A Map for the Future: Measuring Radiation Levels in Fukushima, Japan

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***Abstract*—After the cataclysmic explosion in the Fukushima Daiichi Nuclear Power Station triggered by the Great East Japan Earthquake of March 2011, more than 100,000 citizens living within 20km of the nuclear power station were evacuated. These residents were not allowed to return home for more than a year, until April 2012, when the Japanese government began to lift the evacuation order for some areas. As local governments contemplate strategies to revive these communities, a lingering question remains: how safe is it to live here?**

Answering this question is difficult for a number of reasons. Our project aims to provide data to allow individuals and communities to make their own assessments. The Radioisotope Center (RC) in Niigata University has built a vehicle-mounted radiation monitoring system consisting of a real-time GPS receiver, a dosimeter, and a laptop. This tool allows government officials in the affected municipalities to continuously measure airborne radiation levels. RC has partnered with the Institute for Digital Research and Education (IDRE) from the University of California, Los Angeles (UCLA) to develop a public web-based interface to this data to inform citizens about radiation levels in their communities. Both of these tools enable gathering and making data available to the general public more easily, and allow the public to make informed decisions about the safety of the decontaminated zones in the absence of widely-accepted standards.

Keywords-crisis mapping, GIS, disaster response, nuclear, earthquake, tsunami, radiation, radiation measurements, Fukushima Daiichi nuclear power plant accident

I. RATIONALE

Figure 1. BISHAMON project leader Professor Naito in Namie City (5 km from nuclear power plant).

Communities ravaged by the Great East Japan Earthquake are slowly recovering through reconstruction efforts, but the 20km evacuation zone surrounding the Fukushima Daiichi Nuclear Power Station (shown in Figure 1) has become a no-man's land, a barricaded, desolate space largely left uninhabited since March 11. At the time of the disaster, various contamination hazards in the form of radioactive isotopes were released from the Fukushima Daiichi Nuclear Power Station. Notably, ^{131}I and ^{137}Cs were discharged into the atmosphere, totaling an approximate 1.5×10^{17} and 1.3×10^{16} Bq, respectively [1], rendering the area unsafe for human life. This 20km zone has been off-limits to the more than 100,000 residents forced to evacuate following explosions at the nuclear power station.

Starting in April 2012, local governments from several municipalities that fall within this zone have begun to lift the ban on entering some of these areas, allowing some residents to return to their homes. The affected communities face a particular problem due to both a lack of information and the difficulty of interpreting it. There are no widely accepted standards for safe radiation levels [2-6]. Additionally, radiation readings can be inconsistent, varying greatly between indoors and outdoors. Diffusion patterns can be difficult to predict. Cities and individuals are faced with difficult choices about reopening areas and returning to homes.

In an effort to provide aid to governments and residents of these communities, we have designed a vehicle-mounted radiation monitoring system called "BISHAMON" (BIo-Safety Hybrid Automatic MOnitor-Niigata) that can continuously capture readings and location data.[1] Coupled with a web-based interface, the BISHAMON measuring device intends to help the affected communities by measuring the amount of gamma radiation, generating maps of radiation levels, and making them widely accessible to the public. BISHAMON enables municipalities to gather their own readings and develop their own processes for monitoring radiation in their communities. With this information, local communities and individuals can make informed decisions.

The BISHAMON project's goals are:

- To provide local governments with both vehicle-mounted monitoring equipment and training on how to measure radiation levels in a spatially-consistent and periodic fashion
- To make the findings available to the public via interactive web maps
- To help government officials make decisions on decontamination and opening evacuation areas
- To evaluate effectiveness of decontamination overtime

In the aftermath of the disaster, two other projects were also established to measure radiation levels, KURAMA [7-9] and SAFECAST [10]. BISHAMON complements these other projects and has significant strengths compared to both. KURAMA, a system put together by Kyoto University, uses a NaI (sodium iodide) and CsI (caesium iodide) scintillation detector which can measure gamma-rays. KURAMA is used as a standard for vehicle driven measurements by the Fukushima Prefectural Government and by MEXT (Ministry of Education, Culture, Sports, Science and Technology). KURAMA's accuracy in measuring dose rates is similar to BISHAMON's, but BISHAMON works at a more local scope, with pilot projects in three cities affected by the disaster: Minamisoma, Namie and Naraha. BISHAMON emphasizes detailed measurements in contrast to KURAMA's larger scope, prioritizing routes commonly used by children commuting to school. Additionally, BISHAMON's data is open to the public. While KURAMA's data is also open, their newest data is available only to a limited audience (e.g. city officials) through password-protected domains.

