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Radiological Conditions in Areas of Kuwait with Residues of Depleted Uranium

Report by an international group of experts

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RADIOLOGICAL CONDITIONS IN AREAS OF KUWAIT WITH RESIDUES OF DEPLETED URANIUM

Report by an
international group of experts

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FOREWORD

Various locations around the world have been affected by radioactive residues, sometimes from peaceful activities, such as the mining and milling of uranium ores, and sometimes from military activities, such as nuclear weapon testing. In the recent past, radioactive residues have also resulted from the use of depleted uranium in conventional munitions in conflicts in the Balkans and the Middle East. After these conflicts, questions arose regarding the possible radiological consequences of the residues for local populations and the environment, and the governments of the affected States were obliged to respond.

Many of the residues are in States where the infrastructure and expertise necessary for evaluating the radiation risks posed by the residues and for making decisions on remediation are insufficient. In such cases, governments have felt it necessary to obtain outside help. In other cases, it has been considered to be socially and politically desirable to have independent expert opinions on the radiological conditions caused by the residues. As a result, the IAEA has been requested by the governments of a number of Member States to provide assistance in this context. The assistance has been provided by the IAEA under its statutory obligation "to establish… standards of safety for protection of health… and to provide for the application of these standards… at the request of a State".

An assessment was requested by the Government of Kuwait in relation to the residues of depleted uranium munitions from the 1991 Gulf War that exist on its territory. In February 2001 the IAEA was requested to conduct surveys and assessments in order to evaluate the possible radiological impact of depleted uranium residues at a number of locations in Kuwait.

For this purpose the IAEA assembled a team of senior experts, including a representative of the United Nations Environment Programme, which was led by R.H. Clarke, Chairman of the International Commission on Radiological Protection. The team visited Kuwait in September 2001 to assess the sites identified by the Government of Kuwait and to evaluate the available information. In February 2002 scientists from the IAEA and the Spiez Laboratory in Switzerland, together with local experts, carried out a programme of measurements and sampling at the sites in Kuwait to provide an independent technical basis for the assessment. This report, which includes the findings and conclusions of the team of senior experts and recommendations to the Government of Kuwait, is issued in the Radiological Assessment Reports Series.

EDITORIAL NOTE

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SUMMARY

Depleted uranium (DU) is one of the by-products of uranium enrichment and, like any other uranium compound, has both chemical and radiological toxicity; it is mildly radioactive, having about 60% of the activity of natural uranium. DU has had a wide range of peaceful applications, such as the provision of radiation shielding for medical sources or as counterweights in aeroplanes. DU is also used for heavy tank armour and, owing to its high density and high melting point and its property of becoming 'sharper' as it penetrates armour plating, in anti-tank munitions and missiles.

The 1991 Gulf War was the first conflict in which DU munitions were used extensively. In view of the concerns raised about the possible link between human exposure to ionizing radiation from DU and harmful biological effects, the Government of Kuwait, in February 2001, requested the IAEA to conduct surveys at and assessments of a number of specified locations. The aim of this work was to inform the Government of Kuwait and the public of the possible radiological conditions arising owing to DU residues at these sites.

The IAEA accepted the request for a radiological assessment under its unique statutory functions within the United Nations system, namely: (1) to establish standards of safety for protection against radiation exposure; and (2) to provide for the application of these standards. In 1996 the IAEA, in cosponsorship with other relevant organizations in the United Nations system, established the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources. These standards are fully applicable to exposure to all forms of ionizing radiation, including exposure to any uranium radionuclides in general and, in particular, to DU.

In the past, a number of evaluations of the environmental and health impact of DU munitions have been performed by national and international organizations. This report constitutes the first comprehensive radiological assessment of compliance with international radiation protection criteria and standards for areas with residues of DU munitions that has been carried out under the auspices of the IAEA.

The IAEA assembled an international team of senior experts, including a representative of the United Nations Environment Programme (UNEP). The team was led by R.H. Clarke, Chairman of the International Commission on Radiological Protection. The experts visited Kuwait in September 2001 to assess the sites identified by the Government of Kuwait and to evaluate the available information. The 11 locations selected for the investigation[1] included sites of military action during the Gulf War in which DU munitions were used, sites where DU residues still exist and areas where concern has been expressed about the possible contamination of water and foodstuffs with DU. In February 2002 a mission was conducted to collect samples at the identified sites. The sampling team included scientists from the IAEA Secretariat and from the Spiez Laboratory in Switzerland, representing the UNEP, together with experts from the laboratory of the Radiation Protection Department of the Ministry of Health of Kuwait. Around 200 environmental samples, including soil, water and vegetation, were collected during the campaign and subsequently analysed.

