Artificial Intelligence in support of NE Sector Prof. Nawal Prinja, Jacobs, UK

Berta Oates
Doing today's introduction is Dr. Patricia Paviet. Patricia is the Group Leader of the Radiological Materials Group at Pacific Northwest National Laboratory. She is also the Chair of the Gen IV International Forum's Education and Training Working Group. Patricia.

Patricia Paviet
Good morning, everyone, or good evening. Thank you very much for attending this webinar and thank you to Professor Nawal Prinja who presents again this webinar. This is his second time presenting a webinar.

Professor Prinja has 40 years of academic and industrial experience in the nuclear sector. He is the Technology Director of Jacobs and holds the position of Honorary Professor at four British universities. Currently, he is chair of the World Nuclear Association Cooperation in Reactor Design, Evaluation and Licensing Working Group where he is working on harmonization of Nuclear Codes.

He has been on the IAEA mission to China, South Africa, the United Arab Emirates, Spain, and Poland. He was appointed as an advisor to the UK Research and Innovation, Advisor to the UK Government, to help formulate their long-term R&D strategy for nuclear industry and continues to advise as a member of the Fusion Advisory Board of the UK Research and Innovations, and he chairs Artificial Intelligence Technology Focus Group for Nuclear Propulsion for Ministry of Defense.

He participates in a number of international committees, notably the ASME Code Committee for developing new Plant System Design code and represents the UK at the Senior Industry Advisory Panel of the Generation IV International Forum.

Without any delay, thank you so much, again, Professor Prinja, to give this interesting talk.

Nawal Prinja
Thank you, Patricia, for your kind introduction and, also, thank you, Berta, for organizing this event. I also want to thank Generation IV International Forum to give me this opportunity to discuss what I believe is a very important topic of using digital technologies like artificial intelligence in support of the nuclear energy sector.

In the next 50-60 minutes, I will cover, first of all, the need for AI in nuclear energy sector and then I appreciate, some of you may already know, what AI or machine learning or deep learning is but I'll give just a very, very fast introduction to those technologies and then my own practical experience in using it in engineering and also in nuclear and talk about the current developments. I will share some examples with you and end by talking about the way forward.

Because I am mostly working from home, you have been given two email addresses. One is my work, and one is my home. Feel free to contact me on that.

It does take a while, because of online, to change the slide. There it is.

My introduction has already been given. The only thing is that I just want to point out three particular, very relevant experiences that we have for the talk today. The first one is, as was mentioned earlier, that I do act as the Chair of AI Technology Focus Group for Nuclear Propulsion. The other one is that I have been working with Fusion for Energy. My colleagues over there are really working hard to implement AI in that field. I am the Vice Chair for the Senior Industry Advisory Panel for Generation IV where I have taken a keen interest in, again, talking about the AI.

Why AI?

I have often said that artificial intelligence, there is nothing artificial about it and there is nothing intelligent about it. It is not artificial because it is very real, and the reason is that it is based on real data. We, in the nuclear industry, collect lots of data. In fact, all other sectors of industry collect lots of data but what do we really use, and this is where AI is going to help us. We really need to transform how we make use of the data.

In Project Management Institute's survey, Pulse of Profession, they found that 57% of projects finished within their initial budgets and the probability of delivering a major project on time, cost, and benefit is only half a percent.

How can we improve it?

Another survey, this is the Royal Institute of Chartered Surveyors, they said 95% of project data is not used or just used once and then it's just put away, archived. PricewaterhouseCoopers, they found that 85% of respondents said that AI will significantly change the way they do business in the next coming few years. Nearer to

home, the AI Roadmap, in the United Kingdom, published by the AI Council, found out that AI alone could increase the gross domestic product by 10% by 2030. This is the importance of data and AI that we will be seeing.

Now, very quickly, a lot of people often associate AI as part of the 4th industrial revolution, also known as Industry 4.0. Now, you all know it. I mean, the first industrial revolution was mechanization, then came electrification, then came the computers and, today, we are talking about smart factories. Industry 4.0 originated, I believe, in Germany in the automotive industry. Still, it means different things to different people, but it's often sort of seen as something for smart factories. The message I want to convey today is I4.0 is not just for automation of factories. It can also help nuclear energy sector and, later, we will see how. This is just something that is important for us to grasp.

Why do we really need it?

Look at the challenges that are facing the nuclear energy sector. This picture we have seen before. We have Generation I reactors and then Generation II and, nowadays, Generation III or III+ and, in very near future, there is going to be Generation IV. But if you look at the challenges, first is that the regulators all over the world are asking us to keep improving the safety and so it should be. Secondly, the governments all around the world are asking us to reduce the cost of nuclear.

Here, you are. Increase safety but reduce the cost. I mean, in UK alone, the UK Nuclear Sector Deal, I think it was April 2018, it called for 30% reduction in the cost of new build by 2030. The question is how can we do it. In terms of safety, as you know, following the Fukushima, lessons learned, extreme events which used to be beyond design basis are having to be considered levels of safety to be improved.

How do we do it?

The answer is digital technologies like AI can help us.

Let's look at – this is my view of where we are in using these new technologies. Here is a typical curve of technology when it is introduced. In the beginning, innovation is triggered. There is a great expectation and then things don't quite work the way we think it should and there is a bit of disillusion.

Finally, there is a bit of an enlightenment, people find out, the teething problems are sorted, and you end up at a certain level of productivity. Looking at the three technologies, let's say, look at virtual reality, augmented reality, AR and VR. You know that gaming, entertainment industry is way ahead. Aerospace industry has superb simulators and so on and, nuclear, we are just about at the height of our expectation. When it comes to blockchain, again, you all know about bitcoins and cryptocurrency. The finance industry is absolutely way ahead with it.

