fault Tree Analysis

Regardless of the methodology used, the priority conditions for the correct implementation of a Risk Analysis system are the correct initial classification of the potential error and the correct decomposition of the process for the identification of the microactivity in which the error resides.
In this paper, we choose to use the following Risk Analysis tools:

- Fault Tree Analysis (FTA) o Albero dei guasti
- Failure Mode and Effect Analysis (FMEA) o Analisi dei modi e degli effetti dei guasti.

FTA - FAULT TREE ANALYSIS

The Fault Tree Analysis (FTA) is a deductive method, it starts from an undesired event to determine (or rather deduce) the necessary and sufficient causes in a systematic way, through a backward procedure for successive steps.
The Fault Tree Analysis was developed for the first time in 1962 at the Bell Laboratories of HA Watson, as part of a contract of the "US Air Force Ballistics Systems Division" to evaluate the "Minuteman Launch Control System". Dave Haasl, then at the Boeing Company, recognized the value of this instrument and, in 1963-1964, led a team in the application of the FTA for an entire "Minuteman Missile System" (ie it extended the scope of the analysis to the universal system, not just to the control system). Other compartments within the same company noted the results that this program was able to provide and began to use the FTA also in the design of civilian aircraft. In 1965 Boeing and the University of Washington promoted the first Security Systems Conference, which saw many FTA magazines present, marking the beginning of its worldwide release.
Failure tree analysis was, in the mid-seventies, one of the most popular probabilistic techniques in PRA - Probabilistic Risk Assessment. Thus, at the beginning of the Apollo project, it was used to evaluate the probability of success in sending astronauts to the Moon and their return to Earth in good condition. The result was a probability of success of the mission that was unacceptably low, against the decidedly positive outcome of the real mission. This result has therefore discouraged NASA from using this type of analysis until the 1986 Space Shuttle Challenger accident. After that sad episode, NASA decided again to rely on the use of fault analysis (FTA) and effects analysis (FMEA) together with other qualitative methods for the evaluation of the safety system.
In addition, the FTA has earned its place over the years as a tool for safety assessment, risk assessment, investigation of accidents and reliability. The number of tree diagrams created over time shows that the interest in the FTA is not declined, but currently remains constant over time. As with any new discovery, there have been criticisms over the years, but the unequivocal benefits and strength of the FTA have discredited the arguments against it. Thus the FTA has become today an instrument recognized and used internationally.
The creation of a FTA involves the following steps:

1. Identify the objective of the FTA;
2. Define the FTA top event;
3. Define the purpose of the FTA;
4. Define the resolution of the FTA;
5. Define the basic rules of the FTA;
6. Building the FT;
7. Evaluate the FT;
8. Interpret and present the results.

The basic concept that drives the development of the FT is "thinking small". In fact, starting from the top event defined, it is necessary to identify only those causes, necessary and sufficient, which are immediately preceding. That is, you should not jump directly to the root causes, but you have to proceed for small successive steps through the causes immediately preceding the event analyzed. This backward procedure, only after several steps, will end with the basic causes that constitute the resolution of the analysis.
The FT is presented as a graphical reduction of the logical relationships between fault events that, with their occurrence, lead to the creation of an initiator event (or top event). The events that can be found in one of these diagrams can be grouped into 5 categories: basic event, intermediate event, top event, undeveloped event and conditioning event. The events are located in the tree with a precise hierarchical order, defined by the structure of the system and the logic of correlation. They are also well identifiable by a conventional symbology, as are the logical gates that connect events to one another. There are two main types of logical gates: the OR-gate and the AND-gate. All other types are subspecies of these two.

Qualitative evaluation of the fault tree

Once the fault tree has been drawn, its characteristics can be evaluated using the Boolean equations. The events correspond to the variables and the logical gates to the operations; the OR-Gate, representing the union between the events, corresponds to the sum and the AND-Gate, representing the intersection between the events, corresponds to the product.

