

Corrosion, Environmental Degradation and Surface Engineering
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Lecture – 17
Environmentally assisted surface deterioration- Part 2

Hello and welcome to Lecture 14 of the course on “Corrosion Environmental Degradation and Surface Engineering.” I'm going to cover the second lecture on environmentally assisted surface degradation. As we all know, the topic of environmentally assisted surface deterioration or degradation was also covered in lecture 13. Now, this whole course is basically on surface degradation caused by corrosion or other environmental-assisted devices, mechanisms, or factors. And finally, we will be giving some sort of remedy or mitigation strategy to minimize surface deterioration. So, this lecture 14 is also related to that, and as we studied in our earlier lectures, the degradation of surfaces is significantly influenced by environmental conditions.

When I repeatedly refer to 'significantly influencing' this degradation, it often highlights our limited understanding of all contributing factors. Numerous factors influence environmental degradation, and their dominance in specific situations may become clear only after a failure prompts a detailed study and the formulation of guidelines. So, today's entire lecture is based on the fact that whatever was unknown earlier caused some sort of surface degradation, and how it has been implemented may be some kind of regulation that has changed because of that. Now, we know very well that temperature or heat is one of the influencing parameters; electromagnetic radiation, such as UV, also affects performance or causes surface degradation. We have also observed some form of swelling in the polymers we have studied.

Chemicals: There are a lot of chemicals that really affect surface degradation. We have studied elements in water or rain that contain contaminated water, as well as particles such as soot, sand, or dust, all of which significantly impact surface degradation. What is the actual situation, and what steps should we take next? As previously mentioned, the atmospheric corrosion factor reduces safety. So, even if I design a structure with a sufficient factor of safety against known risks, if I overlook corrosion, it's possible that over time or after significant use, the factor of safety could drop below one or the effective strength could decrease, leading to structural failure. That is why we say the corrosion can reduce FOS for the structure, increasing its likelihood that the surface or may be structure will fail, and that tube in a brutal manner may suddenly even the ductile material, even like steel or iron, may change their fatigue behavior; instead of the ductile material, they become a brutal material, and certain failure occurs.

Throughout our history, numerous incidents have occurred, leading to the implementation of corrective measures by science to address these shortcomings. Let's consider an incident that occurred on April 28, 1988 as an example. We are referring to an airline, Aloha Airlines, operating flight number 243, which was essentially a Boeing 737. During this incident, the aircraft experienced an explosive decompression, leading to the sudden emergence of a door from the plane. And then, because of that, there was one sort of casualty, and then even it was realized the plane landed safely without further damage to the plane, but one casualty happened, and whenever there is a casualty, human health or related, we have to be a little more careful whatever we design. We must select each parameter carefully to ensure that no casualty or health hazard occurs. These are the examples. As you know, we were using very good materials earlier from a structural and performance point of view, but when we realized that those were very bad for human health, we stopped that. Let's use arsenic or any other sulfur compound as an

example. These materials may have excellent characteristics, such as heat resistance or lubrication properties, but over time, we have changed them when we realized they were harmful to human health.

This is a direct quote from one of the references. If you review this reference, you will find numerous case studies. The case studies pertain to airplanes or craft, detailing the problems encountered and the evolution of technologies over time. This incident has taught us a valuable lesson, as it involved a single door that malfunctioned, resulting in corrosion-assisted damage. So, even though we say there may be a fatigue limit initially over x hours, because of the corrosion, it has been reduced to $0.6x$, $0.7x$, or something like that. Another thing that we have also realized is that many times, even though we know the drinking water comes from the pipes, these pipes are made of steel, may be iron, or may be some compound of that. In this case, if many times we find the debris in the water, or, may be, the contamination in the water because of the corrosion by products that are harmful to the health, then naturally those pipes need to be changed immediately, and that has been observed a number of times. Now, instead of water, it can also be an industrial liquid. Naturally, our industry fluid, if it really gets contaminated, will change, and we may get quite different results. That is why we need to really take care of atmospheric corrosion, or, perhaps, environmental factors. These factors are responsible for the surface's degradation, which ultimately leads to system, component, or element failures. Another important topic we've discussed in previous lectures is the need to closely examine the correlation and the actual integration or interaction between corrosion and wear.

Of course, in one of the lectures, I mentioned corrosion wear and fracture, as well as how they interact with each other. Whether they are truly exacerbating damage significantly, the interplay between corrosion and wear plays a significant role in affecting many industrial machines. We can name a number, but one of the very common things that I have observed in my own life is a slurry pump, where the number of particles is there and the pump's erosion happens, and because of the pump's erosion, the new sites and new material that come out will be subjected to corrosion and will deteriorate at a faster pace. Similarly, in mining equipment, there are again a number of erosion possibilities, surfaces getting exposed, and then the presence of water. So corrosion, wear, and erosion will be continuous phenomena. So these are the very important factors that, when we choose a material, we design products, or we say we want to define another component life, or we say that we want to enhance the reliability, we want to increase the serviceability of the equipment. In my previous lecture, I also covered something on a satellite, and on that satellite, which is particularly useful in a low-earth environment, there is some sort of atomic oxygen, which really enhances the damage, or, maybe, corrosive-assisted damage, or erosion plus atomic oxygen reaction increases the overall damage. In my previous lecture, I mentioned 18% in one case and 13% in another.

However, there is also a possibility the UV will act against, along with other components, a charged particle, and even the meteoroid or micrometeoroid can impact the surface of the satellite and cause damage. We also mentioned something like a rocket that is getting launched into space, and then there will be some sort of debris that will also have a negative effect on a satellite surface. So this was to some extent explained in the previous lecture, and then we say that in the low-earth orbit, satellites collide with atomic oxygen at a high speed; the speed has to be very high to maintain in orbit; otherwise, they will be falling back on earth. So then the speed needs to be maintained, and when there is a significantly high speed and the collision happens naturally, erosion will occur. Even in this case, we are talking about the collision energy roughly like a 4 to 5 electron volt or something like that.

We generally talk about millielectronvolt but in this case we are talking about the electronic volt. Therefore, it is crucial to determine whether erosion, or any other material factor, outweighs the considerations discussed in our previous lecture on two coatings and their relative effectiveness. However, this coating material is constantly evolving, with numerous researchers actively working on it. I will provide a link to a paper that attempts to model the degradation of satellites, taking into account various factors. They consider the solar radiation, the infrared radiation coming from the earth, the solar radiation reflected by the earth, and then whatever the immediate radiation is.