Some, I understand, legal companies have started to do smart contracts but blockchain and nuclear, no way. I mean, it is still being talked about. I still come across many well-known companies, big projects, with people just sharing information on spreadsheets and emails and blockchain is still not quite caught on and same with artificial intelligence. Your smartphones in your pocket are best examples of it. We are already beginning to hear and see driverless cars from automotive industry but, in nuclear, AI is still in the very beginning stages.

My conclusion is that the nuclear sector is lagging behind others and there could be several reasons behind it. But let us look at the technology and let us see what can be done. I can share with you, because I come from the United Kingdom, UK's AI journey.

This is in October 2017, when AI Review recommended creation of AI Council and then, in November 2017, Industrial Strategy was published that named AI and data as one of the four grand challenges. Office for AI has been created in the Department of BEIS in the UK and, in April 2018, the UK Government and AI community agreed a £1 billion AI sector deal that I have already mentioned to you. Now, Office for AI is considering recommendations from the AI Council, AI roadmap is being published, and so on. This is what's happening in the AI.

If you look at the UK's National AI Strategy, growth of economy through AI, ethical and safe and trustworthy development of responsible AI. But the most important point I wanted to raise today is the change through an emphasis on skills, talent, and R&D. There are very many nuclear energy sector businesses who still are not paying attention that, for this new technology, you are not going to just create skills overnight. You need data scientists, you need computer infrastructures in place, you need to spend some of the budget on R&D in that AI. I'll share some examples with you later.

But just generally looking around, earlier on, I had attended one of these knowledge transfer webinars and this picture was shared that AI itself is changing very fast. We are actually already on third wave of artificial intelligence.

The first, from 1950s to 70s, was all about the early perceptrons and then came the expert systems. But, today, we are talking about deep learning, artificial neural networks, convolutional networks, and so on. If you look at the opportunities, of course, driverless cars, autonomous vehicles; healthcare, particularly with the COVID pandemic, the AI has been used extensively; manufacturing, industry 4.0; retail; smart cities; and so on. But nuclear is really lagging behind these industry sectors.

Again, if you look at the way things are growing, it was predicted, again, at this knowledge transfer webinar exploring AI at the EDGE that, within years, we will be having million devices augmented by AI selling almost every hour and it is happening and, honestly, we just cannot. As nuclear energy sector people, we just cannot avoid this explosively growing technology. We must make use of it.

One of the things that are often talked about is the various ways it can be used. Initially, the AI methods were primarily rule-based or knowledge-driven. A lot of approaches are continuously being involved in industry and by academics. ISO team has proposed categorization of these AI systems based on purpose, like why do you need it and I think it's important to share with you. You know you could have AI just for the searching of knowledge or logic planning or dealing with uncertainties, which actually is very important for nuclear because we do talk about extreme events, we talk about very, very low probability of failures, and where sometimes the data is not available.

Of course, you can use AI for learning from experience and I'll share one example with you. Inference and, very important, dimensionality reduction that often engineering designs and products and projects involve so many parameters that it is sometimes humanly not possible. We can in our simple minds think in one dimension, two or maybe three dimensions or four but if you have 30 parameters, it's very, very difficult. AI can help to see what really matters. Then, of course, communication like natural language processing. Again, we will talk about that as well. But I thought it's good to know that we should be looking at AI based on the purpose of it.

Coming to the technology, very briefly. What is AI?

Now, artificial intelligence means different things to different people, but it can be mechanical artificial intelligence or even chemical. I mean, I have seen examples of some crystals that change colors and indicate the conditions that they have seen and so on. But if artificial intelligence is actually relying on a computer, then we call it machine learning. Machine learning is a subset of artificial intelligence, and, within that, there is a new subset, which I was talking about earlier, were neural networks. This is where computers are mimicking the way human brain works. That is the deep learning part of it. Okay?

Again, we will learn more about it in a minute but just to share with you that without data, there is no artificial intelligence. Data science plays a very big part and the first skill in nuclear energy sector that we will need, if we are going to really make a big use of AI, is data scientist. Okay? These are just some examples I had borrowed to share with you.

Talking about machine learning now. Traditionally, you all know about the computer programs, you have the data, you write the instructions, we call it the program, and the computer gives you the output. But in machine learning, the computer will actually learn from the output and change the program. This is essentially a very, very quick introduction to machine learning. It can be used to detect patterns in data and then you can adjust the program accordingly.

You can focus on developing computer programs which can grow and change depending on the data that is being fed into it. You can get some hidden insights. You can establish some trends and it is a strong method of data analysis and also automating some analytical models. Again, we will see examples of machine learning.

What is deep learning then?

As I mentioned that this is where we are trying to mimic how a human brain works. Our human brains learned how to talk and walk but, if you look at it, a brain contains a large number of interconnected nerve cells or neurons and they have these tentacle-like things, the dendrites, where the nerve signals come in. A large number of signals come and what the cell then needs to do is to decide whether to fire or stay still. Okay? If it decides to fire, then either a chemical or an electrical signal is sent down through the axon and then it is connected to other cells. This is how the whole network then decides.

Similar to that, you can see on the right side, if we have a large number of input parameters, X1, X2, X3, and so on, and they are all applied, certain weightage is applied to them to decide which one is important, which one is not, and then there is this networking which looks at the final result and that result, if it is wrong, is sent back to readjust the weight. This is how the iterations take place. We call them epochs. That's how a neural network is trained.