The other project, SAFECAST, also emphasizes open data through crowd sourcing. SAFECAST, a volunteer organization, was established one week after the Fukushima nuclear disaster. It relies on crowd sourced geiger counter readings, collecting vast amounts of data that cover the entire country. The collected data is then compiled and published through a web map interface. While this represents a valuable effort, radiation readings vary significantly between indoor and outdoor locations and based on other environmental factors, so crowd-sourced data can be unreliable. In contrast, BISHAMON focuses on a targeted area—the area most affected by the disaster—and emphasizes methodological consistency. While BISHAMON involves communities in data gathering, we train officials from local governments to use devices designed specifically to address problems with gathering consistent data. This data is monitored by public health experts, nuclear physicists, and the other researchers at Niigata University. BISHAMON provides accurate data collected by those who know the affected areas best and analyzed by experts who know the topics best, which enables users to make informed decisions about the safety of their communities.

II. BUILDING THE AIRBORNE RADIATION MONITORING SYSTEM

In designing the BISHAMON measuring device, we wanted to build a device that could take readings in a variety of areas with high accuracy without requiring an expert operator. We designed the device so that local government officials—those directly responsible for making decisions about safe areas—could direct and participate in the data gathering. While the BISHAMON team performs a significant amount of analysis on the data, city governments may choose the areas to monitor, so producing data involves a cooperative effort between local governments, public health experts, and nuclear physicists.

Figure 2. The BISHAMON system mounted in a vehicle

The BISHAMON measuring device, shown in Figure 2, fits in the back of a compact car. It is composed of a survey meter, a GPS receiver, a data acquisition device (DAQ) and a laptop computer. The survey meter used is a NaI(Tl) scintillation survey meter (TCS-161 or TCS-172 [11]) produced by Hitachi

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[1] BISHAMON, the God of Warriors in Japanese folklore and mythology, represents one of the Seven Gods of Fortune; BISHAMON guards places and, we felt, was an appropriate symbol for a project to protect the citizens of Fukushima.

Aloka Medical, Ltd. These devices have energy compensation circuits capable of reading wide energy ranges of 1cm dose equivalent rates (Sv[Sieverts]/hour). The DAQ (model USB-6210 [12]), manufactured by National Instruments Corporation, records the voltage output produced by the survey meter. The DAQ and GPS receivers are both connected to a laptop via a USB connection. A custom application takes in the voltage measurements from the DAQ and translates them into dose rates (Sv/hour). It then takes readings from the GPS receiver every second in the form of NMEA sentences, a combined electrical and data specification standard. The NMEA sentence includes latitude, longitude, speed and altitude measures; the dose rates calculated from the DAQ and the NMEA sentences are combined and outputted as text files by the application (Figure 3). The converted text files are later imported into a Geographic Information Systems (GIS) program to conduct spatial analysis and generate choropleth maps.

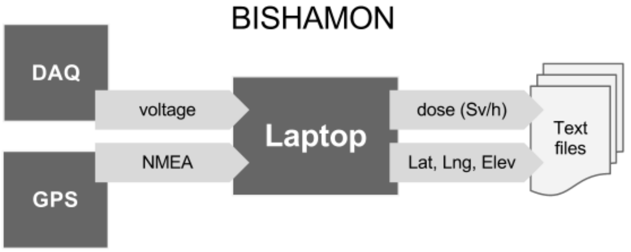


Figure 3. Data from the DAQ and GPS devices are compiled by a custom application and eventually exported as text files

The BISHAMON is mounted on a tray that can be loaded into a vehicle. Once turned on, the monitoring application records radiation levels at a given time interval, allowing a vehicle to drive through a community and gather accurate readings along its route without further interaction from an operator. Once the data has been gathered, we applied procedures to compensate for inaccuracies in the sampling process. The values of dose rates measured from within a vehicle are determined to be underestimations, as the body of the car, doors, or even windows, can reduce the device's exposure to airborne radiation. Thus, a correction rate of 1.3 is used to adjust the indicated radiation values from within the vehicle. This rate was determined based on thorough scientific verification by the team. The BISHAMON can also be carried manually, allowing the team to walk through targeted areas such as school grounds to record readings in places that vehicles cannot otherwise enter (Figure 4). In this case, the compensation rate is not applied. All measurements in the car or on foot are conducted one meter above ground.

