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WEB SITE APPLICATION FOR CALCULATING CESIUM-137 INGESTION DOSES FROM CONSUMPTION OF LOCALLY GRWON FOODS IN THE MARSHALL ISLANDS

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Abstract

Fallout deposition from the U.S. nuclear weapons test program at Bikini and Enewetak Atolls (1946-58) resulted in widespread nuclear fallout contamination of the northern Marshall Islands. About 85-90 % of the nuclear test-related dose delivered to resident populations is derived from ingestion of cesium-137 (^{137}Cs) contained in locally grown tree-crop food products. The Lawrence Livermore National Laboratory (LLNL) has developed a series of interactive internet applications to provide the public with an open access platform to learn more about radiological conditions in the Marshall Islands. The ingestion dose calculator application described here is one such feature whereby users can calculate hypothetical ingestion doses from ^{137}Cs based on interactive user input matched to environmental data on the activity concentration of ^{137}Cs contained in food plants such as coconut, breadfruit, *Pandanus,* and arrowroot. Users are asked to enter a date, an island and atoll location, a plant food type, and a daily intake amount (highlighted by the number of portions eaten per day in estimated gram equivalents). The application computes the user daily dose and the user equivalent annualized dose, and then compares the results with default settings based on dietary models developed for the Marshall Islands from independent dietary surveys. The default diets are based on a local plus imported food diet (or IA diet model) and an imported foods unavailable diet (or IUA diet model). Environmental data are decay corrected to the date entered by the user using an effective half-life of ^{137}Cs of 8.5 years (http://marshallislands.llnl.gov).

Keywords Web application for calculating ingestion doses from cesium-137 ⋄ Republic of the Marshall Islands ⋄ Bikini Atoll ⋄ Enewetak Atoll ⋄ Rongelap Atoll ⋄ Utrōk Atoll ⋄ ^{137}Cs ⋄ Coconut ⋄ *Pandanus* fruit⋄ Breadfruit.

Introduction

The Marshall Islands Dose Assessment and Radioecology Program at the Lawrence Livermore National Laboratory (LLNL) was originally established during the mid-1970s to characterize the nature and extent of residual fallout contamination resulting from the U.S. nuclear test program (1946-58) at Bikini and Enewetak Atolls in the northern Marshall Islands.[1] These large-scale, screening surveys were designed to determine the activity concentration of fallout radionuclides in the marine and terrestrial environment, provide detailed aerial reconnaissance of external gamma exposure rates, and assess the radiological dose delivered to resident populations, future residents of uninhabited atolls, or to those who visit any of the atolls and consume local foods. Dose assessments conducted for Bikini and Enewetak Atolls during the early 1980s clearly showed that the most significant pathway was ingestion of ^{137}Cs contained in the terrestrial food chain.[2-3] These data and information also provided the technical and scientific framework to evaluate the effectiveness of various remedial measures designed to reduce or eliminate the uptake of ^{137}Cs in locally grown plant foods such as coconut (*Cocos nucifera* L.).[4-5]

Today, the continuing LLNL program is focused on providing updated data and information on the levels and distribution of persistent fallout radionuclides in the environment-especially through pertinent food chains, tracking the rate of change in radiological conditions, assessing effectiveness of remedial measures, and building public trust in support of sustainable resettlement programs.[6-8] Large-scale grid survey characterization of islands and atolls has largely been replaced by pantry sampling strategies in order to mimic the present-day use of island resources across individual atoll communities, provide a basis to assess future change in radiological conditions through repetitive sampling of food products taken from individual trees, and to study the potential impacts of expanded use of small pantry islands on radiation doses delivered to resident populations. The pantry sampling program recognizes that food security is a key concern for many remote atoll communities in the Marshall Islands.[6] As part of our strategy to improve communications about radiological conditions in the Marshall Islands and provide open disclosure of data and information, we have developed an interactive web-based application for users to assess hypothetical doses from ingestion of ^{137}Cs on various islands and atolls in the northern Marshall Islands. The application computes applicable radiation doses delivered to an

adult (>18 years) in a table format. The table output shows the atoll name, island name, date, and the computed hypothetical radiation doses based on the prescribed intake scenarios (single and equivalent annualized intakes), and for the local plus imported food diet (IA) and imported foods unavailable (IUA) diet models. Environmental data contained in the data base are decay corrected to the date entered by the user using an effective half-life of ^{137}Cs of 8.5 years (http://marshallislands.llnl.gov).

