Harnessing drone technology to map radiation around Chornobyl

Radiation mapping via manned aircraft suffers from low resolution and the potential exposure of the crew to harmful doses of ionising radiation. At the University of Bristol, Dean Connor is harnessing the power of drones to produce high-resolution maps of radiation around the Chornobyl Nuclear Power Plant. The work has identified previously unrecognised gamma radiation hot spots that pose a potential hazard to those exploring the region in person.

On 26 April 1986, during testing of a new voltage regulator, an explosion ripped through No. 4 reactor of the Chornobyl Nuclear Power Plant, causing what remains, to this day, the most severe release of radioactive material in the history of civil nuclear power generation, and what is considered the single worst nuclear disaster in human history. The accident, which stemmed from both flawed reactor design and operator error, killed two workers outright; and a further 28 died within weeks, suffering from the effects of acute radiation sickness. During ten days of emissions, unprecedented amounts of radioactive material were released, contaminating large areas of Europe as far away as the UK and Sweden.

Whilst the accident had far-reaching consequences (including ~6500 known cases of thyroid cancer), the area worst affected by radioactive contamination covers more than 4730 km^2 of modern day Ukraine and Belarus. The portion in Ukraine defines the Chornobyl Exclusion Zone, with the most contaminated area being the Red Forest, directly to the west of the powerplant. Even now, radiation levels within parts of the Red Forest are considered harmful to life.

In the 34 years since the accident, huge strides have been made in remote sensing capabilities. The technological development of both hardware and software, along with far greater understanding of image processing, have made it easier than ever for researchers to remotely study dangerous environments, with no risk to human health or life.

At Bristol University, Dean Connor is harnessing major technological developments in unoccupied aerial systems (UAS—colloquially known as drones) to rapidly collect high spatial resolution radiation mapping data without exposing the piloting team to harmful doses of ionising radiation. Over the last four years, Connor has used this technology to develop, direct and pilot drone surveys in the areas worst affected by both the Fukushima and Chornobyl nuclear accidents.

DRONING ON ABOUT RADIATION

In 2019, with support from the United Kingdom's National Nuclear Laboratory (NNL), Engineering and Physical Sciences Research Council (EPSRC), and National Centre for Nuclear Robotics (NCNR), Mr Connor and his colleagues, including Professor Nicholas Smith (NNL) and Professor Tom Scott (University of Bristol), were able to use UASs to map large sections of the area surrounding the Chornobyl Nuclear Power Plant. Their data reveal variations in the radiation dose rate, a measure of the amount of radiation absorbed by people if they were present on the ground. Until now, airborne detection has generally utilised manned aircraft, which are capable of covering large areas in a short period of time, but suffer from a low spatial resolution because of the altitudes they fly at; moreover, they are expensive and run the risk of exposing the crew to potentially harmful radiation.

Harnessing the power of drones to produce high-resolution maps around the Chornobyl Nuclear Power Plant.

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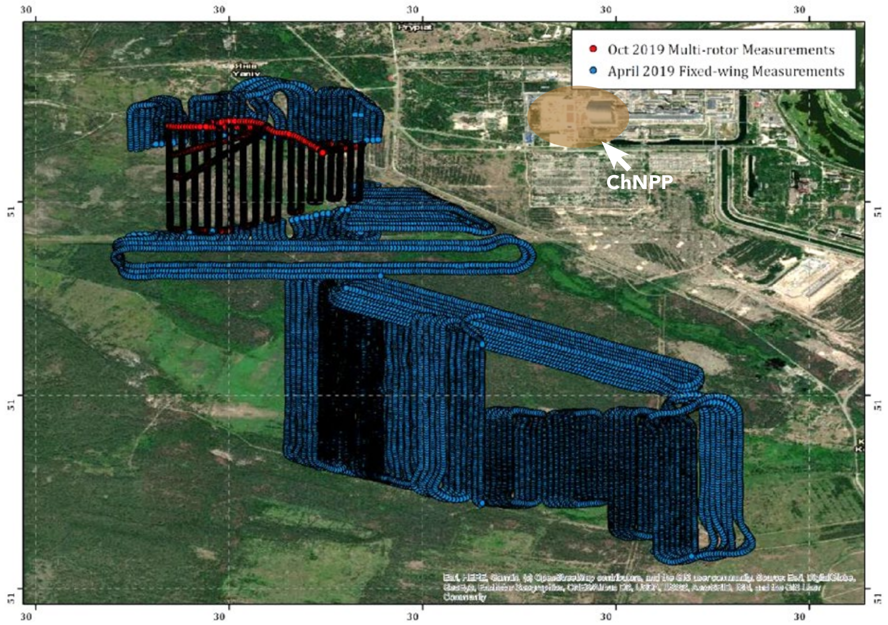
Radiation mapping using UASs has, to date, been limited by technological constraints—the drones have a range that is too limited for the work, or are too heavy to meet regulatory requirements. Mr Connor and his colleagues addressed these issues by selecting a lightweight fixed-wing (aeroplane-style) aircraft; at just 8.5 kg (and with a wingspan of 2.1 m), these drones are highly efficient, and are capable of staying airborne for more than 60 min at a time. The aircraft was hand-launched from different safe locations around the Chornobyl Exclusion Zone, whereupon it autonomously navigated a route around a predetermined area before returning to its take-off location. At this point, the pilot resumed control of the aircraft and brought it in for the landing phase, which was aided by the deployment of a parachute to descend the final 20 m.