If you look at the brain versus computer, this is now, but computer technology, particularly with advent of quantum computing, it's going to change the scene dramatically but the number of units in the brain are large numbers, 10 to power 11 and they are all connected in parallel. But where we lack in connectivity because, in computer mostly, it is a series connection and the number of units we can put in a processor, we make up in speed. A brain neuron fires in about a millisecond, whereas a computer transistor can fire in about a nanosecond.

By the way, you can have large number of interconnecting layers because these layers are hidden that is why it is called deep learning. Okay? I hope you get that idea now about artificial neural networks.

Typically, machine learning is done in phases. The first one is where you actually get the data, which you will call the data used for training, and the algorithms will learn from it, so all the iterations take place. The model is then ready and then you will use part of the data as a test data to check the accuracy. Training and testing are two very important parts of machine learning.

Typically, there are three. One is supervised learning. This is where algorithm learns from the input data where the results are already known. It kind of works, does a prediction, checks against the result, and then adjusts itself. But there are also some self-learning or unsupervised machine learning where we just do not know. It is just clusters which can be created by looking at the similarity. Okay? This is where different classes can then be created, dendrograms and decision trees and so on, a very powerful package in spotting patterns and clusters.

Then, we have the reinforced learning. That is very much like the computer games you try, then you learn from the outcome, then you adjust again and so on. These are essentially three basic methods in machine learning.

You must be wondering where are all the software, they must be costing us a lot, and so on. But the good news is that there are a

large number of machine learning algorithms that are available to us. The supervised learning, you can see, used for regression classification. I am not going to go through all of them. Again, unsupervised learning for clustering, there are various algorithms available. Reinforcement learning, again, agent-based models, a large number of algorithms. Good news is that all of them are available free of charge.

I mean, thanks to providers like Meta AI, Google AI, Open AI, and many other academics. They are products which are available free to you, free to download, Python and AMPI, TensorFlow, and so on. In fact, even to learn and to try out your ideas, there are, I think, at the last count, I saw about 5600 datasets available to you free so that you can build your models and train them.

The only thing I would say is which algorithm to select. You really need to look at what kind of data you have, how much of a data do you have, does it cover all the possibilities because data could be biased towards one and not biased towards other, what level of accuracy are you wanting, and how complex it is.

Some of these algorithms have the tuning parameters so you have got to really spend some time running, changing the parameters, and so on. Is everything linear, how many features are there, can you then scale it to solve bigger problems, so there are a number of things. I mean, I can keep adding there. There could be things that you should have transparency, so if the results are not quite what you think it is, it should be able to explain it and so on. These are just things which will come with experience of using.

Here is just another summary of the typical supervised learning algorithms, linear regression, logistic, decision tree, random forest, Naive Bayes classifiers, and so on.

Another very powerful thing is text mining and natural language processing. A lot of people ask me that and I say that natural language can be turned into data.

Please remember, computers like numbers and data, so the language is – and here are the techniques, tokenization where you can break it into small structures; consecutive words, two togethers or three and so on, bigrams, trigrams; base and the root form like fish, fishing, that's called stemming; lemmatization, these are various inflected forms of a word, past tense, present tense, and so on; stopwords; parts of speech, grammatical type; named entity, name of a place, name of a country, and so on; and syntax tree, which is shown here in the diagram where sentence can be split

between subject and object, verb and noun, and adjectives and adverbs, and so on.

This is how a natural language, or a sentence can be taken, broken up into pieces, and turned into data that a computer can actually read and understand and reply back. A very, very powerful AI method.

I just wanted to share this example I have often used in teaching AI. There is house prices in Boston that has a data set available but look at the parameters they have used. There is a parameter which is per capita crime rate and the proportion of non-retail businesses there or the distance to nearby river, and so on. There are so many parameters there. Pupil-to-teacher ratio in the town and so on. You can do a correlation matrix between these parameters. You can see which ones are highly correlated and which ones aren't. You can do a scatter plot to get a quick view of the data.

Here it is. A quick sort of average number of rooms versus price and you can fit some kind of a trend. An epoch is basically an iteration, so it basically says it took us less than 20 iterations to reduce the sum of square error in this particular example. It's just something for me to quickly share with you.

I am just moving on to my own experience and examples. There are about eight such projects that I have done, rock/mine classification sonar data; electron beam welds; ultrasonic inspection of welding; predicting fatigue/fracture life, environmental impact on the life; material properties for power plant steels; application of natural language processing; doing horizon scanning using a package called Goldfire; and root cause failure; and so on. I will also talk about one very important current project which is probabilistic methods combined with AI for prediction of material properties called PROMAP.

A very quick run through some of the examples.

Sonar Detection: As you know, the sonar signal goes and hits a target, comes back but, on its return, the frequency band changes. This data in 60 columns, shown in the yellow box over here, each column represents the energy within a particular frequency band and there were 60 bands and the 61st column indicates whether it was a rock or a mine because the frequency content changes if it is reflected from a steel container or a rock.

Based on just about 208 observations, so there were 208 rows of data with rock and mine result given, I could do a supervised

learning and, believe me, it didn't take me several hours. It was just done in a matter of minutes on my home desktop and achieved an accuracy of 83.3%. I mean, it can take several months to train a human operator to be able to achieve that level of accuracy.

Moving on. Next example is a vacuum vessel being made by Fusion for Energy for the big ITER Project. It's the most critical component in this. It's a doughnut-shaped vessel.

Excuse me. I'll just take a sip of water.

There are nine sectors, 40 degrees each. Each sector is made from 10,000 different types of welds. Because it's a nuclear component, 100% inspection is needed. Now, we were looking at – of course, all welds don't go well so you get inspected and then if there is some fault that needs to be repaired. We created an AI model looking at a number of variables and here it is at the bottom. Electron beam, what was the length, current, welding velocity, focusing system current; which sector was being done; what was the orientation, horizontal, vertical; type of weld; position; and so on.