Methods

The web-site application functions using a combination of Google Maps API code, PHP, JavaScript, and HTML. On entering the site, a map of Rongelap Island is displayed along with a drop-down menu linking to maps of islands and atolls in the northern Marshall Islands. The data collection and mapping feature is limited to the four main nuclear affected atolls of Bikini, Enewetak, Rongelap and Utrōk (also known in the literature as the 'four atolls'). Data markers on the map represent site locations in the database containing available measurement data on the activity concentration of ^{137}Cs in food plants. Each data marker contains information such as the GPS site coordinates, the measured activity concentration of ^{137}Cs in Bq g^{-1} (wet wt.), the date the item was collected, the island designator, and a category descriptor on the type of plant food or fruit, e.g., drinking coconut meat, drinking coconut juice, copra meat, copra juice, *Pandanus* fruit (*Pandanus* spp.), breadfruit (*Actocarpus* spp.) or Polynesian arrowroot (*Tacca leontopetaloides*). Users may select a specific location on an island, a whole island, or multiple islands on an atoll by drawing a rectangle on a map containing at least one measurement data point. Once users are satisfied with their selection, a 'submit' window will open an input table.

The input table allows the user to enter a date, and the number of hypothetical daily servings of food consumed for each food group or type. For the purposes of this web-site application, we have loosely followed what constitutes a standard serving using guidance developed by the U.S. Department of Agriculture (USDA) under the Food Guide Pyramid, and by the Nutrition Facts label under the regulation of the U.S. Food and Drug Administration. For milk type products such as drinking coconut and copra juice, we designate a standard serving as 1 cup or 226 g. For all other food plant products, we consider a standard serving as a ½ cup or 113 g. The web-site also uses a series of default settings to compute an annual effective dose (milliSievert, mSv per year) for the food plants selected using a model diet consumption table. The diet models consider living patterns where imported foods are either available under a local plus imported food IA

model diet or imported foods unavailable under a IUA diet model (after Robison et al.).[9] Daily intakes (g d^{-1}) for a range of food plants based on the IA and IUA diet models are presented in Table 1.

Table 1. Marshall Islands diet model survey data for adults (> 18 y).[12]

Local Food	Daily Intake (g d^{-1})	
	Imported Food diet (IA)	Local foods only diet (IUA)
***Pandanus* fruit**	8.66	63.0
Breadfruit	27.2	186
Coconut juice	99.1	333
Drinking coconut meat	31.7	181
Coconut milk	51.9	122
Copra meat	12.2	71.3
Arrowroot	3.93	94.9

After entering the relevant information and hitting the 'submit' button, the web-site application runs a ^{137}Cs dose algorithm as described below.

$$\text{Effective Dose } (\mu\text{Sv}) = \sum_{x=1}^{x=n} [\text{C x } \exp(-\lambda_{eff}\text{t})] \text{ x (CA x DCF)} \quad \text{(Single Intake)}$$

where,

C = Activity concentration of ^{137}Cs in the food group (Bq g^{-1}).

CA = Consumption amount (g)

DCF = Committed Dose Equivalent per unit intake (Sv Bq^{-1}) (after ICRP 67).[10]

t = Number of days between sample collection and consumption.

λ_{eff} = Effective half-life decay constant for ^{137}Cs in vegetation ($\lambda_{eff} = 0.000223$)[11]

n = Number of individual food types consumed.

For user annualized and model diet dose calculations, the consumption amount is replaced with the daily intake rate (g d^{-1}) multiplied by 365 (days in a year) to give the annual effective dose (mSv y^{-1}).

To enable users to select multiple areas on multiple islands and atolls, the application assigns each user a random session identification number upon opening the website. Each calculated

dose is stored until the user ends the session or leaves the website, at which point the user's session identification number and information are deleted.

Results and Discussion

The radiological dose from the ingestion pathway scales directly with the total intake of radionuclides, and is directly proportional to the activity concentration of radionuclides contained in the food and the quantity of food consumed. Previous dose estimates show that consumption of locally grown foods make up a significant contribution to the total intake of radionuclides, and that the dose delivered is dominated by ingested ^{137}Cs. Information developed from this web-site therefore provides a reasonable first approximation of the total nuclear-test related dose from exposure to nuclear fallout contamination in the Marshall Islands based hypothetical dietary scenarios.