The international team of experts prepared a report describing the findings of the measurement programme and the subsequent assessment performed by the team. This report provides a detailed description of the IAEA's investigation of the radiological conditions in Kuwait in relation to residues of DU, the results of the radiological assessment, the overall and site specific findings and conclusions of the assessment, and the recommendations of the expert group.

On the basis of the measurements carried out at the sites investigated in the IAEA's study and summarized in this report, DU does not pose a radiological hazard to the population of Kuwait. *No persons who might receive doses from exposure to residues of DU have been identified, either by the authorities of Kuwait or in the IAEA's investigation.* Annual radiation doses that could arise from exposure to DU residues would be very low and of little

[1] The locations investigated were: Al Doha, Al Jahra, Al Mutlaa, the water extraction facility at Al Rawdhatine, the farming areas at Al Wafrah and Al Abdali, the Manageesh oilfields (Manageesh Gathering Centre 28 and Umm Gudayar Gathering Centre 18), and the storage grounds near the Military Hospital, at Al Sabhan and at the military base of Um Al Kwaty.

radiological concern. Annual radiation doses in the areas where residues do exist would be of the order of a few microsieverts, well below the annual doses received by the population of Kuwait from the natural sources of radiation in the environment and far below the reference level recommended by the IAEA as a criterion to help establish whether remedial actions are necessary.

Complete DU penetrators or fragments can still be found at some locations where DU weapons were used during the Gulf War, such as at the oilfields at Manageesh. Prolonged skin contact with these DU residues is the only possible exposure pathway that could result in exposures of radiological significance. As long as access to the areas remains restricted, the likelihood that members of the public could pick up or otherwise come into contact with these residues is low.

The authorities of Kuwait have the competence and equipment to carry out the necessary monitoring and survey activities in relation to DU. The analysis techniques used by the Radiation Protection Department of the Ministry of Health of Kuwait are sufficient to determine whether concentrations of uranium in environmental samples are of radiological concern.

1. INTRODUCTION

1.1. REQUEST FOR ASSISTANCE AND THE RESPONSE OF THE IAEA

In February 2001, during a visit of the Director General of the IAEA to Kuwait, the First Deputy Prime Minister requested the IAEA's assistance in conducting independent surveys and assessments with a view to informing the government and the public of the possible radiological consequences of depleted uranium (DU) residues in Kuwait; the Director General acceded to the request.

The authorities of Kuwait and the IAEA agreed that the IAEA's assistance would take the form of a study conducted by an international group of experts appointed by the IAEA within the framework of a project of the IAEA's Department of Technical Co-operation. The radiological framework for this study was provided by the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the Basic Safety Standards) [1]. The involvement of the IAEA in this study derived from the IAEA's statutory function to establish standards of safety for the protection of health and to provide for their application at the request of a State.

Plans for this study were discussed at a meeting held in Vienna in May 2001 between experts representing the Government of Kuwait and representatives of the IAEA. Representatives of the United Nations Environment Programme (UNEP) and of the World Health Organization (WHO) also attended the meeting, and the two organizations were invited to nominate experts to represent them in the study. The UNEP accepted the IAEA's invitation; the WHO, however, decided on no further involvement in the study, since the investigation did not conform to the remit of the organization. The WHO did, however, request to be kept informed of the outcome of the study.

This report provides a detailed description of the IAEA's investigation of the radiological conditions in areas of Kuwait with residues of DU. The remainder of this section provides information on the general programme of the work, the personnel involved and the scope of the study. Section 2 gives some background information on radiological protection and an overview of uranium and of DU in particular. Section 3 describes the approach used for site investigation and radiological assessment, and Section 4 describes the results of the radiological assessment. Section 5 sets out the findings and conclusions of the assessment and Section 6 presents the recommendations of the expert group.

1.2. WORK PROGRAMME AND PERSONNEL INVOLVED

The overall aim of this study was to produce an independent assessment of the radiological conditions in Kuwait due to the presence of DU. The scope of this study covered only sites designated by the Government of Kuwait.