A sample output from a round trip drive conducted on April 14, 2012 from Niigata and Minamisoma City is shown in Figure 5. The total round trip distance covered was 480 km. Measurements from within Minamisoma City are clustered at the midpoint (around the 10,000 point mark). Results appear to be mirrored at the midpoint as a result of taking the same route back to Niigata. Dose rates rise until they hit their peak in Iitate (a village next to Minamisoma city, in Fukushima Prefecture), and drop considerably within the city of Minamisoma.

Figure 4. The BISHAMON system is taken out of the vehicle and carried around an elementary school by foot

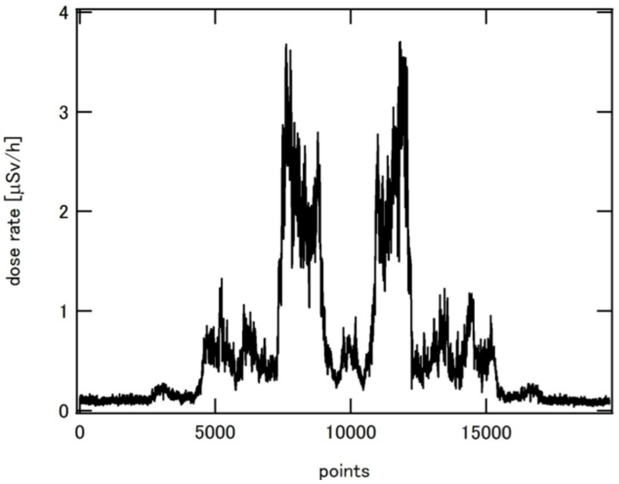
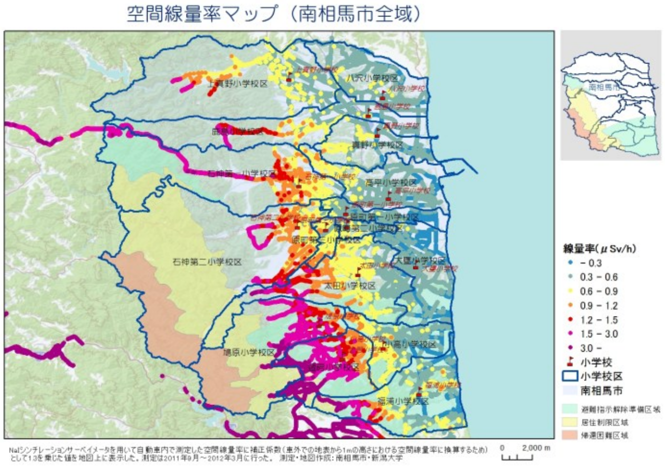


Figure 5. The custom application records a point every second of this 480km drive from Niigata to Minamisoma

We began the data collection process in the summer of 2011 on vehicle and foot, focusing on routes that children use to commute to school. At the time that this report was written, the data collection process has been conducted over multiple trips to various communities both in- and outside of the 20km evacuation zone, between September 2011 and April 2012. All in all, more than 700,000 readings have been collected. We have been training city government officials on how to use the device, and initial runs by these officials have resulted in expanding the areas we survey.

We have used a couple of approaches to publishing the data. In the case of Minamisoma City, the first step was to create a series of static maps that were then published on their governmental web site, which summarized the initial data collection. Our second phase of the project, however, is to create a web site that provides more direct access to all the data BISHAMON has collected, along with several components for interpreting that data.



NaIシンチレーションサーベイメータを用いて自動車内で測定した空間線量率に補正係数（車外での地表から1mの高さにおける空間線量率に換算するため）として1.3を乗じた値を地図上に表示した。測定は2011年9月～2012年3月に行った。 測定・地図作成：南相馬市・新潟大学

Figure 6. Radiation levels in Minamisoma city.