So, they formulated a comprehensive equation, solved it, and then explored what improvements could be made to coatings or structures to achieve slightly better results compared to current coatings or materials. In the previous lecture on atomic oxygen, we mentioned that in the low earth orbit environment, if the distance or altitude from the earth surface is between 200 and 700 kilometers, a significant amount of atomic oxygen is already present. Therefore, the reaction rate will be significantly faster, and the impact will be significantly higher compared to orbits beyond 700 kilometers. We mentioned yesterday that this Low Earth Orbit (LEO) spans from 200 to 2000 kilometers. So the remaining 1300 kilometers of atomic oxygen will not be available in abundant form.

However, if molecular oxygen is present in the environment and reacts with UV light, it will naturally initiate a type of photochemical reaction that generates AO as a byproduct. So if there is molecular oxygen available, there is a possibility of AO, but more AO will be available in the range of 200 to 700 kilometers from the earth surface. Therefore, it is crucial to consider the true altitude of the spacecraft, or in this case, the satellite. If the satellite is within a range of 700 kilometers, the natural impact or the effect of AO will be more significant. If the satellite is located beyond this range, we must naturally assess the actual level of molecular oxygen and determine whether photosynthesis will take place. What kind of AO will be released from that, and what will be created from that, and then that will impact the satellites? So these are the important aspects, and fortunately, this reference paper, which was published in 2016, covered a few features of that and then tried to elaborate on that work only. This reference paper will offer valuable insights into the implementation of atmospheric and corrosion effects in real materials.

So that's what they did: they worked on a thermal control coating. They wanted to regulate the complete control system of the thermal, or maybe the temperature, regulation system. They require a coating, and subsequently, they employ a second coating known as "white paint." White paint is a conventional coating used in various systems, and the name has been given S781. and there was another new coating something like a F46 and they use a word as second surface mirror. Basically, the mirror system may be using the silver was created so the reflection happens. This allows the harmful radiation to bounce back without directly affecting or damaging the thermal coating. Researchers concentrate on this aspect, highlighting the importance of thermal control coatings in maintaining satellites at safe operating temperatures without causing damage.

And then if it is not happening, then what will happen? The other environmental factor, like even mention of the AO, will impact the spacecraft surface, or we say the satellite surface, and it will cause degradation and failure of the coating, and the whole system may fail also. Another observation is that even with the best coatings, their performance tends to decrease over time. Therefore, no single coating in use today can be guaranteed to last for years. Time dependence will manifest itself in one way or another. That's why I suggest that they discuss the quality of the coating and its associated performance.

What is an associate's performance? They use the word low solar absorption, then the reduction in absorption of the solar race, and then strong infrared emittance. Therefore, maintaining low absorption is considered a good performance. If there is a possibility of emittance shifting to a higher or stronger value, then performance is good. If the performance naturally deteriorates over time, we should consider the coating's overall lifespan. How many days or months can the coating last before we need to adjust our design accordingly? So this is what they have done, and then, of course, they use one coating, something like, as I mentioned, white paint S781, and another coating, something like F46 SSM, which has already been shown as a second surface mirror. We use a specific zinc oxide as a pigment in the first coating, a conventional method, because it is chemically stable, non-toxic, and cost-effective.

So it is affordable; however, in a space craft, we may not focus on affordability. We say that we require more consistent performance; we do not really look at a low cost because if failure happens, it will cause a phenomenal cost. So, to some extent, affordability may not be really required for that purpose. However, in situations where there is significant competition, affordability may be taken into account. In this instance, we specifically utilized

zinc oxide as a type of binder, also referred to as an organic binder. What is an organic binder? It consists of silicon rubber, silicon resin, and epoxy resin, resulting in a remarkably thin coating. When applying a thin coating to a surface, we naturally need to maintain a high level of quality control, which is why we employ this type of organic binder. This allows the zinc oxide to adhere effectively, potentially reducing the incoming radiation and ensuring the safety of the satellite surface.

This is the outcome of a zinc oxide-related study. Then coming to the F46 SSM. FEP, a fluorinated ethylene propylene material, serves as a surface attachment in that scenario. In this situation, they use silver backing, as I mentioned, as a second surface mirror to reflect the solar radiation, allowing only the solar energy to pass through. We need energy, but our goal is to eliminate harmful radiation or perhaps reflect it back to us. During this process, they have incorporated silicon oxide as a binder coating, ensuring its adhesion to the surface and the complete attachment of the silver to it. The air gap should be as small as possible, ideally nearly zero. However, they kept another ITO, which is indium tin oxide.

We kept the conductive layer on the outside surface to prevent further thickness growth. In our previous lecture, we mentioned a thickness of around 10 nanometers, but here, it's 100 nanometers thick to safeguard this layer from erosion caused by AO, as discussed before. In this case, the researchers used ITO as a different type of coating, and their overall study revealed that this new type of coating, known as a composite coating, performs better than a single-layer coating. In this case, we find that there is a single coating, whereas in this case, three coatings have been utilized on the surface. So this F46 SSM is considered the better coating compared to the ZnO coating, but again, we cannot say that this is the best; it is quite possible. There is ample scope for further research in this area. However, it suggests that implementing a multi-layer coating, where each layer serves a specific function, could potentially enhance performance and yield better results.

However, it may be a little costlier compared to the single coating, but we will cover this topic when we discuss the coating lecture. Now we will take a few important failures that happened in our history, and then we will analyze how we account for those things. In this case, these are important for us. Let us take the famous failure of the Titanic, and of course, many people have already seen a movie on this, and then there are various theories and people say many things about that. We say that this is a kind of history, and then the people thought the science had overcome most of the hurdles, but that created more problems, and that is what we are trying to cover in the next 3 slides about my way of thinking about the Titanic failure in this case. Naturally, I am drawing inspiration from a 2022 publication that discusses the sinking of the RMS Titanic and presents a perspective that resembles a thermal inversion.