The senior experts in radiological protection nominated by the IAEA to conduct the investigation were:

— R.H. Clarke (Chairman), Chairman of the International Commission on Radiological Protection (ICRP).
— P.A. Burns, Director of the Environmental and Radiation Health Branch, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).
— P.R. Danesi, Director of the Agency's Laboratories at Seibersdorf to April 2001, at present a consultant to the IAEA.
— V.A. Kutkov, Senior Scientific Officer, Kurchatov Institute, Moscow, Russian Federation.
— B.C. Winkler, former Chief Executive Officer, Council for Nuclear Safety of South Africa, at present a member of the Board of Directors of the National Nuclear Regulator of South Africa.
— B.T. Wilkins, Principal Scientific Officer, National Radiological Protection Board (NRPB), United Kingdom, who acted as a rapporteur.

The UNEP was represented by H.N. El Habr, Deputy Regional Director, Regional Office for West Asia.

T. Cabianca of the Division of Radiation and Waste Safety was the IAEA Scientific Secretary for the project; D. Al Ajmi of the Kuwait Institute for Scientific Research (KISR) was the liaison officer.

The tasks agreed to by the senior experts to be carried out within the scope of the investigation were:

(a) To collect and examine information on the radiological conditions arising from the presence of residues of DU in Kuwait;
(b) To carry out a sampling campaign at locations in Kuwait that may be affected by the presence of residues of DU;
(c) To conduct an assessment of the radiological conditions arising from the presence of residues of DU in relation to the requirements of the Basic Safety Standards;
(d) To make recommendations on appropriate protective measures and/or future activities with regard to the radiological conditions arising from the presence of residues of DU;
(e) To make specific recommendations on the handling of material contaminated with DU currently stored in Kuwait.

The work programme for this study included two missions to Kuwait: the first mission was conducted in September 2001 and involved the senior experts in radiological protection selected by the IAEA; a second mission, which dealt with field sampling, was carried out in February 2002.

The broad objectives of the first mission were to make an initial assessment based on existing information and to develop the survey, sampling, measurement and assessment strategy to be subsequently used. Information provided to the senior experts by the authorities of Kuwait indicated that relevant measurements had already been carried out by specialists at the Radiation Protection Department (RPD) of the Ministry of Health of Kuwait. The senior experts were of the opinion that these data could form a valuable input to the final assessment, provided that the reliability of the data could be demonstrated independently; an assessment of reliability was included in the work programme, which is discussed later in this report. The experts therefore considered that it would be inappropriate to make any preliminary assessment of the radiological conditions during the mission in September 2001.

The sampling campaign was conducted under the supervision of the Agency's Laboratories at Seibersdorf, with support from the Spiez Laboratory, Switzerland, representing the UNEP, and from the RPD. P.R. Danesi was responsible for the overall direction of the sampling mission and M. Burger, Head of the Spiez Laboratory, was the lead scientist on behalf of the UNEP. The analysis of the samples collected during the sampling campaign was carried out at the Agency's Laboratories at Seibersdorf and the Spiez Laboratory in 2002. The assessment described in this report has been based largely on the results of this sampling and measurement programme, supplemented by the results of the analysis of some samples previously collected by the RPD, together with relevant data generated by the RPD.

The submission of the information gathered in Kuwait was co-ordinated by S.S.Y. Yousef, Director of the RPD. Staff members of the RPD provided a substantial input of local information and assistance, thus significantly helping the IAEA in this project. A full list of contributors to this study is given at the end of this report.

1.3. SCOPE OF THE STUDY

This study was limited to the assessment of the radiological consequences that could arise owing to the presence of residues of DU in Kuwait. No consideration was given to the presence of radioactive material other than DU in the environment, and the study did not consider the possible radiological consequences in the short term after DU munitions had been used. The assessment was confined to the possible radiological consequences of the