This defines the Top Event in terms of Minimal Cut Sets, or the smallest combination of events that, if all verified, cause the occurrence of the Top Event.

$$\mathrm{D} = A \cdot (B + C)$$

Quantitative evaluation of the top event

When the Top Event equation is expressed in terms of Minimal Cut Sets, the probability of occurrence of the Top Event can be approximated as the sum of the probabilities of each minimal cut set.

$$\mathrm{P(TE)} = \sum_{i=1}^{n} \mathrm{P(Mi)}$$

$$\mathrm{P}(D) = \mathrm{P\,(A) \cdot P(B+C)}$$

The probability of occurrence of an event is defined by the product between the failure rate (λ) and the relevant time interval (t).

$$\mathrm{P} = \lambda \cdot \mathrm{t}$$

The failure rate corresponds to the frequency of occurrence of an event, defined as the ratio between the number of injuries and the number of hours worked. The relevant time interval considered corresponds to the duration of the work in hours, relative to the specific construction site.

FMEA - FAILURE MODE AND EFFECT ANALYSIS

Failure Mode and Effect Analysis is a technique for assessing the reliability of a project by considering potential failures and their effects on the system. It aims to define corrective actions to minimize the effects of failure modes. Generally, but not necessarily, the analysis is performed in advance and is therefore based on theoretical and non-experimental considerations. FMEA analysis can also be used as a basis for the evaluation of a redesign, a proposed replacement during manufacturing, assembly, installation and control phases.

The FMEA originated in the United States on November 9, 1949, with the introduction of the military procedure "MIL-P-1629" (Procedures for Permissioning to Failure Mode, Effects and Criticality Analysis), with the aim of classifying failures based on the impact on the success of the mission and on the safety of personnel and equipment.

In the 60s it was applied for Apollo space missions.

Subsequently, in the 80s, it was used by the automaker Ford to reduce the risks on a car model, the Pinto; this car had a repetitive problem of breaking the tank which caused fires in case of accidents.

In 1994, Chrysler, Ford and General Motors, sponsored by the USCAR (United States Council for Automotive Research), formalized a common procedure for the implementation of the FMEA.

To date, the use of the FMEA is foreseen by various quality management systems. This analysis is one of the main components of the PPAP (Production Part Approval Process) and is also applied within the Six Sigma

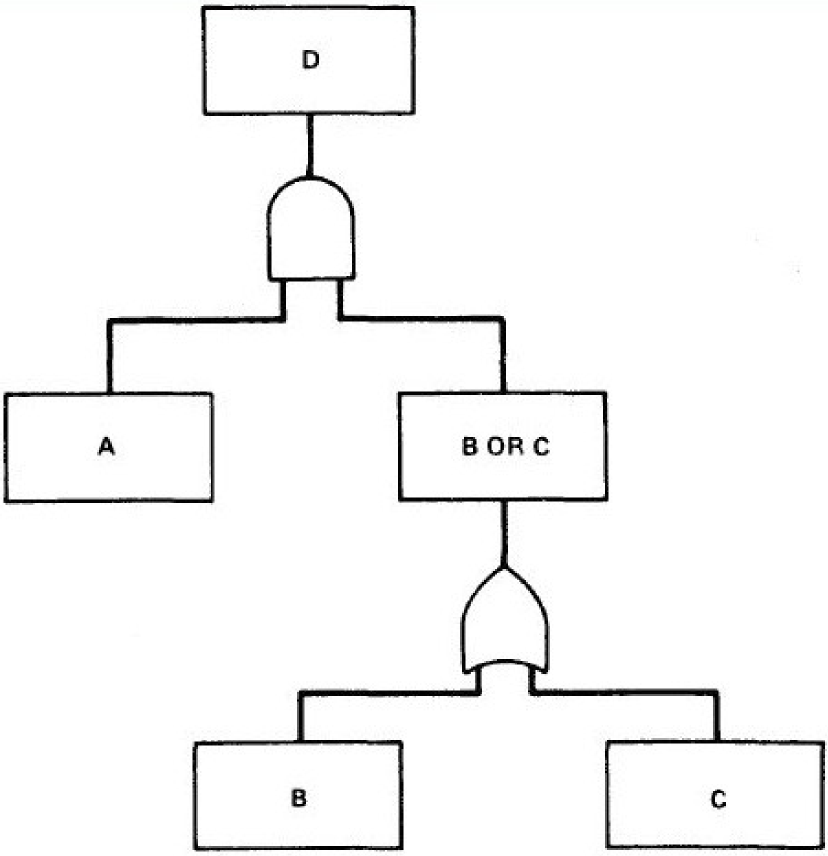


Figure 1: Structure of the fault tree for the equation D = A [illegible] (B + C).