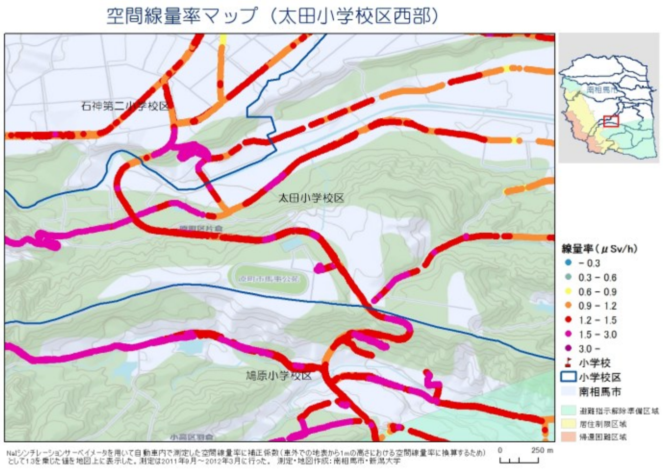


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Figure 7. Radiation levels in the Ota school district, in Minamisoma city (8.6 km from the coast).

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Figure 8. Radiation level in the Omika school district, in Minamisoma city (2 km from the coast).

For example, Figure 7 shows one of the generated maps for the western region of the Ota Elementary School District, located just outside the 20km evacuation zone and 8.6km from the coast, showing many readings with high levels of radiation (over 1.2 μSv/hour). In contrast, Figure 8 shows part of the Omika School District, also just outside the 20km evacuation zone and 2km from the coast, showing many readings with low levels of radiation (under 0.3 μSv/hour).

These maps yield a geographic spread of radiation inconsistent with the circular, no-entry buffer zone mandated by the government. While much of the area inside the zone shows high readings (greater than 1.2 μSv/hour), large pockets of terrain on the north side (Minamisoma City) reveal equally high levels of radiation. Geographic factors such as elevation and slope affect radiation levels, and climate factors such as precipitation and wind can impact readings. This illustrates the need for local data gathering by groups familiar with the area, as well as the need for individual decisions: not only are readings difficult to interpret, but it can be difficult for a single authority to make decisions about many small communities which may be affected differently.

III. THE WEB INTERFACE

While the static maps provide snapshots of changes in radiation levels over time, such snapshots have their limits. We also built an interactive, dynamic web map application to provide greater access to detailed data. A web map allows users to hone in on particular points and view certain parts of the data in greater detail, even down to the level of the individual reading. Additionally, it can be updated with greater frequency as cities contribute new readings. Our web map attempts to provide the most accurate data possible and to allow users to make informed decisions about the safety of the affected areas.

Developing an accurate, yet accessible, method for visualizing the data proved to be a significant challenge. Providing users with maps that were easy to interpret also threatened to interpret the data too much. In some cases, it led to inaccurate presentation of the data. Initially, we considered providing estimations of radiation levels inferred via spatial statistical techniques. This early version provided a surface estimation of radiation levels for areas around the actual measured coordinates using an interpolation method called inverse distance weighting (IDW). IDW assigns values to unmeasured locations based on the values of surrounding points, taking into account the weight (in this case, the radiation level) and proximity of those points. Applying this technique creates a seamless image, as shown in Figure 9.

However, this method did not take into account a variety of factors. As all measurements were conducted in an outdoor environment, usually on the road, this method may not reflect levels inside buildings. It also conceals the actual times and locations of the readings, which is especially important because environmental factors can affect radiation levels: measurements taken on snowy days tend to be lower because accumulated snow reduces gamma ray levels. While IDW is a widely accepted statistical interpolation method, we made the decision to exclude all estimations for areas not directly recorded.