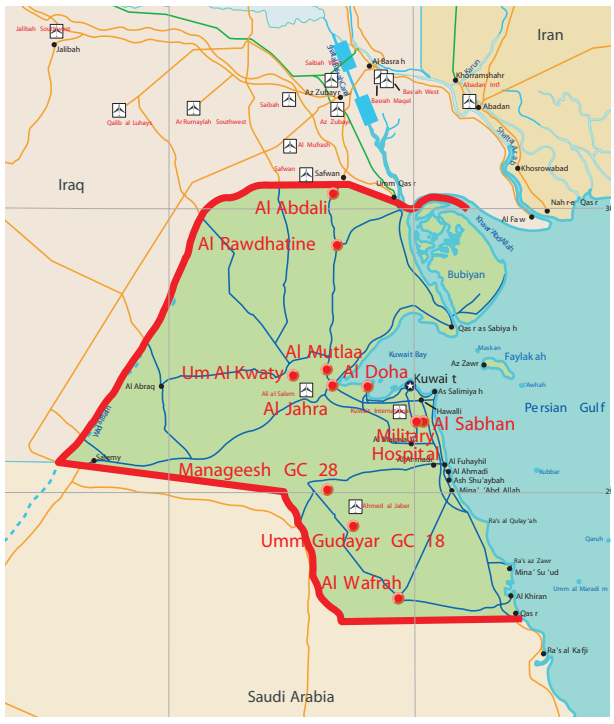

FIG. 1. Sites in Kuwait included in the IAEA's investigation.

presence of DU; the chemical toxicity of uranium was not considered.

The investigation was limited to a number of locations that might be affected by the presence of residues of DU or that are considered important from the public reassurance point of view. The locations that merited investigation were proposed by the Government of Kuwait. It was agreed that 11 locations would be studied (shown in Fig. 1).

The original scope of the sampling campaign was limited to the corroboration of the measurements and information provided by Kuwait's experts, together with the provision of supplementary data, to obtain reliable information to be used in the radiological assessment. During the mission in September 2001 the senior experts emphasized that, if problems were encountered with the reliability of the data already available, then a new sampling and measurement strategy would be developed. In the light of the findings of the evaluation exercise carried out at the Agency's Laboratories at Seibersdorf, the scope of the sampling campaign did require widening.

2. BACKGROUND

2.1. ACTIVITY AND DOSE

The amount of a given radionuclide in a particular material is normally expressed in terms of activity, which is the rate at which nuclear transformations occur; the SI unit of activity is the becquerel (Bq). Radionuclides can differ markedly in their physical characteristics (decay mode, radioactive half-life) and in their behaviour in the human body and in the environment. Consequently, the relative importance of different pathways of exposure to radiation is also dependent on the radionuclide of interest. Exposure can occur via external irradiation, when the radionuclide is outside the human body, or via internal irradiation, for which ingestion and inhalation are usually the important processes. These different factors need to be taken into account in order to bring the effects of different radionuclides onto a common basis. This requires the calculation of a quantity referred to as 'dose'. The dose is a measure of the energy deposited by radiation. The quantity 'effective dose' takes account of the type of radiation and of the different sensitivities of different organs and tissues to the induction of the stochastic effects of radiation; its basic unit is the sievert (Sv) [2]. The IAEA [1] and the ICRP [2, 3] have published coefficients relating intakes of activity and dose, based on the results of extensive international research. In practical terms, doses arising from the presence of radionuclides in the environment are expressed in terms of the millisievert (mSv), which is one thousandth of one sievert, or the microsievert (μSv), which is one millionth of one sievert.

Exposure to any radioactive material, whether of natural or artificial origin, gives rise to an incremental risk of developing cancer. This risk is assumed to be proportional to the dose received. The additional risk of fatal cancer associated with a dose of 1 mSv is assumed to be about 1 in 20 000. This small increase in lifetime risk can be contrasted with the 1 in 5 risk of fatal cancer that people usually incur.

2.2. INTERNATIONAL SAFETY STANDARDS

The IAEA, together with other relevant international organizations, has established the basic requirements for protection against the risks associated with exposure to ionizing radiation, which are published in the Basic Safety Standards [1]. The standards are based primarily on the recommendations of the ICRP [4] and on the assessments of the health effects of radiation of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [5]. The standards do not apply to non-ionizing radiation or to the control of the non-radiological aspects of health and safety, such as chemical toxicity.

The Basic Safety Standards cover a wide range of situations that give rise to or could give rise to exposure to radiation and are applicable to exposures from any combination of uranium isotopes, including those found in DU.

The Basic Safety Standards do not, however, include dose criteria directly applicable for aiding decision making on remedial actions for DU affected areas in Kuwait. Instead, Ref. [6] recommends a generic reference level for aiding decisions on remediation: an individual existing annual effective dose of 10 mSv from all sources, including natural background radiation. In addition, an upper value is recommended at which intervention is justified under almost any circumstances: an existing annual equivalent dose of 100 mSv to any organ.