What are the thermal inversion and refraction mechanisms or phenomena? What are the things we will try to cover in these 2-3 slides? The Titanic disaster occurred around April 14, 1912, over 110 years ago. The primary cause of the disaster was the ship's collision with an iceberg. The iceberg was a kind of solid mass or a cold mass, and the big unit, if we know even that the ship has been struck by that and the iceberg got damaged to a number of pieces, but it has also significantly harmed the ship. Another point that has come is that it has also sunk much faster compared to what was expected any time a breakage happened. It will take some time to really sink. It is not immediately, which means something went wrong, or it may be that whatever the contingency measures were or whatever the safe measures were required could not be done, and that is why several deaths happened because of that. So in this paper, they have given a figure of the sunken Titanic, and then they have given a kind of iceberg. They found that there is a possibility that it struck against this iceberg, and then the location where exactly the wreckage of the Titanic happened. Location has been given, and Labrador current is the kind of cold current, and in the Gulf stream current, which is a high temperature current, they found that there is cold water and high temperature water, where they gave a mix this kind of phenomenon. There is a possibility, and often people use the word optical illusion, that something that we are seeing may not be correct, and then we have seen this kind of situation. Particularly when you drive a car on a road and then they find that some water is available, or it may be coal tar-based, and then on the road there is some sort of water appearance, but it may not be water. It is basically

a refraction phenomenon, upward refraction, and that is giving the wrong illusion that there is a possibility of water.

Similarly, in a desert, many people believe there is water, which may be a few meters away, but when they arrive, they do not find that kind of thing. So what do we call a mirage or optical illusion, or there may be many names for that? So this is what they have mentioned, and now they try to explain what the thermal inversion is. We say this is a meteorological phenomenon, and it basically consists of the trapping of a layer of warm air near the earth surface by a layer of cooler surface. So there is something like a temperature difference: cool air, then high temperature air, then cool air; otherwise, what will happen in nature? We know that as temperature increases, air will move up, and then as it moves up, the temperature will drop. In this scenario, we observe that normal air cools as altitude increases.

Now if there is some sort of high temperature layer above the cold temperature, it will give us some sort of illusion because cold air will not be able to skip, and then we may feel a little more cold or there may be a change in the weather or something like that. This is the phenomenon known as thermal inversion. We say that when warm air near the surface is unable to rise and mix with colder air above during thermal inversion, this layer operates like a lid. Therefore, the presence of a thermal cap on the surface acts as insulation, trapping cold air in the environment without allowing it to escape, while hot air similarly remains trapped and retains its temperature. Therefore, this phenomenon is not consistent with the way nature operates, but rather, it leads to the occurrence of certain opposite outcomes.

And then, because of this incident, they mention that the iceberg visibility was difficult, which is why, if you look at them, in much of the literature, they find that the captain was not able to see the kind of iceberg that was already there, and then that was the reason for the refractive phenomena, or, as they may say, superior even in the mirage or inferior in the mirage. Another one is that, whatever they have as lookouts and as cameras, they could not really find out what the real distance is. It may be that the real distance is something like a few meters, and then they were observing for a few hundred meters. So that means they were thinking there is a enough gap and we can really take the defensive measures, but they could not take the measure soon being that immediately the really struck happened, or may be the collision happened, and then there was not a plan or may be the overall planning was missing for this kind of casualty. We are referring to 1912, which was 110 years ago. Since then, science has significantly improved, increased, and produced better results. So if I want to express in my language this complete thing, we say thermal inversions are widespread in particularly winter seasons, and then the cold air remains on the lower side, and there will be some sort of pollution layer or contaminated layer, which will be somewhat of a cap on the surface above the cold air in our case.

This creates a kind of trap fog, which means that this kind of trap fog will also reduce visibility, and if that is what happens,. We have also experienced that it will create a lot of transportation problems in real life. There is certainly fog coming, and we need to reduce speed because, then, visibility will reduce significantly. Of course, many cars and many vehicles now have better visibility units than even the fog case. I mean, there is some sort of phenomenon that is happening in nature, and visibility is not clear, but because we have good cameras now, we will be able to improve visibility using those devices. Essentially, the inversion process involves maintaining a certain level of visibility. So we can assume that this is a kind of cloud formation, and this cloud can also prevent our dirt, or maybe whatever the exhaust cases are moving away from the environment. So it will create an unhealthy environment, so this kind of thermal inversion should be minimized. Whatever the reason or if it is happening naturally, now we need to understand, and then we need to take care to minimize that one.

Now, the question arises: why are we discussing this topic in our course? The reason is that, in my opinion, thermal inversion is a significant factor that can impact air quality. In this lecture, we are addressing the importance of minimizing chemicals in the atmosphere that can exacerbate thermal inversion and contribute to atmospheric corrosion. And another thing is that there is a trap, and there is some sort of cloud that is really giving us an us an artificial layer, and then these contaminants are not able to skip the environment naturally, which will

really affect our product. Whatever is made will affect human health. So it is important to understand that so we can say the sluggish condition and restricted mixing of air during the inversion, which happen because in cold air does not get a skip from the environment, and then because there is a layer on top of the contaminated layer, it will really give a kind of in because the mixing is not happening. So it will really give off a kind of smoke and poor air quality, and we have also realized this in the winter season. Particularly the quality of the air drops, or maybe it goes in versus side, and then we need to take many measures, and then the water is spraying to reduce this kind of contamination. From a technical perspective, I can assert that the Titanic's failure resulted from numerous material-related issues and design flaws. In this instance, the rudder proved to be insufficient for controlling the ship, and despite their belief that the water-tight compartment would suffice to prevent flooding, we discovered that a component of the compartment also experienced flooding.

Another factor at the time was the use of lower-grade steel, whereas today we have access to superior steels that could have better withstood such impacts. The use of lower-grade steel contributed to the hull fracturing more severely than would be expected with modern standards. Additionally, because the hull fractured immediately upon collision without deflecting, there was no opportunity for the captain to take corrective measures in time. Another thing is that the report says there were some sort of riveted heads, and then they got completely removed or may have been broken off, and then even the hull assembly became weak there. So there are many, many parameters, many technical difficulties, design, manufacturing, and corrosion-related problems with Titanic. But the major question is that everything happens after striking an iceberg, and quite possibly the scientist who was working on that, or may be the researcher who was working on or who made this kind of ship, may not have thought that this kind of collision would happen with an iceberg. Therefore, when designing something in the modern era, it is crucial to thoroughly consider all potential outcomes, which is why we are considering this case study.