methodology, a quality management program based on the control of the average square deviation (indicated with the Greek letter sigma) that has the aim of bringing the quality of a product or service to a certain level, particularly favorable to the consumer.
Analysis consists in identifying the fault modes, an element or process of the system, and for each failure mode the possible effects and all potential causes are determined.
Once these aspects have been defined, for each identified cause, the Risk Priority Index is calculated, defined by the product of three factors:
O – Occurrence – Probabilityof occurring the cause.
S– Severity of the potential effect.
D– Detectability of the cause, it is the probability of identifying the cause through the controls normally used in the process.
These indices are evaluated with a scale from 1 to 10, where 1 represents the minimum risk and 10 the maximum. Thus, a value of Risk Priority Number (RPN) between 1 and 1000 is obtained, which highlights the seriousness of the problem to establish a priority of intervention; the problems with major RPN will be clearly addressed, for which corrective actions must be decided to allow greater control of the cases examined.
To reduce Occurrence factorit acts on prevention, through adequate training and operational organization; to reduce the Severity factor, on the other hand, protection is applied, and therefore using PPE and DPC. Preventive controls can be made to decrease the index of Detectability.
FMEA can be repeated following the improvement actions to check if the values of the RPN index have decreased. Therefore, a new hypothetical RPN index value is obtained to estimate the effect of the interventions applied and to highlight the items on which to intervene subsequently.

FTA AND FMEA FOR HAZARD ASSESSMENT OF ASBESTOS ROOFING REMOVAL PROCEDURES: CASE STUDY

The developed approach involves a probabilistic risk assessment, using the tools of the FTA - Fault Tree Analysis and the FMEA - Failure Mode and Effect Analysis. The analysis is carried out on the three remediation techniques, analyzing for each the operations to be carried out, the products to be used, the individual protection devices to wear and the operation work procedures for safety.
To carry out the analysis, a work carried out by a company of Bologna, leader in the field of decontamination materials containing asbestos, was examinated on an Eternit roof of an agricultural building located in Minerbio, in the province from Bologna.
For the purposes of this study the INAIL, ISTAT and Confartigianato reports, specific of construction sector, were consulted to obtain values of failure rate and relevant time interval. The injury is the result of succession of several different events connected to each other, whose study represents an important step in the identification of main risk factors and consequent development of effective prevention strategies. Knowing how accidents occurred is the basis for a correct prevention and protection action, but a homogeneous information system must be used for recording data related to accidents in order to make them comparable. Since the 1990s, this need has led to the development of a project called ESAW, an acronym for European Statistic of Accidents at Work, created with the aim of using recognized and defined codes at European level for the cataloging of accidents. INAIL through the ESAW variables codifies accident reports: causes and circumstances reported in the individual complaints are traced to codes and constitute an indispensable database for preventative analysis. Within its database, which can be consulted online, INAIL provides data on injuries reported for each type of activity and it is possible to filter the search through the variables of specific interest. From the combination of the variables we obtained the number of

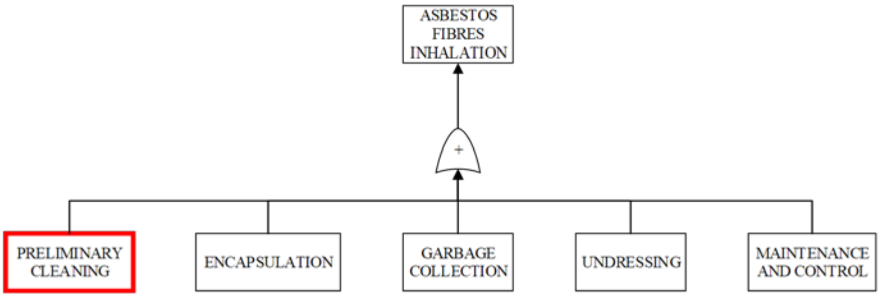
accidents for the purposes of research. On the basis of INAIL database, for the purposes of a more rapid and complete identification of injuries, a database was prepared containing all the possible events that cause the injury and the material agents involved in such events. This elaboration was carried out for the construction sector, the area of interest for this study. From the combination of deviation, or rather the action that led to the occurrence of the accident, and the material agent involved in the deviation, the number of accidents of interest for the purposes of probabilistic calculations is obtained.
Instead the number of work hours was obtained from the Confartigianato site, in the construction report based on ISTAT statistics.