Looking at all those, we fed that into an artificial neural network, which was based on 1802 weld data, and there were 70 new welds which were to be done and we made a prediction of those, and we identified one particular weld which was with 90% chance of failure and believe me, it failed. Sixteen others with 56 to 60% chance and 7 out of 16 failed. The remaining, which were predicted to pass, did pass. This was a level of accuracy.

You must be wondering what use it is, so here it is. We can use it to improve the quality control. Please note that, in nuclear energy sector, we are very, very good with quality assurance. We have processes in place, we assign responsibilities, we have programs, we collect data. Very, very good on QA. But, if things go wrong, do we really analyze? Do we evaluate what went wrong? Do we change the planning? Do we implement lessons learned? How fast do we do it? This is where AI can help. Just the example I shared with you, artificial intelligence can help de-risk and accelerate your programs.

Moving on. Next example is applying it to accelerate ultrasonic testing inspection of welds. Here you are a typical T weld joined together. There is a flaw and ultrasonic testing is done. Nowadays, there is this increasing tendency to prefer ultrasonics over X-rays. Radiography is a little bit more involved. But, even with ultrasonics, it can cost anything from $1 million to $5 million to train and qualify

and inspect and that human inspector then can take hours inspecting a weld, writing a report, and so on.

Here is an example. My colleagues…

Oh, sorry. I just went too fast.

At Fusion for Energy. This picture shows the producers obtaining a scan, which was typically an S-scan. Most of you are familiar with an ultrasound scan. It is made up of large number of beams, a beam at 70 degrees and at every 2 degrees or approximately 29 beams generating this whole sector from 14 degrees to 70 degrees. Each beam is showing – we call it an A-scan and if there is a reflection, an extra echo from a defect, it is shown there, as shown here in the middle, and that is what is shown as a contour plot in an S-scan.

Human operators have to go through it, inspect it, and decide if there is an extra echo or not and if it is due to a defect or not. Believe me, some of the AI models that have recently been trained for Fusion for Energy team have shown accuracy of up to 98%. That is the level of accuracy that has been possible to achieve.

We can look at the S-scan image as well. I am only showing you here image of a motorcar. It can be any image and convolutional neural network will convert that image, break it down into pixels, and establish patterns. This is how image classification is done.

Moving on. If you have waves, like the sound waves that I was showing to you, or speech, this wave analysis can be carried out using what we call long short-term memory or time series analysis. Again, there are artificial neural networks but there are four of them. One looks at the memory, one looks at the new signal, one decides how much of old information needs to be retained, and so on.

I won't spend too much time there, but these are very complex things. Just a word of warning, I know some people have tried it. They have used LSTM to predict share values in stock market. I will not recommend it. If you want to do it, do it at your own risk.

Another example. This is environmental impact on fatigue and fracture behavior of steel, very important in the nuclear industry. This is one of Horizon 2020 project. A large number of tests were done, 246. A lot of input features, 135. You can imagine what the material is, what kind of conditions there are, and so on. We did feature importance, principal component analysis to reduce the

number of features and did a 10 dense layer deep artificial neural network.

We split the data. We kept 80% to train and 20% which was basically 38 tests. Having trained the model, we then asked the model to predict the fatigue and fracture life of the 38 tests and we achieved 95.4% accuracy. The picture here shows you prediction of these 38 tests, the life prediction. Believe me, if each test was costing roughly about £15,000, at 38 tests, you can imagine, it could have saved £0.5 million. I am not saying that tests should not be done but you can reduce the number of tests, or you can actually design the tests to be done.

The other one was material properties for power plant steels. There were 58 steel types in tubes, plates, and bars. If we knew the chemical composition and the processing history, we could actually train an AI model to predict what the tensile properties will be and creep properties will be. We attained accuracy ranging from 85% to 98%. You see such models – I am sharing these examples because they can help us develop new materials for Generation IV reactors. If you want changes in properties or chemical composition or processing history, you don't have to engage on a very large expensive testing. You can actually learn first from AI and then start to do the tests.

NLP, I won't spend too much time. Essentially, I have personally used it for translation because I was working on a Japanese project and a Polish project, and I was able to translate technical documents very quickly.

Here is one example where we can use artificial intelligence for horizon scanning. As you know, there are many, many applications in AI and there are different tasks and methods which can be used, time series and speech to text, text to speech, and so on. But the most important one that we can do in natural language processing is to retrieve information and understand documents. This is where I have personally used the commercial package called Goldfire from IHS. It can be any other package by the way. But I just wanted to share this example that I was able to intelligently do the search.

Here is a horizon scanning where we were able to look things outside our organization. You are not in the cloud or on the websites or inside our own organization. From various sharepoint sites within Jacobs, we were able to retrieve information, apply natural language processing, understand the documents, and ask the question, and depending on the relevancy of the information, it

was filtered and given to us and, very quickly, I can share that example with you.

I was interested in Primary Water Stress Corrosion Cracking, and I simply typed PWSCC, and I got 7595 results. I could use lenses. I could break it down based on publisher, author, dates, and so on. But the important thing for me was to look at typical sort of example and the one that I came across in HMS Tireless. It's a name of a nuclear submarine. I think it was a publicly available document. I clicked on it, and it was a newspaper article from The Guardian Newspaper. This just shows that you can actually even spot a needle in a haystack, one newspaper article hidden in among the millions of publications.

My question was why were cracks missed?