Figure 1 and 2 show example 'input' and 'output' tables generated by users of the web-site application. Users may select a subsection within an island, a whole island or multiple islands. The only stipulation is that the selected area must contain at least one data point for one of the listed food types. The dose calculation output table contains the user input daily intake effective dose (μSv), the user equivalent annualized effective dose (mSv y^{-1}, based on the daily intake × 365 days) along with the annual effective dose (mSv y^{-1}) computed for the same food products using IA) and IUA diet models. The tabulation of data from the IA and IUA model diets is done to give application users some insight into what is considered a reasonably achievable or practical dose limit.

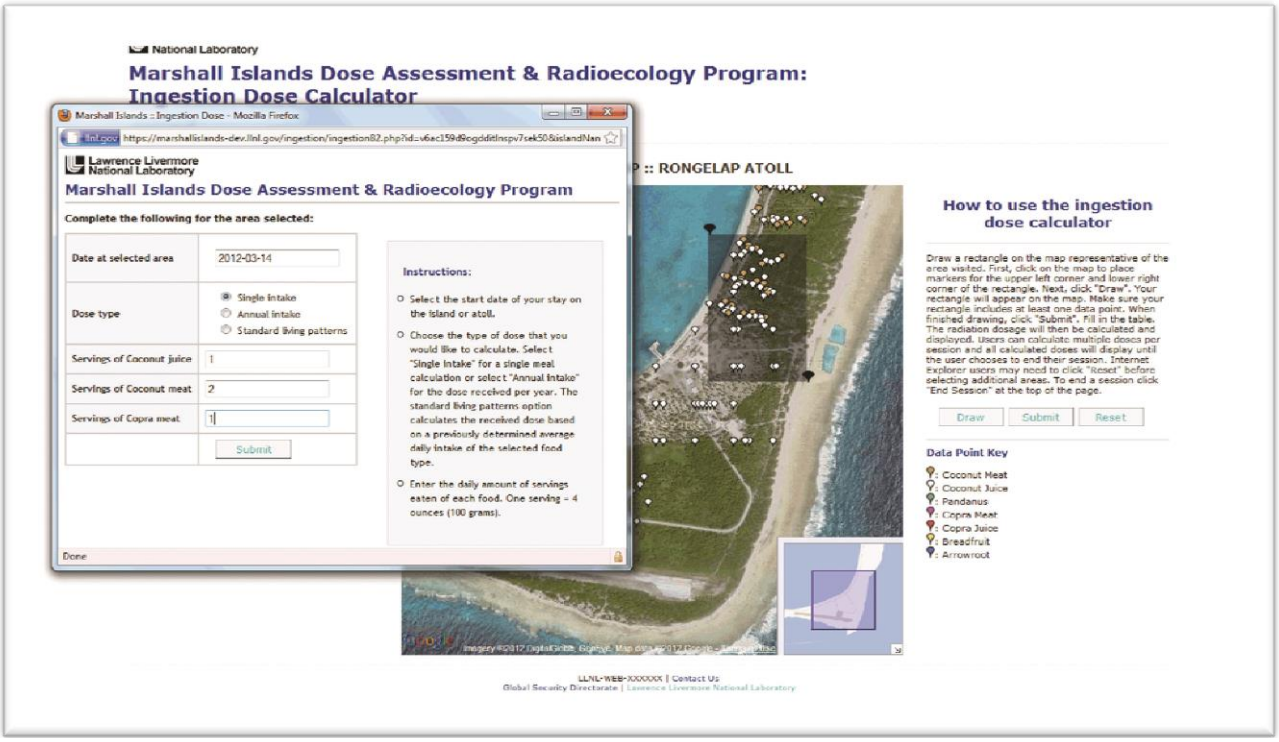

Figure 1. Users enter date and the number of daily portions consumed (based on 1 cup for fluids or ½ cup for all other products).