Asbestos slabs remediation through encapsulation

The remediation of an Eternit roofing with the encapsulation technique involves the following operational steps:

- Preliminary assessment of the coverage status;
- Site construction;
- Cleaning and preparation of the support;
- Encapsulation;
- Garbage collection;
- Undressing;
- Maintenance and control.

Let's now look at the application of the Fault Tree Analysis to remediation by encapsulation.



The Top Event is represented by the risk that is being analyzed, that is the inhalation of the asbestos fibers, which represents the failure of the process. As the first intermediate events, the operating phases during which the Top Event could occur, and the first logical gate used is that of the OR-Gate, since we want to impose that the TE occurs if even one of the inputs is occur. All inputs are secondary failures of a system component, so they must be further developed through another OR-Gate.
For example, the "Preliminary cleaning" event is developed. The failure during this phase occurs if, for example, a machine-related fault occurs, or if there is a lesion in the cover, or if there is a fault related to the PPE.
For example, the event is developed to the machinery. It can occur if there is a malfunction or if it is misused.

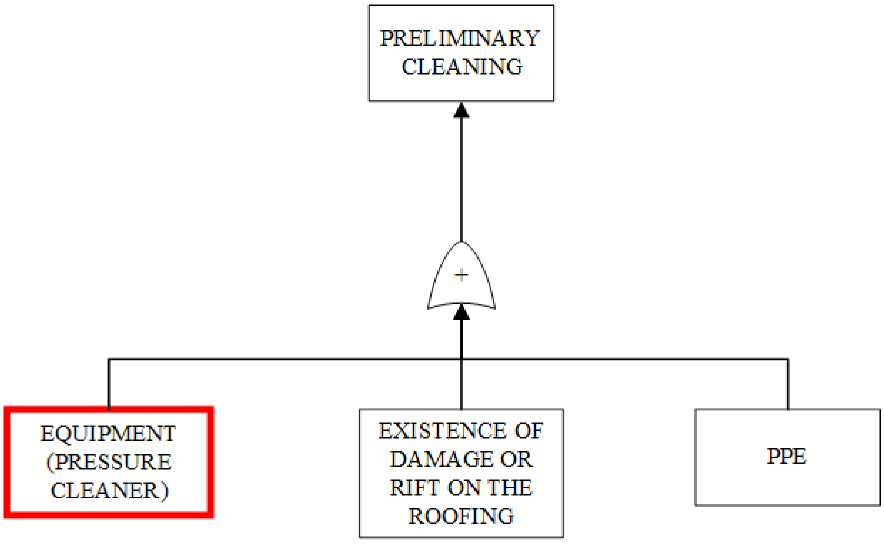
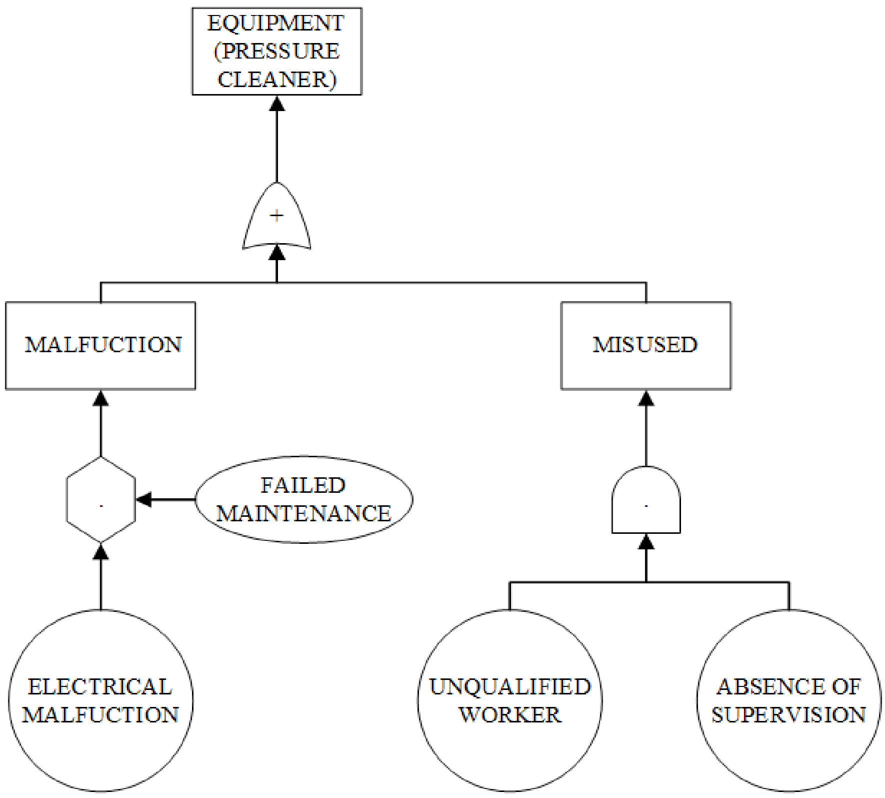
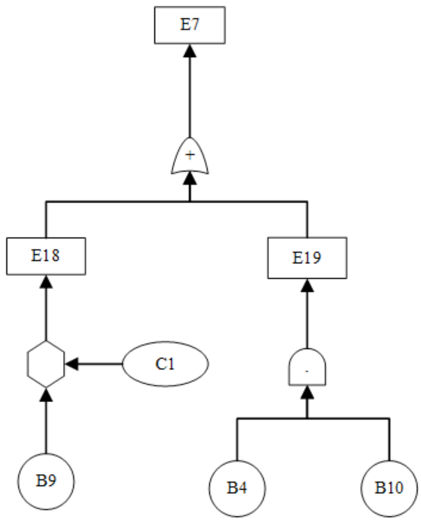