I simply typed that question, and I got several answers back. Again, you can see on the left-hand side, I could filter by publication date, publisher, and so on. But just to cut the story short, I just wanted quick answers and summaries and there they are. Various documents that were relevant to me were summarized and you can see there, I have already picked up. Tube cracks were missed because sensitivity of the probe was reduced, defects at this location, if not detected and removed from service, were known based on industry experience to have significant likelihood, and so on.

This important summarized sort of outing could be extracted in a matter of minutes. A human could have taken several days or weeks. The benefits are, that I want to share with you, claims, arguments, and evidence that are needed to make a safety case can be extracted from large number of unstructured documents, PDFs, Microsoft Word, or whatever, as long as they can be read, scanned, and read quickly and efficiently. It can save several days of work.

My final message is the way we are doing engineering is going to change. This is the impact of artificial intelligence and data science. In the past, we did engineering based on experience, empirical understanding, what worked, what didn't work. Nowadays, it is based on science. We try to understand what is the mechanism, the physics and the chemistry, what's the equation and the variables, we write that equation, we understand the theory, so it's a very much mechanistic understanding. This is the present.

The future is where we will look at the data, the enormous amount of data that we have already collected and learn from it. I am not

saying that we will stop doing the science bit. No way. We will carry on, but it will AI. The data-based understanding is going to help us in future.

This is where I want to share the latest current project that I am working with the University of Strathclyde and the Risk Institute at Liverpool University. Here, the aim is to combine AI models with probabilistic methods. The reason is that the existing AI models need a lot of data but, in nuclear, particularly nuclear materials, there isn't that amount of data available. There are gaps.

What do we do?

The idea is that from whatever little data we have, we can use interval predictor models of Bayesian statistics to fill that knowledge gap and then use the artificial neural networks to do the predictions. This is a feasibility study, only a three-month feasibility study, and my offer to you, anybody out there listening is, if you have a nuclear material database that you want to enhance it, share the database with us, we will share the results with you. This is something I just wanted to share with you as to what AI can do.

A lot of people ask me, how can we quickly make use of AI, what are the steps we need to take. Eight simple steps from my experience.

Firstly, quickly define the project. What is the opportunity? What's the problem you want to solve?

Secondly, as I have said many times, without data, there is no AI. Do you have the data? Is it biased? Do you need to clean up the data? Data wrangling, how valid it is, and so on.

The third is what kind of algorithm. I spoke about them earlier on. Okay? You have got to really then select that algorithm, finetune the parameters, train it, test it, validate it, and the people who are going to make use of it. Of course, for all that, you need an IT infrastructure, the computer machine, the CPUs. You don't always have to use a GPU. Cyber security, data warehouses are there, or data safe havens are there, and so on. Then, of course, you will train the people on that infrastructure, you will do proof of concept, you will try it and, finally, in the eighth step, you can actually deploy it. Some of these activities can be run in parallel.

Quickly before I finish, I want to share with you some of the examples. This was actually collected as a part of a quick review I did for an article published in the American Society for Quality. If

you need a copy, get hold of us and we can send it to you. People have already done accident identification. Probabilistic graphical models, a part of AI, has been used in machine learning too. If you have in a power plant, I think it was a simulator, a number of variables are there. It will actually monitor them and, if things go wrong, it will immediately tell you what has gone wrong. It can identify the change. Okay?

System performance, plasma control. In fact, this is for fusion people, maintaining the shape of plasma is a big challenge. Artificial intelligence has been used to achieve that.

Information Retrieval: I have already talked to you about it. How natural language processing tools can be used to retrieve information, to pick up the lessons learned from previous events, and so on.

Structural Integrity: I have given and shared the example about predicting the fatigue and fracture life, impact of the environment on material properties.

Predictive maintenance is another very big thing in oil and gas. It is being used in other industry sector. It is being used when you have a power plant with large number of components. You can monitor them. It will actually keep monitoring the signal and, if there is an anomalous behavior in the signal, it can because things don't suddenly go wrong. There are telltale signs you can pick. I have had experience of picking anomalous behavior hours, half a day or something, before a failure had taken place in an oil and gas rig.

Weld Inspection: I have already explained to you. You can save yourself hours and hours of time.

QA versus QC: Again, root cause failures in welding and many other industrial processes.

Finally, robotics in construction and decommissioning. Of course, in nuclear, we want to keep people safe. We want to keep them out of harm's way. Robotics are being used but artificial intelligence and robotics are two distinct domains but there is an opportunity to combine the two to turn them into smart robots and that is being done as well.

Finally, I want to conclude by saying AI is playing a crucial role in Industry 4.0, the 4th industrial revolution. Data science and machine learning is being used to stay ahead and remain competitive, like in terms of increasing safety, reducing cost.

Innovative solutions with AI technologies are being developed. Previously, people thought it was science fiction, but it is happening. Every problem is different. Talk to experts to understand which aspect of artificial intelligence, machine learning, or deep learning can be used.

Finally, artificial intelligence is powering the future. Nuclear is powering the future. I would end by saying, AI and nuclear energy are contemporaneously together meeting our future energy needs.

With that, I want to thank you for your attention. I have taken my time. Back to you, Patricia and Berta. Thank you.

Berta Oates
Thank you, Dr. Prinja. Thank you very much.

There is the contact information, again, sharing with you, if you have questions that you'd like to reach out directly, please go ahead and do so.

If you have questions today, please go ahead and type those into the questions pane and, while those are coming in, we'll take a quick look at the upcoming webinar presentations that we have scheduled. In March, a presentation on scale effects and thermal hydraulics with an application to the French SFR. In April, the GIF/IAEA joint webinar. The discussion will be on the role of nuclear energy and reducing CO2 emissions. That's a panel discussion and it looks to be a very interesting event and all people are welcome to join for that. In May, development of nanosized carbide dispersed advanced radiation resistant austenitic stainless steel for Gen IV systems.