We must carefully consider all potential scenarios, especially when dealing with atmospheric conditions and transporting people by vehicle. Given the significant health risks and potential loss of human life, it is crucial that we take all precautions. I found another website, Fox Weather, which provides a comprehensive analysis of the events and their impact. So, we ask, "Why did the Titanic strike the iceberg?" Now, from a researcher's point of view and a designer's point of view, it was never ever thought that there was a big iceberg and people would not be able to see it, and there would be strikes against that. There is a huge mass, and something like wrestling is happening between the two units. It is not possible to think from the designer's point of view.

But now what is really happening is because of the atmosphere that has been shown there. The Labrador current, as mentioned in the previous slide, is essentially a large surface current in the North Atlantic Ocean. The Labrador current originates in the Atlantic Ocean, transporting frigid water from the Arctic Ocean to the Grand Bank region. The preceding slide illustrates its connection, and it then traverses the western side of the Labrador Sea. Now what they mentioned clearly is that there is very cold water, what we call frigid water, which is something like an almost icy form of water, and then there is warm water. There is a significant temperature difference between the two streams of water.

This will trigger a naturally occurring thermal inversion process. What is the thermal inversion process we're talking about? What will happen if the captain sees a false horizon? What does a false horizon mean? It means that he could see an iceberg similar to this one. In reality, a much larger iceberg was present, but it was not visible due to the poor quality of the camera at the time. So the actual horizon was that the level of this iceberg was very high, and the height difference was very high. In reality, the height of the huge mass was nearly two to three times higher than what they could see.

Now, if we view the scene from a slightly different perspective, you can see that there is a ship, and this is an iceberg. Then the iceberg's dimensions are huge. What would happen if the ship were to strike this iceberg again? Naturally, a big collision will occur. The first scenario involves a collision, while the second involves maintaining

a high speed of 22 knots. Whenever we receive such a warning, we should at least reduce our speed. Similarly, if we are driving a car, we should immediately reduce our speed. For example, if we are traveling 40 or 50 kilometers, we may suddenly find that our visibility is diminishing, and we can only see a few kilometers, which could be as little as 10 percent of the original speed. However, the captain maintained a speed of around 22 knots, while the design speed was only 23 knots.

This type of ship was capable of reaching a maximum speed of 23 knots, while the captain maintained a speed of 22 knots. So huge mass and huge speed are also the maximum speed; naturally, everything will happen immediately and instantaneously. Regardless of the approach you choose, a defensive measure might not be adequate; it can only rescue a small number of individuals, not a large number, as demonstrated by a significant collision between an iceberg and a ship. So, essentially, the optical illusion was caused by thermal inversion. The captain misperceived the ship's height, relying on the ship's technology to navigate past a seemingly insignificant iceberg with confidence. Therefore, it's plausible that we can anticipate overcoming this challenge.

Now one of the papers has given everything in detail. Whatever I mentioned, they say that the camera's position and what they were able to see is like a straight line, but in reality, what will happen because of the change in temperature variation? Even whatever we are looking at in the street may not be correct, and then that is why they say that they found this a green line of sight, and then they found there is some sort of portion of the iceberg only, which was a negligible small unit that can be damaged. Also, that is the big ship moving on this side. However, the actual horizon was somewhat different, and then the reason was that there was a bending of the sight, and then the false impression came, and then they tried to show that this was also an iceberg, and then because of the false in this unit, they had to blow the line, while in this case either this tip was visible or there was no tip at all. They could not see anything, even though there were a number of warnings, and that is how the experiment says there were at least six warnings issued. At that time, from neighboring places, there was an iceberg, but the captain was not able to see it. Therefore, he was unable to discern whether the warning was intended for him or for someone else. So this is what has been shown here, and then the authors have tried to show the kind of looming horizon from a Titan, and then the vision was seen when camera they found there was no iceberg as such, and then they use also green dotted yellow dotted that is what have been shown this was a green I have made kind of a violet color.

Now this is a yellow color, and then they found a false horizon; they were not able to see the surface of the iceberg, and then they struck directly against the concealed iceberg, and this was caused by the thermal inversion, or what we call the refractive index, or maybe refraction. Now because of that, in this case, if I see that this is a natural phenomenon and the captain cannot see the iceberg, that is why everything that happened looks to be natural. Now other things, if I look at them in totality, I find there is human error, which is there, but another faulty construction because of the of the number of design features. When we look at them and we find there are mistakes, maybe we are now able to find those mistakes, or maybe at that time they could not figure them out. Therefore, human error, faulty construction, and environmental conditions all played a role in the damage of the Titanic ship, regardless of the speed at which it occurred. Why am I using the term "human error"? It's because a warning could have potentially slowed down the ship or significantly lessened its impact. After issuing at least six warnings, the ship could have undergone repairs, potentially reducing the damage.

Whenever there is a significant collision, it is crucial to consider the energy involved. If there is a collision, there is a V^2 the sensitivity of velocity is very high, and there is also a large mass that is going to strike against the surface that needs to be accounted for very clearly. Now another point comes: whenever this phenomenon happens, there is no complete direction on how evacuation should happen. We can assert that a lack of organization in the evacuation process contributed to the high number of deaths. This serves as a lesson, and we don't intend to place blame. It's crucial to underscore the importance of taking these measures seriously and thoroughly documenting them. It's important to have a clear plan in place for what to do if such a situation arises. Additionally, human nature often prioritizes self-preservation, as seen in the preference for saving oneself over

others. So that is why even the boats that were there could not take all the people, the reason being that there was some sort of lack of clarity about what was really happening, and few people had a lot of emotion for the ship. So they wanted to be there, not taking and getting away from the surface.

So there was a lot of confusion, and there were no clear directions. So many problems happen. It is not only the technical, which may be human errors, but also the environmental, but this compounded effect becomes a history, and it is well documented. But however we are trying to cover in this lecture, we say that atmospheric corrosion or atmospheric casualties will really cause a major problem. So we need to account for many points whenever we decide we want to reduce the surface damage of anything. Another thing that I found, particularly when a ship hulls, is that we should keep in mind that this kind of damage happens because it should be divided into many sections, the reason being that the surface area will increase, and then there is a possibility of floating. However, they also found that those were not water tight. The surface area is then there, but if water leaks into it naturally, it will also sink. This is what they discovered: the design had various difficulties and drawbacks, and the bulk unit itself was not safe. Additionally, the use of two engines, or the use of additional engines, increases the risk of atmospheric damage.