Figure 2: Phase 1 of construction of the FT.
Figure 3: Phase 2 of the construction of the FT.





The malfunction can in turn be caused by an electrical fault, but this failure could be avoided through preventive maintenance or control. Therefore the "Failed maintenance" event becomes a condition to be imposed for the occurrence of the malfunction. On the other hand, the event "Misused" can happen if the worker, for example, has not received adequate training and if there is no control during the work, otherwise the error could be noticed. This proceeds with the construction of the fault tree until the causes are all represented by basic events that can not be further developed.
Once the Fault Tree has been built, in order to proceed with an evaluation of the Top Event, the event descriptions are replaced with the corresponding codes. In the present study the intermediate events were indicated with the letter E, with the B the basic events and with the C the conditioning events.
Then it proceeds with the qualitative evaluation using the Boolean equations,

$$E_7 = E_{18} + E_{19}$$
$$E_{18} = B_9 \cdot C_1$$
$$E_{19} = B_4 \cdot B_{10}$$
$$E_7 = (B_9 \cdot C_1) + (B_4 \cdot B_{10})$$
$$P(E_7) = P(B_9 \cdot C_1) + P(B_4 \cdot B_{10})$$

after that the equation must be solved in terms of probability of occurrence. to have a more concrete vision of the results obtained.For the encapsulation, the probability of inhaling asbestos fibers during the remediation work is 3,66•10-6, so approximately 4 yards per million.
As it can be seen from the graphs, the riskiest phases are "Garbage collection" and "Preliminary cleaning”, which affect the TE for 53% and 21% respectively.

As for primary events, the most influential are related to training and control, which are the basis of a safe construction site.
The results have come to light from FTA have been confirmed by Failure Modes and Effects Analysis, indeed the causes with higher RPN are related to preliminary cleaning and collection of waste.
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Figure 4: Phase 3a of the construction of the FT.
Figure 5: Alternative representation of the FT with the codes.