I do see some questions that have come in already. Give me just one minute and I will…

Nawal Prinja
Okay. I am looking at the chat and I can't see any.

Berta Oates
There's a questions pane separate from the chat. In my roll down, it's just above the chat and you can undock that. There's an icon to the left of the X where it will undock and allow you to make that screen a little bigger to read through those with the scroll bar. The first one. Where there are accuracy predictions, for example, 95% inspecting welds, what's the corresponding figure for human inspectors?

Nawal Prinja
I have been told that it depends on, of course, the training and the quality of the human inspector but it's very difficult even for human beings to achieve 100%. But I have been told that 95 to 98% accuracy from the AI modules is very, very good.

Berta Oates
Thank you. We have one that reads, I am interested in the NLP for information and retrieval such as to get keywords in an article. Would you please describe the flowchart to find out the results? Thank you.

Nawal Prinja
There are many packages available. The one that I used was I mentioned in my talk. You can definitely use it to extract keywords. In fact, you can go through millions of documents and not only just search for keywords but ask a question and it will make a sense of your question and extract relevant information. Keyword is actually old style. Keyword was when people wanted to just not read the entire document and say what is it about and so on but not anymore. Let artificial intelligence read the entire document. There could be a paragraph hiding somewhere which is not picked up by your keyword. I would recommend that, please, actually, use proper NLP packages. As I said, I have used one.

Berta Oates
Thank you. Which applications in nuclear energy can reinforcement for machine learning be used?

Nawal Prinja
Reinforcement for machine learning can be used for many. Like, for example, I was showing earlier on, if you are making a large number of observations and then you say, ah, result, like this thing failed or it passed and so on. As long as you have data which shows the observations you made and the result which you observed, it could be pass/fail, it could be anything, you can apply the reinforcement learning there – sorry – the supervised learning there.

Reinforcement is the way things have to be learned. You try something, and it doesn't quite work, and you say, no, this failed. Okay. Next time, don't do it this way. You will have to try a different way of doing it. There are a number of – particularly in robotics, I would say where these methods can be applied or even on testing, which is the best way to test, which is the best way to lift and so on. There are several things that you can do in

engineering. If you have already done it, you can learn from it or you can also apply the reinforcement learning.

Berta Oates
Thank you. This one's a little longer. Thank you, Professor Nawal, for a comprehensive presentation. Please ask permission [ph] one. For the implementation of machine learning, for example, on welding quality inspection, which type of machine learning has the best results among supervised learning, unsupervised learning, or reinforced learning? The second part of that, for each of the three types of machine learning above, for example, a supervised learning has several algorithms such as regression, decision tree, etcetera. The question is which algorithm determines the best results from each type of machine learning.

Nawal Prinja
Okay.

Berta Oates
It sounds a bit long. I have shared it in text so maybe it's easier to read it also.

Nawal Prinja
Thank you. For some reason, I still can't read the questions, but I can read your text. Yes. Thank you.

Please remember that it all depends – I gave you the criteria – on selection of the algorithms. Okay? It is the accuracy. It is the type of data. If your data is very much linear, linear regression will work. If not, then obviously, it is not going to work and so on. As to which type of algorithm I will recommend. It depends on what type of data you have, what is it you are trying to do, what level of accuracy you want, and so on. Okay?

Now, regarding this question about the weld inspection, there are a number of things that we have been trying. It is still research work that is being done. We have applied it as image analysis. We have applied it as a wave analysis. We can also apply it as a regression analysis because we have thousands of welds which have already been inspected. Why not take advantage of it? Can you imagine, around the world, how many welds have been inspected? How many hours of experts have already passed their judgment? Why throw it away?

What I have been saying, and this is the work we are doing with Fusion for Energy, is to get hold of all those inspection reports, look at the data, and say, aha, the experts think this kind of signal,

when you get from this, means that there is this kind of a fault and so on. We can do image analysis or back [ph] their algorithms. We can do wave analysis or back their algorithms, and so on.

But we have done both and, as I said – I am not at liberty to explain the full details of the AI model here, but I can say that these algorithms work, and they gave very good accuracy. The point I am making is please do not waste the data that you have collected over the years. It is valuable. You are sitting on gold. Apply AI and learn from it.

Berta Oates
Thank you. The principal component analysis or PCA assumes that the relation between parameters is linear. But what about nonlinear correlations? How can we reduce that space?

Nawal Prinja
There are. Please don't get me wrong. There are very, very clever algorithms available to handle nonlinearity as well. Absolutely! It's just that the linear ones are easy to use it but there are several. There are support vector machines that will multiple linear, sort of, demarcations and nonlinear ones as well.

Berta Oates
Thank you. Several questions have accolades in them, and I don't mind sharing those at all. This one reads, fantastic lecture. Thank you. I totally agree.

Nawal Prinja
Thank you. Thank you for your…

[Multiple Speakers]

Berta Oates
Nuclear cycle includes also the storage of rad waste. How do you see the use of AI for this very delicate task?

Nawal Prinja
Brilliant question. Absolutely! AI should be applied throughout the whole project lifecycle from concept, design, construction, operation, maintenance to decommissioning and storage as well. Why not? The big issue with storage is lifetime. These are long term and, believe me, there isn't enough data available to predict what things will look like in 1000 years or 10,000-year time. This is where AI can help.