So they use only the single hull, while in these days that regulation has come after that, particularly that there should be a double hull. So the ship should be protected in all the situations, and another one, as I mentioned, is that, particularly when you travel in these days, aircraft use all the safety norms at the beginning itself. Therefore, when an atmospheric casualty occurs, it is not just the responsibility of individuals to ensure their safety, but also everyone else's. That's why it's crucial to equip individuals with adequate knowledge about the safety precautions to take in the event of such a disaster. So, if you have traveled by air, you know that at the beginning of five or three minutes, they give a complete measurement. Often, we tend to ignore this and dismiss it as unimportant. However, it's crucial to emphasize the importance of safety drills. It's crucial to recognize that such incidents are a possibility, even though they shouldn't occur. However, we must be adequately prepared in case they do occur. We need to understand how to effectively manage the situation, how to prevent chaos, and how to prevent further incidents.

So that there was a radio station and some heart because of the anxiety, or whatever reason they could not use a radio transmission also effectively. So this is another problem related to it. This case study, in particular, provides valuable insights into the process of product design and damage minimization. Understanding the various types of atmospheric conditions, thinking through every aspect, and creating a comprehensive document are crucial steps in ensuring the appropriate implementation of safety measures. Now this is what we have mentioned about the Titanic, but there is a similar kind of incident that we are talking about in 1912. A similar kind of incident happened in 1999, too. Of course, human involvement was not much there, but whatever happened after that, society got really bad, and this is the hammer because of that, which may have lasted for years and years. What occurred on December 12, 1999, was the sinking of the Eureka vessel.

The Eureka ship was basically carrying on with the oil, particularly the heavy fuel oil, and the capacity was something like 31,000 metric tons. Then it was carrying something like 20,000 metric tons at the time, and then an incident happened: the whole oil got spilled into the water or the sea water because the ship was divided into two parts, a major failure. You can find this case study on the website. What happened in this situation? Basically, corrosion was the main culprit in the complete failure. Whenever we talk about corrosion as a main failure, we know it has to be associated with some sort of maintenance. Corrosion will not give a failure in a day; it will only give sufficient warnings because we are involved in some activities we do not consider that much. So, this is a regular phenomenon; we do not have to worry about something like that, but in reality, corrosion gives sufficient time; it does not cause immediate failure; it gives a number of things; whatever we perceive, we say 5 years; 2 years; 2 months; but it does not happen instantaneously. At another point, we take a ship from one place to another and it has moved safely, but after that again, we start to see that there is a possibility that failure will occur because this is a continuously progressive failure. It is not going to be stagnant; it will not be the kind of only one crack

that, say, 1 mm will remain; it may be quite possible that 1% growth will occur; and naturally, we need to know the sensitivity at which time it will fail. If you can accurately simulate this, then it would be beneficial to operate or utilize this type of unit.

If we do not have knowledge, we do not have science. We should not use this kind of corrosive product. So, that is what we have mentioned. When the corrosion leads to a structural breakdown, or as I say, the ship is split in two parts, and the whole oil leads to the sea water, you know that when the oil leads to the sea water, naturally, life in the sea water will not be good enough, and there will be this kind of casualty, not on the human, but on the fish, or, may be, animals, or the complete units there, and there will be more and more problems. And now, after that, once this kind of failure happens, they have stronger norms, and then, after the Titanic, the new norms come to the ship design. Subsequently, a new standard emerged, defining the upper age limit, which we must now abandon due to its unsuitability for use.

We are highlighting that Eureka, a 25-year-old vessel, has already endured 25 years of operation, with numerous cautions issued in 1994. That means after completing 20 years of life, enough failures were indicated that this ship would fail because of that safety measure, but somehow it continued, whatever the reason for that. So then, in this case, in the age of another one, almost all this kind of cargo vehicles may be ships; they need to use a double hull on the double hull tanker design; it cannot be a single hull design for safety measures. In this scenario, adhering to international marine time laws would prevent the ship from moving from one location to another.

These details are already given on this website, as I mentioned. Now, as I mentioned, enough warnings were given to the concerned company that these are the corrosion issues in a Eureka ship and should be corrected, but maybe they could not or maybe they did not really pay much attention, and this is a normal thing and it will sustain for some more life, and many times I have experienced it will survive for 3 years; I have experience for 5 years, but now in new science we need to really prove everything we need to do a simulation only feeling may not work, and then if we need to really document everything it will be good for the science it will be good for the future also. The next generation will have the opportunity to learn and grow more effectively. They will then be able to develop better and better products. If I think only from my experience point of view it will work, it does not make much sense because we need to really list down why I feel we need to document properly, and if that is a really right thing, at least a new generation will learn that. The report specifically pointed out that even firefighting systems couldn't handle the situation. In the event of a fire while the ship is carrying 20,000 tons of oil, what would be the composition of the firefighting teams?

So again, it will cause more problems naturally. Another point mentioned was that the society periodically issued reports on corrosion. The website noted that their certification expired in March 1999, but the incident happened in December 1999, nine months later. So they went without a certificate or any kind of insurance. So, that's another thing. So we need to see whether there is a possibility that we should account for everything, and there was no attention paid to the maintenance. What kind of maintenance strategy should they follow? If they had properly followed the maintenance strategy, this kind of failure would not have occurred, and perhaps it was because it caused a significant problem for both the area and the economy.

We are well aware that tourists are unlikely to visit this location due to the potential health risks they face. So naturally, the overall economy will come down for the people who are living there. Is it their fault, because of our lack of maintenance strategy, or maybe because of a lack of science? As we progress, we will inevitably encounter additional issues, necessitating our attention, whether from a scientific or a planning perspective. I will now focus on a few more case studies. Let us now consider the example of a steel bridge. You may have observed several steel bridges exhibiting discoloration, pitting, and signs of corrosion. Similar stresses, like those experienced by the Titanic, can cause misalignment and even separation on various bridges.

Now this is a kind of initiation of failure. Initially, the system may appear flawless, but as time progresses, even a single loose nut or bolt can cause a shift in the load, leading to a change in stress concentration. Initially, we may have assumed that the load was evenly distributed among the 10 bolts, but if one bolt were lost, the remaining 9 bolts, which were not fastened, would bear a greater load. The unfastened second bolt will inevitably cause misalignment and separation, which is the primary issue with steel bridges due to their numerous joints. So I find that either we should remove all the joints, but again, in that situation, the construction will be very costly. Therefore, in order to significantly reduce costs and keep construction costs to a minimum, we must include joints. However, when it comes to joints, it's important to consider that many people learn welding through hands-on experience rather than formal training in proper welding techniques. They do not know how to make the face appropriately, how to align the face appropriately, and then what points really need to be welded, but this is really happening in many places where the bridges are getting fabricated by people who are not very skilled, and then initially, maybe for 3–5 years, we find the bridges are very good, performing well, but after that, the deterioration happens, and sometime then the bridges are closed and routine maintenance is done. This is a positive development, as it prevents the possibility of any type of collapse or failure. Now, we have taken this from a 2015 reference, and then we say the effect of the corrosion cracks, and particularly, they have covered some steel bridges that have failed. These are basically material fatigue and corrosion. These are the two phenomena that happen frequently in this kind of failure, particularly steel bridges.