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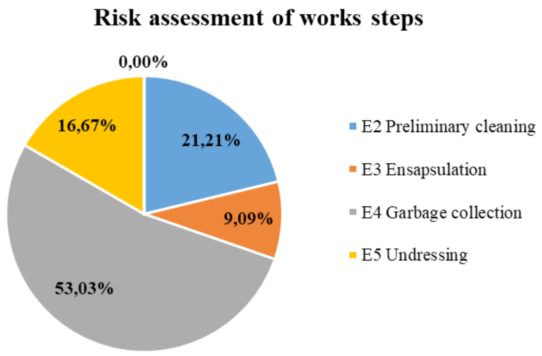
Asbestos slabs remediation through confinement

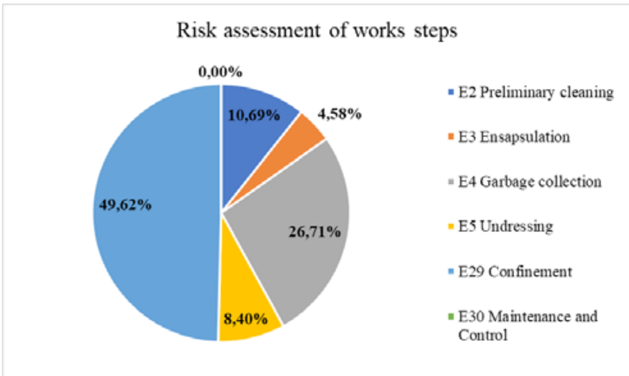
The remediation of an Eternit cover by means of the confinement technique foresees the following operational phases:

- Preliminary assessment of the state of the coverage;
- Site construction;
- Cleaning and preparation of the support;
- Encapsulation;
- Confinement;
- Garbage collection;
- Undressing;
- Over – roofing maintenance.

The same analysis procedure was carried out for the remediation by confinement, where the probability of inhalation of the asbestos fibers is equal to 7,27•10-6, about twice the previous case. In this process, the riskiest phase is precisely the "Confinement" phase of the coverage, which represents about 50% of the total risk and the most influential primary events are "Worker goes down from the basket and walks on the cover is not feasible" and "Improper use of the tools ".



ANALYSIS				ASSESSMENT				SOLUTION				
				PARAMETRI FMEA					PARAMETRI FINALI			
PROCESS STEP/INPUT	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECTS	POTENTIAL CAUSES	OCCURRENCE (O)	SEVERITY (S)	DETECTION (D)	RPN	ACTION RECOMMENDED	OCCURRENCE (O)	SEVERITY (S)	DETECTION (D)	RPN
cleaning with electrical brush	damaged slub	dispersion of asbestos fibres	misused equipment (high pressure cleaner)	3	10	2	60					
			high aggressive cleanser	3	10	2	60					
			already deteriorated roofing	10	10	2	200	preliminary ispection and assessment	2	10	2	40
garbages with asbestos in the bags	dispersion of asbestos fibres	contaminated space	not completely closed bags	8	10	8	640	training and supervision	2	10	4	80
			not resistant bags	5	10	8	400	using high resistant bags	1	10	2	20



Asbestos slabs semediation through removal

The remediation of an Eternit cover using the removal technique involves the following operational steps:

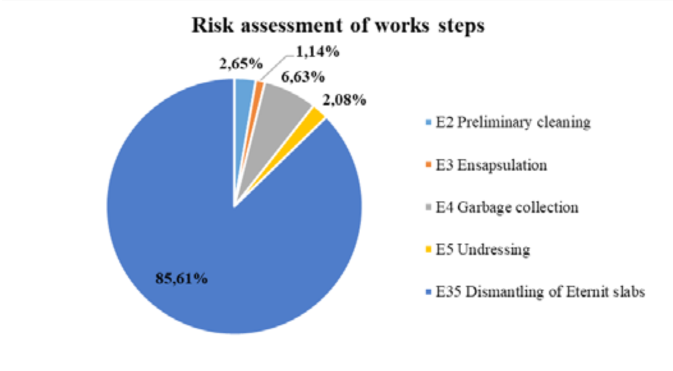
- Preliminary assessment of the state of the roofing;
- Site construction;
- Cleaning and preparation of the support;
- Encapsulation;
- Removal of MCA powders from the eaves;
- Dismantling of Eternit slabs;
- Plate movement;
- Packaging of the removed plates;
- Garbage collection;
- Undressing.