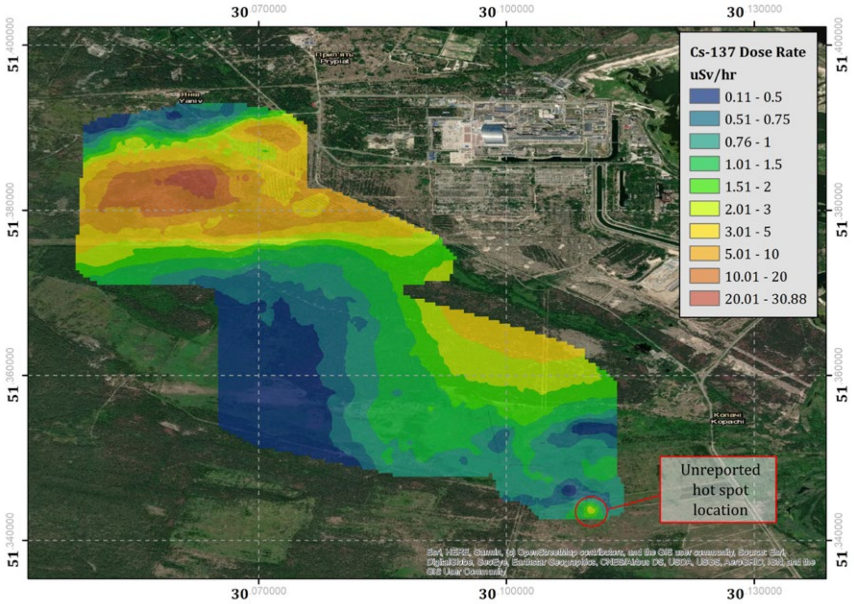
Remote sensing capabilities: two distinct areas within the Chornobyl Exclusion Zone mapped by unoccupied aerial systems (UAS). The blue data points show the data collected.

Over the course of 7 days, including more than 9 h and 580 km of in-flight surveying, the team successfully mapped approximately 15 km^2 of the area surrounding the power plant in high spatial resolution (~ 20 m per pixel)—by virtue of their low operating altitude, these fine-scale observations allow for the monitoring of small-scale changes.

PEEPING THROUGH 'SPECTRAL WINDOWS'

To process data collected by the drone, the team used a modified procedure based on the 'Spectral Windows' method, recommended by the International Atomic Energy Agency (IAEA) for manned aerial gamma surveys. Originally developed for manned aircraft, the spectral window method takes measured gamma radiation spectra and sorts them into an energy window histogram, within which given energies correspond to different isotopes.

The algorithms used for this method have been optimised for large-volume detectors with large gamma-ray energy



The ^{137}Cs equivalent dose rate of the area surrounding the Chornobyl Nuclear Power Plant. The location of the previously unreported hot spot location is labelled.

ranges (0 to 3 MeV); however, the volume (and detection efficiency) of sensors aboard UASs are limited by the strict weight limits. The main issue with low-volume detectors arises from their more limited gamma photon stopping power and hence sensitivity. To address this and other issues, Mr Connor and his colleagues chose to deploy two scintillation detectors (as opposed to only one solid state radiation detector used in their earlier systems). In 'semiconductor' detectors, incident radiation induces a current directly through ionisation of the active material, with the magnitude of the current proportional to the energy. In scintillation detectors, ionisation of a crystal releases a flash of light, the intensity of which is proportional to the energy deposited into the detector. By using two detectors, the team were able to increase the detection volume and offset reduced count-rates.