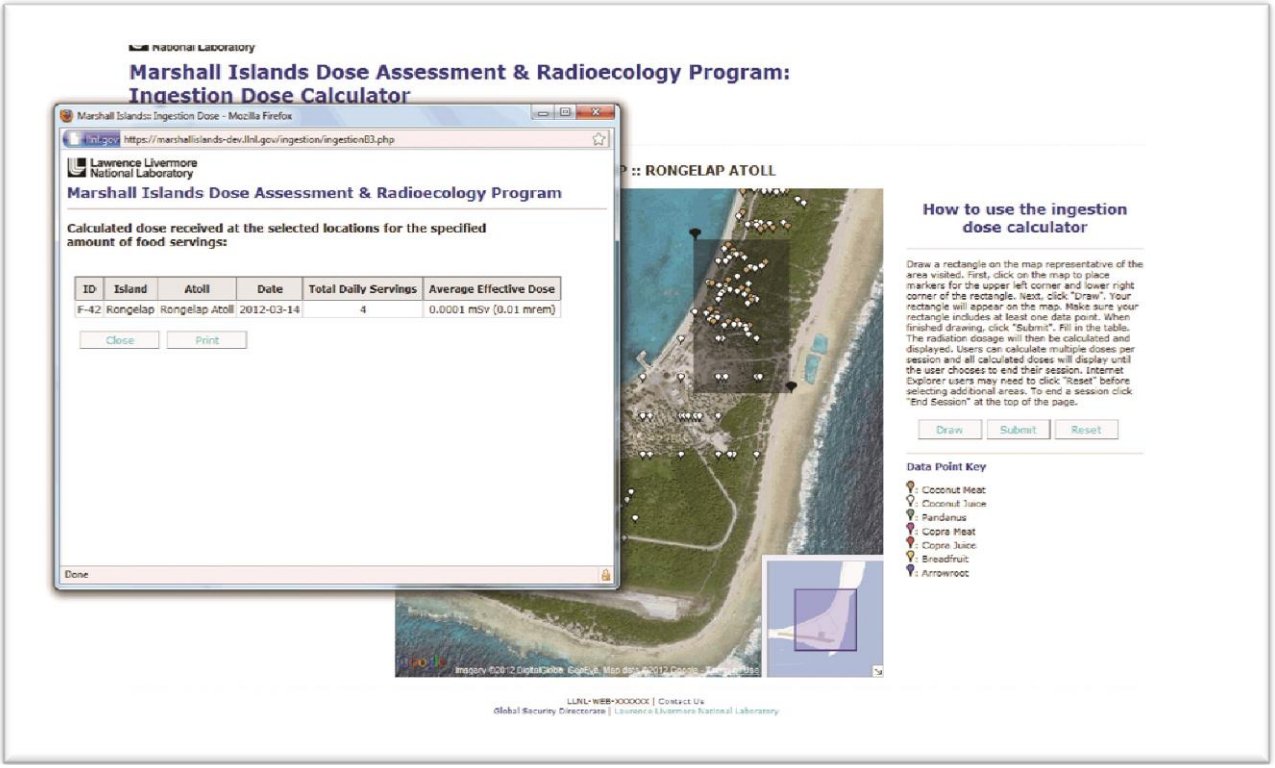

Figure 2. The ^{137}Cs dose algorithm computes a user daily dose (μSv), and a user equivalent annualized dose (mSv y^{-1}) along with the annual effective doses (mSv y^{-1}) based on the IA (imported food available) and IUA (imported foods unavailable) diet models for consumption of the same food products over 365 days.

Today the people of Rongelap Atoll are moving closer to making a final decision on resettling of their home atoll.[8] Based on simple dietary scenarios, this web-site application can give prospective residents a sense of the radiation doses that they may experience on Rongelap and allow a self-assessment on how these levels might compare with national and international standards in radiological protection. Take for example two people living on Rongelap – one person consumes drinking coconut juice and meat based on the IA diet model, and the second individual consumes drinking coconut juice and meat more consistent with intakes derived from the IUA diet model. The model derived annual effective doses in this scenario will 0.01 and 0.02 mSv y^{-1}, respectively. If the same two individual were to consume the same amount of drinking coconut juice and meat from Kabelle Island, the annual effective doses (based on the available measurement data through year 2011) will be 0.02 and 0.07 mSv y^{-1}. Kabelle Island is located on the northern reaches of Rongelap Atoll where levels of contamination are known to be higher. For comparison, the annual effective dose under the IA and IUA diet models on Enewetak (using averaged measurement data for the three main residence islands of Enewetak, Medrin and Japtan) and Utrōk Atolls would be 0.001 and 0.0054 mSv y^{-1}, and 0.005 and 0.02 mSv y^{-1}, respectively.