Now why is this kind of problem coming? I frequently observe imperfect assembly due to the large number of units being assembled. So if assembly is not a proper imperfection, are there now, if I take a factor of safety, 1.5, maybe say 1.6, or maybe say 2 or 2.5? So some sort of assembly says that stress level is a dynamic process. Currently, the safety factor stands at 2.5; in 5 years, it may drop to 1.2; in 10 years, it may drop to 1; and beyond that, failure is inevitable. Therefore, this process is dynamic. Initially, we designed it in a static manner, but as it becomes dynamic, every situation changes, necessitating frequent real-time maintenance. We make predictions, yet we must observe the actual situation to determine the necessary immediate actions. So, most of the time, this failure is caused by inadequate maintenance. Therefore, it's crucial to focus on developing a maintenance strategy, especially for heavy structures and areas with high traffic. Additionally, it's common for population growth to occur continuously over time. If I have designed some bridge for 5000 people walking over that bridge every day, it is quite possible that the increase in population will be such that 5000 becomes a 6000, 6000 becomes a 7000, or maybe we have designed some sort of 10010 load kind of thing. Maybe the load will be maximum 10010, but the possibility that more and more vehicles are coming is increasing the load, and maybe sometime there is a traffic jam and many vehicles are simultaneously there. Therefore, we need to consider these dynamic situations, design the bridge accordingly, and determine the maximum permissible load. If not, we must devise maintenance strategies. How can we implement a maintenance strategy that guarantees the effectiveness of the initial aesthetic design over time? Perhaps the maintenance strategy should address dynamic design aspects to ensure its effectiveness throughout its lifespan. What we're trying to convey is that imperfections and assembly errors can lead to the creation of stress hot spots.

There is a misalignment; naturally, some portions will be bearing more load compared to other portions, and that is basically where the crack initiation starts and the crack propagates. If there is a crack, which we already studied earlier in the previous lecture, an increase in the crack causes a fracture. I have repeatedly discussed the issue of atmospheric corrosion, which stems from the presence of water and crevices in the assembly. This corrosion persists because the assembly provides an ideal environment for the formation of an electrochemical cell, thereby elevating the stress level and potentially contributing to corrosion. We assert that over time, atmospheric corrosion erodes the stability of steel bridges. If we fail to maintain the corrosion, we fail to address it effectively through a maintenance strategy. This implies that we need to remove any existing corrosion, take the necessary steps to reduce its expansion, and ultimately, the bridge's failure. Another thing is that when the bridges have a foundation and soil, there will be water, and there is a possibility of a misalignment load that will also cause a failure. Therefore, we assert that corrosion and material fatigue are the primary issues, and if we aim to extend the bridge's lifespan and ensure its longevity for many years, we must conduct frequent inspections and maintenance.

These aspects are crucial. They provide front and side views of a bridge, illustrating various failures, including a complete collapse in one instance, according to their cited examples. Now there is another one in the failure that has been shown, and lastly, there is a mid-span of the complete bridge that has been removed because of whatever reason the bridge failed. So the paper indicates there is a structural deficiency, and the reference to the paper has been given here in 2009 that these are the deficiencies in the bridge in the structure; that is why the failure has occurred. Now what are the real highlights of this? Basically, there will be localized buckling; if there is a misalignment, the load will increase one way or another, and if there is some sort of cantilever over stress condition in that situation, there will be a possibility of localized buckling. Now what are the parameters? Sometimes the width-to-thickness ratio is not kept constant, or maybe it is not kept in a proper way.

Therefore, an uneven distribution of stresses across different sections can be caused by factors such as an inadequate width-to-thickness ratio, improper insulation leading to increased load, misalignment, loosening of fasteners, corrosion of rivets, and resultant stress concentration. Therefore, when only a few components are under stress, the stress level will naturally increase, and if corrosion is present, the strength will decrease. So stress is continuously increasing, strength is continuously decreasing, a factor of safety will continuously come down, and failure will be a result. As I previously mentioned, atmospheric or air corrosion causes the steel bridge connections to weaken and become vulnerable, particularly at the joints, welds, or other locations where the connections are built. These are the weak points when the material strength is high, but if I make a weld connection, the strength we need to count is only 60, or possibly even 67 to 70 percent, as that is the weakest point.

Naturally, when we are connecting two units, even though we design them completely fastened, if there is some sort of loosening, the strength will come down significantly. So basically, they are, I can say, the inadequately built connections, and then, whenever there is an inadequately built connection, what will happen? Even the mode of the fatigue will change. Whatever I thought the fatigue would happen in this manner may not be, it will shift, the mode will shift, and then the one mode will shift to the other side of the of the other condition, and then the overall life time of the fatigue, whichever we estimated, will come down. So that is why the fatigue life time or the components will be shortened is concerned in this case basically poor welding gives us sites to make a corrosion, that corrosion really weakens unit completely and so I can flame finally, insufficient fabrication may be design is perfect, but fabrication is not correct or fabrication methods are not correct, the welding that has been done may not be correct. Therefore, the realization won't occur immediately; it will take time.

The performance of the system is declining over time. Static design is beneficial, but dynamic design will lead to a decrease in strength, an increase in stress, and a continuous decline in safety, ultimately resulting in a major failure. Insufficient fabrication methods can reduce a bridge structure's fatigue under atmospheric corrosion conditions, ultimately leading to structural degradation. As a result, the integrity of the bridge members will deteriorate, potentially leading to catastrophic failure. So, as I mentioned, this is one of the steel bridges. Let's now focus on another crucial aspect, specifically the atmospheric-assisted surface degradation of aircraft.