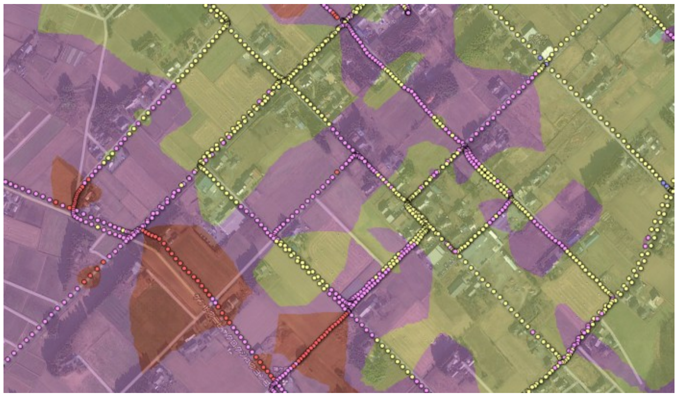

Figure 9. Radiation levels inferred for areas not directly measured

We decided that providing access to the actual points measured by BISHAMON rather than spatially-interpolated maps was a better practice for the project because it made our methodology clear. Access to the individual readings provides general guidance to users, but also highlights the provisionality of our readings and the need for users' own careful interpretation of the data. While we are confident in the accuracy of our readings, the variations caused by environmental factors illustrate the need for continuous and thorough monitoring by municipal governments, which BISHAMON provides.

Additionally, as no standard for safe levels of radiation is universally accepted, providing access to fine-grained readings is important to allow communities and individuals to make informed decisions. The lack of a standard is well-known: in 2007, the International Commission on Radiological Protection (ICRP) set the maximum annual radiation exposure levels for citizens at 1 mSv (1,000 μSv), excluding background radiation and radiation from medical treatment [4]. Under this guideline, many governments have deemed that areas with an annual radiation level above 1 mSv (the equivalent of 0.23 μSv per hour) are unsafe. In October 2011, the Japanese Ministry of Education announced a "hot spot" standard of 1 μSv per hour. Accordingly, many cities have adopted their own standards.

Therefore, we decided to build a web map that did not have to adhere to any particular standard for safe radiation levels, but allowed the user to evaluate data easily against competing standards. We built a Google Maps application that emphasizes three UI components: a zoomable information layer for displaying readings at many different levels of detail (#1 in Figure 11), a slider for selecting breakpoints for the coloring of the radiation layer (#2 in Figure 11), and a set of information layers from other sources (#3 in Figure 11). These three items, we felt, were crucial for helping users to interpret BISHAMON's data.

Given the varied standards [3] for safe levels of radiation, and the potential variations in reading levels, we felt that it would be better to provide an interface that gave users access to the readings as directly as possible. Data collected by the measuring device are exported as CSV files into desktop GIS software. With the software, data points are grouped by month and by quarter to provide snapshots, which indirectly accommodates seasonal environmental factors. To compensate for the vast number of data points, a grid system approach was implemented. Grids of 50, 100, 200, 400, 800, 1600, and 3200 meter cells were generated, and spatial analysis was conducted to calculate the average airborne radiation level for each cell (Figure 10). The layers were then imported into Google Fusion Tables, which has an API for providing data directly to Google Maps. Each cell is assigned a color indicating its radiation level, which represents a summary of that area, but this is a summary forced by scale. Additionally, clicking on any grid cell displays the radiation level of that area (#4 in Figure 11).

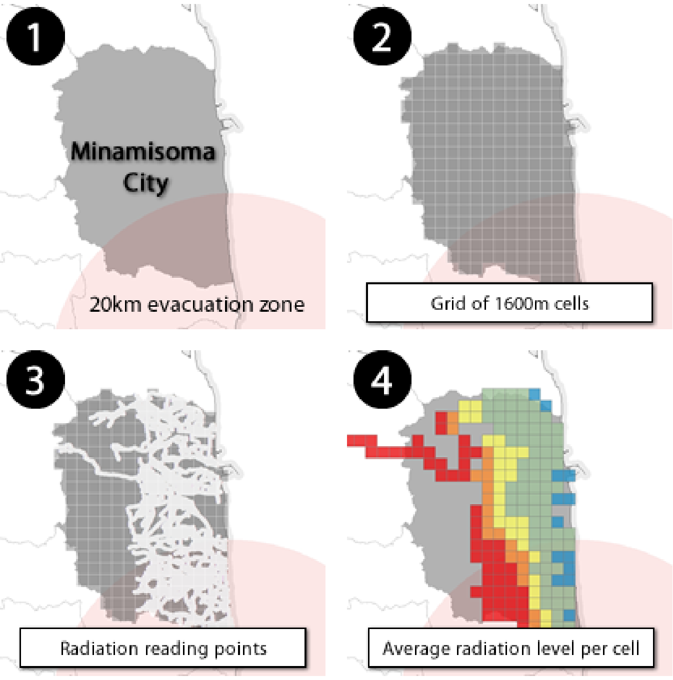

Figure 10. Data is displayed as average values per cells in predefined grids

The second significant component is a slider that adjusts the colors assigned to different radiation levels in each cell. If a user decides to investigate which areas fall within other standards for safe levels of radiation, the slider allows him or her to do so. While the map suggests an initial danger level of 1.2 mSv per hour, the user may adjust that level to 1.0, or any other value. Our web interface allows the user the freedom to investigate BISHAMON's data from different perspectives.