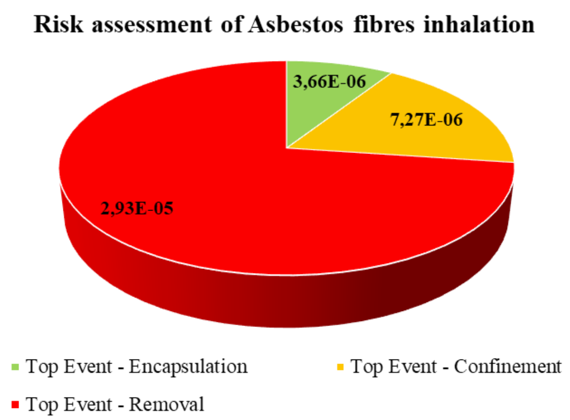
During the remediation through Removal the most risky phase is the "Dismalting of Eternit slabs", as it could be expected, and it represents about 86% of the total risk, equal to 2,93•10-5.

Figure 6: Risk assessment of works steps.
Figure 7: Example of analysis FMEA Encapsulation.
Figure 8: Risk assessment of works steps.

The most influential primary events were found to be linked to a hardly predictable factor: human error.
Comparing the results obtained the remediation through Removal is undoubtedly the riskiest. It must however be considered that the Encapsulation phase is present in all cases, as it represents the basis for carrying out the work, so it was obvious that the Confinement and Removal of the roofing were riskier than the other.

The results of this research reflect the statistical data and the data collected in the literature, in fact the remediation by removal turns out to be the riskiest for the type of processing, having to manipulate the asbestos-cement slabs.





CONCLUSIONS

The analysis and assessment of risk through the application of Fault Tree Analysis and Failure Mode and Effect Analysis techniques is a valid choice to make critical and reasoned choices in order to optimize resources and at the same time ensure a high level of security; these methods allow the analysis of the process to be dealt with in detail, thus allowing a meticulous evaluation of all the possible causes that lead to the occurrence of the accident phenomenon. It is therefore possible to intervene on individual events by making preventive changes.
The joint use of the two techniques leads to an accurate analysis because the FTA method, which represents the most consistent and complex part, allows to reach a definition and quantification of the risk and its causes, while the FMEA method contributes to a better definition of the quantification of the risk and its consequences.
One of the fundamental aspects to take into consideration when doing an analysis of this type is the subjective nature of the risk itself, which leads to obtain different results for the same object under analysis depending on the context, the data and the level of detail, that whoever makes the analysis chooses to take into consideration. Another consideration to make is that the preponderant component is the worker and is associated with the uncertainty of human error, difficult to define in a statistical way. The probability of occurrence of the Top Event, therefore, being the result of a product between probabilities related to multiple variables of human errors, will be influenced by a high degree of uncertainty. The results obtained are useful as indicators of the risk associated with the specific project analyzed, but they are subjective and therefore affected by numerous uncertainties.
To improve the efficiency of FTA and FMEA analysis techniques, a more detailed database collection of the specific processes would be required, thus ensuring the most precise and objective results. For example, for the work done in this study, a database of injuries of companies carrying out remediation work on materials containing asbestos could be useful; in this way the analysis would lead to even more detailed and precise results.
Finally, it is important to underline that, however precise a risk analysis may be, a zero or very small failure rate is almost impossible to obtain because it refers to real situations in which many several factors come into play; interferences are often difficult to predict or keep under control.
The data obtained reflect the statistical data and the data collected in the literature, in fact the remediation by removal turns out to be the riskiest for the type of processing, having to manipulate the asbestos-cement slabs.
It has therefore been shown that the methods of analysis used prove to be effective by returning values that are like reality.

Figure 9: Risk assessment of works steps.
Figure 10: Risk assessment of Asbestos fibres inhalation.

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