You may be familiar with clouds, but they contain a multitude of particles and water. When an aircraft passes through such a cloud, its speed increases significantly. So whatever we were thinking earlier for the iceberg and the ship aircraft finds a similar kind of situation, but of course, the mass is much smaller and the speed is much higher almost every time. Naturally, their coating, or surface protection, in this type of unit needs a lot of pattern, and they've done that for years to develop a good product. We have cited the impact of erosion, specifically on aircraft, from 2011 in this discussion. Now, these dowels have a hatch portion with small and large dots.

So they have a demonstrated erosion possibility on the aircraft surface. What are the possibilities? These are the possibilities. Regardless of the size of the black dots, the possibility of erosion of the aircraft surface exists, leading us to conclude that larger dots are present. Therefore, the larger dots correspond to the particle's medium speed. Again, the medium speed of the particle impinging on a surface does not imply that the particle is

stationary, but rather that the vehicle is moving at a high speed. Therefore, we only need to consider the relative speed, not the absolute speed. For example, if a bird is flying and an aircraft suddenly strikes it, a collision will occur, causing significant damage, even though the bird's mass may be relatively small compared to the aircraft's mass.

So that is what we say. The larger dot typically represents medium speed. A smaller dot means kind of a lower speed, and in a in a harsh region, as I mentioned over here, this is giving high speed. As a result, major failures will only occur on the front end; others are also shown as failures. However, we need to closely monitor any pit formation that leads to corrosion, which is why we typically maintain aircraft with great care. We don't simply build an aircraft and then neglect it after a year. Next, they were really observed continuously. As I previously mentioned, the birds and insects are the subject of continuous observation. Whenever the birds or insects strike against the aircraft, they use the word FOD, something like foreign object damage. If the bird strikes again the surface of the aircraft, they use this kind of terminology.

So, that is also something we need to account for. Now coming to the air atmosphere, we say the airborne pollutants. There are many; it can be rain, a kind of ice, small particles, sand, ash, various dust particles, and then they will cause short-term physical damage. So when the bird strikes the surface, a particle strikes the surface. There will be some sort of deformation, some sort of impingement, or maybe some sort of depression, but that is what we call short-term physical damage. Corrosion causes long-term damage because it creates a pocket cell that allows water to accumulate and initiate activity. So the initiation happens because of the initial impact, and that is why they wanted this reference; they wanted to distinguish erosion and impact from impingement. They say there is a kind of impact, but it is not really removing the material. Erosion essentially refers to the removal of material, also known as erosive wear, whereas impingement refers to the striking of the material.

Now, because of the striking, there is a possibility of the material getting removed, which will cause erosion. We want to use both the terms impingement and erosion. Now that we have studied erosive wear, we can conclude that a smaller angle of attack will result in more cutting wear; a higher angle of attack, such as 80 degrees or 90 degrees, will also lead to fatigue failure. That is what we were discussing with erosion: it can be classified into two categories: one is abrasive wear, and the and the other is fatigue wear. While this impingement may not cause erosion or material removal, it may cause some sort of pit formation or deformation, which is short-term physical degradation or damage, while corrosion, because there will be water particles available, will cause long-term corrosion damage.

So, this happens to the aircraft's surface. Now, what is really more dangerous? Greater damage is primarily caused by hailstone impacts, where larger particles strike the surface, resulting in significant harm due to the formation of bigger dents rather than smaller ones. Now it can also remove material from a surface. So surface abrasion is also possible, and then even the whole structure, not just a localized structure, gets completely deformed. Despite being more harmful, sand ash and other air-bonded dust also possess a high hardness, surpassing even that of the steel surface, which naturally leads to abrasion. So that is why we believe that the aircraft's outer surface may be eroded. When this type of air and its particles arrive, they impinge and contribute to the atmospheric-assisted surface deterioration of the aircraft.

And this is the impact many times they remove also the protective coating or maybe the paint that has been used for protection purposes, and then it will further cause a risk of corrosion. Atmospheric corrosion will dominate and overall reduce a life in this case. Now, when a sample pit is created, particularly where indentations or impingements occur, and rainwater is present, the rainwater will naturally dissolve any gases present in the environment. Therefore, the rainwater dissolves the gases naturally, unlike mineral water. So while this may contain gases, it may also contain other contaminants. Therefore, it will provide an ideal environment for electrochemical reactions or the enhancement of corrosion.

These are the potential scenarios that could lead to surface degradation. I am now presenting two figures that illustrate lessons learned from failures. One figure shows the SABRE aircraft, specifically the OOL 8, intact. It was found that the radome was damaged, particularly after exposure to rain. This is the radome, which is a kind of front portion of the aircraft, and this incident happened in 1959, and then this aircraft damaged at a very high altitude of only 5000 feet, and then the speed was reasonably high; the speed was somewhere around Mach number 0.76. So in this case and then after that, this failure, particularly when they found this kind of erosion is happening on the front portion of the aircraft, naturally we need to change the design, and then to mitigate that is why they change the design, even the operation procedure, and then what kind of maintenance strategy should be done. They heavily prioritize the design for maintenance and determine the appropriate actions to take in the event of a malfunction.

So, particularly for aircraft, they find very good maintenance, and then they go with regular maintenance as well. This particular instance dates back to 2011. In this case, they particularly used a new design because they wanted to improve the aircraft design. They thought about the prototype aircraft design in this case, and then they presented the results. In 1973, they conducted erosion tests on phantom aircraft and subsequently altered the aircraft's profile design, as demonstrated here. They kept the altitude below 5000 feet but increased the Mach number. The Mach number was 0.99 and then very high speed, and then they found damage almost everywhere, and then they found the radome damage, pent work damage, and at the particular speed measurement probes damage also. So after this, if they want to really go hard with a very good design of high-speed vehicles, which is, but in these days demand that if the speed of the vehicles can be increased significantly, that will be more useful because overall it will save time for so many people also.

Many efforts are being made to improve the design, but if this type of failure occurs naturally, the aircraft cannot continue to operate at such high speeds. So that is what they have provided: many suggestions to improve that type of surface. Let's move on to our final case study, which focuses on the deterioration of buildings. Both India and other countries boast numerous monuments, many of which have earned a place on the UNESCO World Heritage List. Therefore, it's crucial to consider the potential impact of these monuments on human health. For instance, consider the presence of banned metals in India. These metals are present in the monuments themselves, and their surface acts as a storage facility for these elements.