There is a project that I am working with and, I have already mentioned on the PROMAP as well, where people have to use probabilistic methods. What is the probability that this concrete structure that is going to contain the storage, what strength it will have in 500 years' time? People haven't done that experiment. You don't have deterministic data. It will be probabilistic. That is why this PROMAP Project, that I mentioned towards the end that we are doing a feasibility study on, we can combine probabilistic methods with AI to do that kind of prediction and absolutely right for storage, particularly long-term longevity predictions for nuclear storage areas. Absolutely, I agree. That's where AI can help.

Berta Oates
Great! Thank you. What about the regulatory aspects in the future? Do you have any thoughts on that?

Nawal Prinja
Regulators. Of course, we are engaging with the regulators as well. One thing has emerged, and I can share with you. AI application in nuclear can be split in two areas. One, where it is a numerical sort of assistant to the operator to help improve de-risk decision making or reduce the time it takes to go through documents and so on. Very, very relevant and I don't think regulators will object to that.

The second part is the autonomous nature, particularly where it is a safety-related component. I think, and I haven't come across any regulator which will allow autonomous control of a safety-related system. That is something still to be looked at, worked at but, of course, automotive industry is beginning to and many other. Aircrafts are also flown autonomously.

But a time will come. The work has to be done very carefully. Confidence has to be built. But that is for future. What I am saying is, because of that, we should not ignore AI in nuclear. There are many areas the regulators will definitely approve where we can increase the speed, where we can de-risk, where we can provide numerical or the computational aid to the decision maker. That's what my current view is with the regulators.

Berta Oates
Thank you.

Nawal Prinja
By the way, I will be speaking at US NRC Conference being organized later in April and I'll raise this point.

Berta Oates

Great! Thank you. All things today were actually about the performance and reliability in some ways. Live [ph] focused question.

Nawal Prinja
Sorry, can you repeat the question again? Okay. CI-focused question? Sorry. All things today were actually about performance and reliability. Not really. I mean, they can be to do with design as well. Why not? There are innovations and selecting a new material. Why not? It's not just performance and reliability.

Berta Oates
Okay. Thank you. You have talked about the link with the software delivery. MLOps is a real subject in Google Talks and its paper about technical debt of machine learning. Can you talk to us a little bit more about continuous integration and continuous delivery models to deployment? What's your vision on that?

Nawal Prinja
That is another big next step for AI, continuous delivery, because things are not – you may get an impression as if I am talking about AI is only good if you have the data, historical data. If you have the history, you can apply AI which is not quite true. Okay. If things are continuously changing and you are getting new data and new information, that also can help. You can integrate AI with continuous systems as well.

One very important part there is LSTM. I very briefly touched upon it, long short-term memory models. What it does is it decides which bits it should hang on to from the past memory and then the new information comes, which information is important for me to merge into the existing one to create the next step and so on. It's wonderful. I'll often give you one example.

Say, if I say my name is Nawal Prinja, my name is Nawal Prinja, my – so it learns and then I suddenly say my name is dash. Yes. It will fill it with Nawal Prinja because it has learned that this is what comes naturally next to it. But if it then comes across suddenly a sentence, which says, my name is Berta. Then, it will say, aha, error, I was expecting it to be Nawal Prinja.

Berta Oates
These are the kind of…

Nawal Prinja
Yes, honestly. Or if I say I lived in France for 10 years and then next sentence is, I can speak and, if I leave it blank, it will say

French because it has worked out the context. It has been mapped [ph]. These are very, very clever packages in NLP. You don't have to have history. You don't have to have the data. You can apply AI on continuous systems as well.

Berta Oates
Very interesting. Thank you. Any implications for using machine learning for licensing, for example, probabilistic safety assessments for plant regulators? I don't know if you have any more thoughts than what you have already shared on that.

Nawal Prinja
Right. Licensing is all about existing regulations, showing that your product meets the rules and the laws and how, therefore, it can be licensed and so on. I will say that, yes, AI can play a role in searching through those large number of documents, clauses, just to make sure that there is nothing missed out. Definitely, it can help you with the licensing and permitting.

I have come across and I have worked with certain groups where this issue has been looked and believe me, in nuclear, it is a big task, and a large number of documents have to be dealt with. You can actually do that. You can have on one end, a huge number of documents which come from your projects, various reports, and specifications and then you can have large number of documents which set down the regulations and the requirements and you can actually marry them. You can use NLP and you can use AI to actually show where they are compliant and not compliant and so on.

Berta Oates
Thank you. You touched a little bit on this before, but I don't know if you have additional thoughts. Can AI be enforced to build an autonomous nuclear power plant? But how?

Nawal Prinja
Of course, it can. If it can be trained to do autonomous motorcar or the autonomous sort of pilotless planes and so on, one day will come. But this is Generation IV reactors which are inherently safe and if they are inherently safe, then I guess there will not be very many safety critical features requiring human intervention or human decision. This is thing of the future.

But, yes, one day, definitely, if you have inherently safe nuclear power plant and it just needs running – by the way, there are plants which are running autonomously. Human beings are given the warnings and they can just watch it. They can intervene, of course.

I am hoping that's the future that we are all aiming for. That is what Generation IV International Forum is, to bring and look at futuristic reactors and bring them into play. What I am saying is AI will help that.

Berta Oates
Excellent! I think that might be a great dovetail into what might be a little bit more challenging question. How can we increase the accountability against society of AI in the nuclear sector? I think that's kind of what you were just saying. Do you want to expound any more or have any other thoughts on that?

Nawal Prinja
Okay. Well, this is all about exposing the technology to as many people. It's there in many governments' strategies as well. There has to be a level of openness. But, believe me, a lot of people do not realize they are already relying on AI. Just as I said, look at your smartphone in your pocket and you will realize how much AI is already being used. There is like fraud checks being done by banks. You don't realize it, but it is already being used and so on.