The study was the first to use fixed-wing drone radiation mapping in a real-world environment. The radiation maps produced by the survey are consistent with the findings of soil surveys and other ground-based studies, confirming the utility of the method. Soil surveys and other in situ studies are time consuming and expose personnel to ionizing radiation; in addition, they have a low spatial resolution and poor ground coverage that only allow the collection of data from limited numbers of sampling locations, and as such, often miss small-scale details. During the surveying, Mr Connor and his colleagues identified a previously unreported and intense hot spot approximately 5 km south of the power plant, highlighting the effectiveness of aerial mapping with UASs. This hot spot had a point-source geometry and was centred around an old agricultural metal structure. It is unlikely that this radiation is the result of natural post-disaster deposition; instead, it is theorised that this structure may have been used to sort or load contaminated material during the immediate clean-up response to the accident.

However, even after more than three decades, the intensity of radiation in the Chornobyl Exclusion Zone remains problematic—during an initial field campaign, intense radiation in the Red Forest saturated the detectors, leaving a gap in the data around a key area. Ultimately, such set-backs can be seen in a positive light, providing a driving force to further refine and improve the technology. A subsequent visit to the zone in October 2019 with a modified detection system managed to infill the gaps in the data to produce the most comprehensive and up-to-date maps of radiation in the Chornobyl region.

A LOFTY FUTURE

With the initial testing stage complete, Connor and his colleagues can now focus on optimising the system, which could also be used as a low-cost tool for mineral prospecting, particularly in developing countries with limited resources.

Despite recent advances in UAS systems, especially those that are lightweight, still suffer from a number of limitations. In particular, they are at the mercy of the weather, including wind and rain. Whilst they can be waterproofed for rain or snow, due to their light weight, UAS are unable to fly safely in storms or heavily unsettled weather due to the high windspeeds. This means that at present they cannot be deployed on every day they might be needed.

However, Connor and his colleagues believe that the benefits of the system far outweigh the limitations. The system developed in this study is small enough to be launched by hand and is recovered using a parachute system; that is, it does not require a runway, making it highly versatile and suitable for a wide range of environments.

Under optimal conditions, the drone can fly for up to 60 km in a single flight; with future developments in battery technology, this will further increase, allowing remote monitoring over even larger areas.

Finally, and perhaps most importantly for widespread adoption, the total cost of building and deploying the UAS is in the region of $24,000, a fraction of that needed for a manned survey; repeating the survey costs just $9,000. Each time the system is reused, the cost-benefit increases significantly compared with that of a manned aircraft system. With such an impressive capability, available at such a low cost versus manned aircraft, it is expected that the adoption of this technology in the global nuclear and mining industries will take off over the coming decade.

The system developed in this study is so small that it can be launched by hand and is recovered using a parachute system.

Behind the Research

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Research Objectives

Dean Connor is harnessing technological developments in UASs to rapidly collect high-spatial resolution radiation maps.

Detail

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Bio

Dean Connor is an early career researcher who has spent the last four years studying the use of drones to conduct airborne radiation mapping surveys. Over this time, he has directed and piloted a number of drone surveys in the areas worst affected by the Fukushima and Chornobyl nuclear accidents.

Professor Nicholas Smith is NNL University Lead and Fellow in geocharacterisation and remote laser and quantum sensing. He leads research collaborations and commercial engagement in geology, GIS, laser characterisation and 3D visualisation. He is a former Royal Society Industry Fellow, and holds a Visiting Professorship at the University of Manchester.

Professor Tom Scott holds a Royal Academy of Engineering Professorial Research Fellowship with expertise in materials, devices and instrumentation applied to nuclear energy challenges. With extensive experience in radiation detection, Scott runs a multi-million-pound programme of fundamental and applied research working closely with the nuclear industry, government and international partners.

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Collaborators

- Dr Kieran Wood
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- Erin Holland
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References

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Personal Response

Tourism in the CEZ has increased significantly in recent years (along with illegal incursions by so-called 'stalkers'); based on your results, are such activities safe?

" The major factors to consider when assessing radiological hazards and risks are the intensity of the radiation (the dose or exposure rate) and the exposure time. None of the areas we worked in during the fieldwork posed significant risks in terms of exposure, even over the extended time periods we were often working in them for. The areas tourists are shown exhibit relatively low intensity radiation and the time spent at each location is low, so the activities are safe. Our findings, however, show that detailed monitoring of the zone is required to ensure there are no other surprise hot spots near tourist routes in the zone. "

Where do you plan to test your system next? You mention possible use for mineral mapping—is this something you will be exploring further?

" That is certainly an avenue we are working towards. The challenges of mineral mapping with lightweight drones are that the gamma-rays emitted from the naturally occurring radionuclides in the earth, which are used to find mineral deposits, have a higher energy than those found in nuclear accident fallout. Our current small-volume detectors struggle to stop (and detect) enough of them passing through the detector to quantifiably map their intensity. We are currently looking at new detector systems and detection materials that would be able to appropriately complete this task without degrading our flight performance due to the extra weight required. It's a bit of a balancing act! "