Let's use the brake shoes as an example. The brake shoe composition was changed. Old brake particles may fly from vehicles to monuments, and if these monuments don't receive regular maintenance, the particles will settle there. So now, from a common place, we are not getting health issues, but when we are visiting those monuments, we are touching those monuments, and it may be that the particles are also coming within our hands or fingers, and we are taking along with that. So, that will cause health issues. So, when we think in totality, these are the important aspects. So that is why this paper has been referred to. This paper was published in 2021, and they have studied the two architectures of France, and then they have been shown various portions, and then they found almost every portion has contamination, and then they took some sort of EDX and also analyzed those.

So I will be presenting this in two slides. So in this case, as I mentioned, two French historical buildings were taken that were being listed on the UNESCO World Heritage List, and many tourists want to really see these kinds of buildings. What is the true purpose of this study? The primary objective is to understand the effects of air pollution, specifically the damage caused by atmospheric pollution, which is why I am focusing on this particular case. As you can see, air pollution primarily stems from human activities such as driving, automobiles, public transportation, and occasionally, manufacturing and agriculture. These activities can lead to failures or contamination, or they may exacerbate particulate matter, resulting in the deposition of particulate matter on building surfaces. As previously mentioned, the formation of an electrochemical cell leads to a continuous increase in corrosion. This can lead to structural collapse or discoloration. It's crucial to consider the preservation

of monuments, especially those significant to tourism. Without maintenance, these structures' materials will deteriorate, compromising their integrity and appearance. In certain instances, it's possible that 200 years ago, aluminum didn't see widespread use, or perhaps titanium didn't see widespread use.

Naturally, those things have come from other sources. Now that it has come from other sources and is residing on the surface of the monument, naturally it needs to be cleaned, and then we need to really think about what is really happening. Whatever the science gives us as a sort of understanding, we need to implement that. So in this case, particularly what they mentioned, they concluded that the procedure for the routine and the routine maintenance must be there because they found many places with a black crust, and a black crust means maybe a lack of oxygen or sunlight as well. Now, if there is some sort of contamination on top, maybe it is not allowing the sun rays to reach the surface. Actually, it will cause more cumulative damage. Therefore, it's crucial to remove it immediately upon discovery. Therefore, regular maintenance is crucial for this type of monument, as black crust not only diminishes the structure's aesthetic value but also continuously degrades its surface.

One aspect to consider is aesthetics: individuals tend to focus on aesthetically pleasing surfaces, such as genuine monuments, rather than overlooking layered or masked structures. Additionally, it's crucial to minimize any degradation. If we fail to prioritize proper maintenance, degradation will inevitably occur. I'm presenting their in-depth analysis of this microscale image, where they discovered both spherical and nanoparticles. They explicitly stated that the poor air quality in many buildings stems from their porous structure. These materials, which are spherical, originate from the outside and settle on the buildings, rather than causing damage.

These particles also contain a specific type of nanoparticle, which is an agglomerated nanoparticle. We are well aware that nanoparticles attract other particles, leading to immediate agglomeration if proper care is not taken. Therefore, these agglomerated nanoparticles may contain hazardous substances such as arsenic, cadmium, and chromium, which are all considered toxic and should not be present in our environment. These materials may have been banned several years ago, but they are still present on building surfaces today. Naturally, the presence of these agglomerated nanoparticles can lead to the release of toxic substances, potentially causing health issues. Therefore, it is crucial to take this matter seriously. Additionally, researchers have discovered ultrafine particles, specifically nanoparticles, which have the potential to cause health issues. These particles often remain close to the structure's pores.

Furthermore, it's important to note that these pores don't fully adsorb; they remain in place, but they are also easily removable. This implies that regular maintenance allows for thorough cleaning and proper upkeep. Failure to do so could potentially spread to other visitors, leading to an increasing number of issues. So, to preserve the building, it is crucial to address hazardous materials, particularly if there are nanolabial particles. We should not enter through our breathing system or nostrils. But because when we go too close to those buildings, there is a possibility that we inhale those particles also, or maybe we touch the buildings, or maybe we want to really feel the texture of the surface of this monument, and finally, we inhale those particles also. Therefore, in my opinion, these buildings resemble storehouses. Regardless of the particles or materials used, it's highly likely that these monuments will eventually transform into storage facilities.

So, you are not seeing this particle come to our building. I will be able to provide you with something like a storage house for them. So, this is very important, and then particles are there, and naturally there will be a possibility, and then there are already health hazards there, and if we do not clean it, there is a possibility that neighborhood residents will also be subjected to this kind of danger toxin because air will be the particle, and the toxic material that remains here can be really transferred through air to other places, and then there are neighborhoods, and then they can really, you know, find this kind of hazardous for them also. So, this is important, and that is why I say that even in these nanoparticles or the spherical particles they remain, they have observed that they are all outside particles. These particles were not present during the construction of the buildings. However, they mentioned that some of the current particles may be toxic, even if not all of them are. Now, they

have also shown what the element structures are using the EDX, or they use the term EDS energy dispersive x-ray spectroscopy, and in these days, we also use an XRD.

So, they have used this kind of thing to understand what kind of particles they are creating. What they have observed is that the EDX results reveal the presence of elements such as aluminum, silicon, calcium, potassium, sodium, chromium, iron, antimony, and molybdenum, among others, on the surfaces under investigation. These particles, when combined with a soil or may be settled dust from a building material, are probably what they think came from brick shoes, or may be even the tracks, particularly the train tracks, and this alarms two things. One is that the particles have come from the railway track, or may be the bricks and particles have been released from those materials, those systems, and finally settle on those buildings. That is one possibility, but if that is really happening, then when we are traveling through the train or when we are really traveling on the road, What happens is that the brick shoes are going to really give off a number of particles, and whenever there is a strike, or may be, particles will keep coming. We have also found that whenever you go for the maintenance of a car, the brick shoes need to be changed because they have already worn out. That means we really require some sort of design where the life of the life of the brick shoes can be extended significantly. There should not be any brick shoes, and if these particles are kind of nanoparticles or very small particles, and if they are easily absorbed by humans, they will go inside the human body, and naturally, they will really cause many issues as well. Specifically, this issue pertains to trains, even if we don't frequently travel on them. However, individuals who operate or maintain these trains will unavoidably encounter this type of pollution and contamination.

So, this kind of science really helps us to understand that system failure should not happen, building failure should not happen, and health hazards should not happen. If we are able to take care naturally, we will be able to really achieve a better and better scientific society, or science; we say there is a society by science also. Thank you.