Every time you make a transaction, there is an AI package behind it, looking at the various parameters and seeing if it is fraud or not. Even your emails are being detected for whether it is to be sent down your junk mail or not and so on. These are sentiment analysis. People are not realizing but a lot of it is already being used. Even in medical world, it is being used. I think the whole idea behind that is expose it as much as it can be, remain open, and convince people that the time will come that the society will be ready to embrace this new technology.

Berta Oates
Thank you. I think that was a wonderful response. Thank you for your presentation. Expert systems based on AI techniques have been used for many years already in support of nuclear operators and decision-making process. However, they are not considered to be able to replace the human operator. In your perspective, how much more reliable are those systems considering they are able to analyze and get more information than humans in the same time? Could it be possible to have autonomous controls and supervising systems without any operators for new reactors? Thank you very much.

Nawal Prinja
Okay. I think there was a slide I showed expert systems. You are talking about old times now. Okay? That was the second wave of AI. That's what I think my slide showed. Expert systems are

second. We are now on the third wave. If people are still using expert systems, yes, I am not saying that they were wrong, but they are behind times, at least 10 to 20 years behind or even longer.

What I would recommend is, I have already answered on the autonomous control that, yes, for non-safety related systems, it can happen. It is already happening. Okay? I still think that there is still a little bit more work to be done with the regulators in order to look at safety critical, not safety related, or safety classification of systems and the use of AI in them. But ultimately – I mean, theoretically, it is possible now, but you need to have, of course, the confidence of the people, the society, the regulator, the laws.

Believe me, driverless cars were ready, but they could not be tried on the cars till the regulations were ready, the insurance laws and government rules and everything else. The society, the government, the regulators need to do a lot before the technology can really be brought in. This is where Codes and Standards Development organization – I work with large number of them through WNA CORDEL. You have to start to look at these new technologies and write new codes and standards, write the regulations which will allow these technologies to be used. It will come. A time will come that we will have them.

Berta Oates
Thank you. PROMAP sounds super interesting. Have you published about it? Can I read more?

Nawal Prinja
Sorry. What was the word, question?

Berta Oates
PROMAP. P-R-O-M-A-P.

Nawal Prinja
Oh, PROMAP. Yes, I can definitely. If you can send an email to me, I will send you a poster which explains more about it and the feasibility study is going on. It ends at the end of March and then we will engage into the full study and all the listeners are welcome to join us and give us ideas.

I honestly feel I belong to this project so I am bound to say it that combining probabilistic methods with artificial intelligence will help nuclear materials because there is not enough data yet. There are gaps in knowledge, particularly radiation-induced damage and corrosion and everything else that we see in the nuclear materials.

Yes, by all means, contact us and we can give you as much information as we can on PROMAP.

Berta Oates
Great! Thanks. We have one last question and it's really similar to the things that you have just talked about. Do you believe AI can help lead development of an optimized, standardized nuclear reactor?

Nawal Prinja
Optimized, standardized. Currently, even without AI, it is a big challenge to have a kind of international optimized, standardized, and I feel jealous. By the way, my first degree was in aerospace. I feel jealous of aerospace industry because they design airplane, they license it, they train a pilot, and it can fly all over the world. Everybody accepts it.

But in nuclear industry, we are still nowhere near it. World Nuclear Association is actually working on it. I chair their CORDEL group, and this is something that we would love to do, to have a standardized nuclear reactor at international level and, of course, optimized as well. It is possible. There are various stages. But the nuclear industry – I think right at the beginning of my talk, I did draw a curve and I showed you that we are a bit behind other industry sectors. But on the international standardization, we are way behind things like aerospace. But it will happen. It will happen. It needs to happen, and this should be one of our objectives in Generation IV International Forum as well.

Berta Oates
Thank you. We did have one more question come in while you were responding there. Are you following digital twins being combined with AI/ML?

Nawal Prinja
Absolutely! Digital twins just mimic what is happening. It's part of what I call augmented reality or virtual reality and absolutely. What we want to do with digital twins can be, decision making can be done through artificial intelligence and machine learning. There is a project with Exeter [ph] University that we are talking about where digital twins for dismantling of nuclear reactors could be created where we could enhance it with artificial intelligence. There are some very, very clever things.

For example, if you want to create a digital twin of a nuclear plant, you need full information, but full information is often not available. You only have snapshots. Then, you need to build a digital twin in

order to mimic what must be out there and a lot of decisions have to be made, a lot of trending has to be done, a lot of classification like, oh, this type of object will look like that and others. This is where artificial intelligence plays a huge role. Yes, absolutely. You are right. The two needs to be combined. Same as robotics need to be combined with AI. I will say digital twins or augmented reality – virtual reality needs to be combined with AI. Yes, thank you.

Berta Oates
Thank you. Thank you so much for sharing your time and your expertise with us. It was a delight to have you. I am privileged to have the second webinar experience with you, and I can't say enough great things about your presentations. You can tell from the long question and answer how much engagement there is. It's a greatly fascinating topic. Thank you, again, Dr. Prinja. Thank you very much.

Nawal Prinja
Thank you. Thank you for all the questions as well. Thank you.

Berta Oates
Patricia, do you have any closing thoughts?

Patricia Paviet
Yes. No. I would like to say thank you again to Professor Prinja. Excellent, you see. I can see now the other questions. We had approximately more than 20 questions. Great answers. Really a great Q&A session as always. These sessions are wonderful when we have presenters like Professor Prinja. Thank you so much again.

Nawal Prinja
Okay. Thank you, Patricia. Thank you.

Berta Oates
Have a great day everyone. Bye-bye.

Patricia Paviet
Good day, everyone. Bye.

END