Taking another example, if two individuals were to live on Bikini Atoll with one person living on Eneu Island and the other on Bikini Island under current conditions (year 2012), and each person consumed equal portions of coconut meat equivalent to the intake rates described under the IA model diet, then the individual living on Bikini would receive an estimated dose that is a factor of 24 × higher (about 0.1 mSv y^{-1}) than the individual living on Eneu Island (0.004 mS y^{-1}). This information makes clear that radiological conditions on Eneu Island are already considerably 'safer' than those on Bikini Island. This information could provide options for the people of Bikini to at least start considering limited resettlement of their home atoll while actions are taken to reduce levels of radiation exposure on Bikini Island. For example, treatment of agricultural areas with potassium has long been presented to atoll communities as a viable, effective and practical option to reduce leaves of ^{137}Cs uptake into locally grown food products.[4,

[12] The effectiveness of potassium treatment of agricultural areas on Bikini Island in reducing the ^{137}Cs activity concentration in edible tree crops and fruits has been clearly demonstrated in large-scale field experiments.[13] Based on these experiments, the addition of about 2000 kg potassium per hectare is expected to reduce ^{137}Cs concentrations in coconut meat by a factor of about 20 on Bikini Island, by a factor of 7-8 on Enjebi Island at Enewetak Atoll, and by a factor of about 3 on Rongelap Island at Rongelap Atoll. This in turn will significantly reduce the ^{137}Cs ingestion dose from eating locally grown foods. In this case, using the simple scenario given for Bikini Island, the potassium treatment will likely reduce doses on Bikini Island down to levels similar to that on Eneu Island and well within the range of accepted reference levels for cleanup. Rongelap Atoll is likely to move towards resettlement in the very near future, perhaps as early as year 2013. Resettlement of Bikini and Enjebi is not under consideration at this time so doses presented here are likely to be considerably less depending on the actual resettlement date. This web-site application could also be used as a predictive assessment tool to allow individuals to make a more informed choice on when in the future radiological conditions on Bikini (or other impacted islands or atolls) might be more acceptable to them to consider possible resettlement options. Future updates of this web-site will include a hypothetical potassium treatment option.

Currently, there is no explicit international guidance for establishing action levels associated with chronic exposure situations, such as a dose standard or concentration limit for exposure to residual fallout contamination resulting from nuclear weapons testing outside of recommendations of the International Commission on Radiological Protection (ICRP) to protect people living in long-term contaminated areas after a nuclear accident or a radiation emergency.[14] The Commission recommends that reference levels should be used in conjunction planning and implementation of an optimization process to reduce levels of radiation exposure under sustainable living conditions. Based on past experiences, typical dose values for managing existing exposure conditions should be close or equal to 1 mSv y^{-1}. This reference level provides a level of consistency with accepted guidelines for general protection of the public from radiation exposure as promoted by the National Council on Radiation Protection and Measurements (NCRP)[15], and the ICRP.[16] Both of these agencies have adopted a public annual effective dose limit based on stochastic effects of 1 mSv for continuous exposure. However, the government of Republic of the Marshall Islands (GRMI) has adopted a cleanup standard based on an annual

effective dose of 0.15 mSv y^{-1} based on guidance outlined by the U.S. Environment Protection Agency (EPA) for cleanup of superfund sites within the United States. This simple web-site application demonstrates that this more restrictive GRMI cleanup standard is readily achievable under current conditions for former residence islands in the northern Marshall Islands with the possible exceptions of Bikini Island on Bikini Atoll, and Enjebi Island on Enewetak Atoll.

Conclusion

The Marshall Island program is focused on providing updated data and information on the levels and distribution of persistent fallout radionuclides in the environment-especially through pertinent food chains. About 85-90 % of the total nuclear test-related dose from exposure to residual fallout contamination in the Marshal Islands is derived from ingestion of ^{137}Cs contained in locally grown terrestrial foods. Recognizing that food security is a key concern for Marshall Islanders, we have developed an interactive web-based application to support program initiatives in public outreach, and help build public trust. Our aim is to provide full and open disclosure of data and information in an easily accessible format to better serve Marshallese communities directly impacted by the nuclear test program. This web-site application remains under development. It currently hosts maps of islands from Bikini, Enewetak, Rongelap, and Utrok Atolls where data are available for recently completed pantry sampling survey missions to the islands. The web-site will be updated as more data becomes available and, in addition to locally grown terrestrial food products, include other food groups such as chicken and pork muscle and organs, coconut crab, fish and other marine biota for current conditions and for the potassium treatment option.

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