The web map also includes overlays reflecting official government data, such as safe entry zones. These varied data sources allow users to access a variety of information. The web map therefore serves as a tool for disseminating and comparing information from a variety of sources. Together, these three components provide a flexible means of accessing and interpreting a variety of data, with the goal of helping users to make informed decisions.

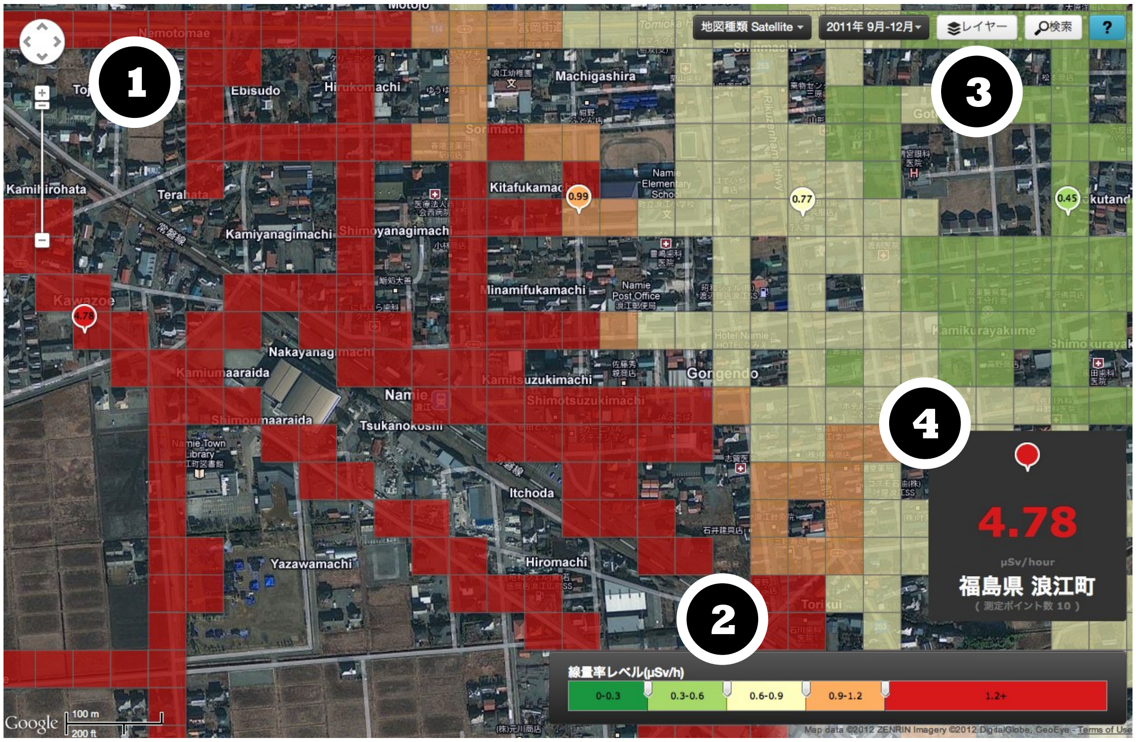

Figure 11. The user interface for the website

IV. CONCLUSION

A year after the nuclear disaster, the eleven municipalities forced to evacuate their populace are slowly lifting their entry bans, allowing residents to finally return to their homes. The safety of these residents, both short term and long term, are of major concern and under close scrutiny by the Japanese people, as well as the international community. With little precedence for similar catastrophes in our history, much remains unknown about the implications for public health, long term radiation effects, and the general safety of the community. In the absence of national standards for measuring radiation levels over time, affected communities continue to make painstaking efforts to decontaminate surfaces, but residents are made to seriously contemplate the safety of continuing life within these confines. BISHAMON is intended to assist with these efforts by empowering cities to gather their own data and users to make their own judgments.

ACKNOWLEDGMENT

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