For perspective, the worldwide average annual effective dose from natural background radiation is 2.4 mSv, with a typical range of 1 to 20 mSv [5]. The most significant contribution to the worldwide average annual effective dose comes from exposure to radon and its decay products (1.15 mSv); exposure to terrestrial gamma rays and cosmic rays accounts for 0.48 mSv and 0.38 mSv, respectively. The contribution of the intake of natural radionuclides in air, food and water to the average dose is 0.31 mSv, mainly due to ^{40}K (0.17 mSv), ^{210}Po (0.086 mSv), ^{210}Pb (0.032 mSv) and ^{228}Ra (0.021 mSv); uranium

[2] Unless otherwise stated, the term dose used in this report refers to effective dose as defined in the Basic Safety Standards [1]. The term includes doses arising from external irradiation and doses integrated to age 70 from intakes of radionuclides.

isotopes contribute little to the dose (0.0006 mSv; see Section 2.5).

2.3. URANIUM AND DU

Uranium is a naturally occurring radioactive element. In its pure form it is a silver coloured heavy metal, similar to lead, cadmium and tungsten. Like tungsten, it is very dense, with a density of about 19 g/cm^3. In its natural state uranium consists of three isotopes (^{238}U, ^{235}U and ^{234}U). Other isotopes not found in natural uranium are ^{237}U, ^{236}U, ^{233}U and ^{232}U.

During the enrichment process for natural uranium, necessary to produce energy from uranium in nuclear reactors, the fraction of ^{235}U is increased from its natural level (0.72% by mass) to 2% or more by mass. The uranium that remains after the enriched fraction has been removed has reduced concentrations of ^{235}U and ^{234}U. This by-product of the enrichment process is known as DU. Typically, the percentage concentration by mass of ^{235}U in DU used for military purposes is 0.2% [7].

The total specific activity of natural uranium (i.e. the activity per unit mass of natural uranium metal) is 25.4 Bq/mg. In nature uranium isotopes are in radioactive equilibrium with the other isotopes, such as ^{234}Th, ^{231}Th, ^{226}Ra, ^{223}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po, created as a result of radioactive decay. In DU only traces of decay products beyond ^{234}Th and ^{231}Th are present, as these decay products have not had time to form since the DU was produced. The specific activity of DU is 14.2 Bq/mg.

Table I gives the half-lives and specific activities of the three isotopes of natural uranium and compares their relative abundance by mass and activity in natural uranium and in DU.

There have been reports that the DU in munitions contains small amounts of other radionuclides, such as isotopes of americium and plutonium, as well as ^{236}U. The presence of these human-made radionuclides indicates that some of the DU has been obtained from uranium that had been irradiated in nuclear reactors and subsequently reprocessed. Published information for other theatres of war indicates that the amounts of these radionuclides present in DU are very small [8, 9]. The RPD sent five penetrators taken from Kuwait to the IAEA in order that the concentrations of the isotopes of uranium and plutonium could be determined (Fig. 2). Three penetrators were analysed by alpha spectrometry, and the results are shown in Table II. The activity ratios of ^{234}U/^{238}U indicate that the uranium of the penetrators is depleted. The activity ratio of ^{234}U/^{238}U in natural uranium is approximately 1.

The data were consistent with the findings of earlier studies conducted on penetrators found in the Balkan region [9] and indicated that only the activity concentrations of ^{238}U, ^{235}U and ^{234}U could be of some hazard from the radiological point of view. Doses due to isotopes of americium and plutonium and uranium isotopes other than ^{238}U, ^{235}U and ^{234}U were therefore not considered in this study.

FIG. 2. Penetrators collected by the RPD and analysed at the Agency's Laboratories at Seibersdorf.

TABLE I. HALF-LIVES, SPECIFIC ACTIVITIES AND RELATIVE ABUNDANCE OF URANIUM ISOTOPES IN NATURAL URANIUM AND IN DU

Isotope	Half-life (a)	Specific activity (Bq/mg)	Relative isotopic abundance (%)			
			Natural uranium		DU	
			By mass	By activity	By mass	By activity
^{238}U	4.51×10^9	12.44	99.28	48.2	99.8	87.5
^{235}U	7.1×10^8	80	0.72	2.2	0.2	1.1
^{234}U	2.47×10^5	230 700	0.0055	49.5	0.0007	11.4

TABLE II. ACTIVITY CONCENTRATIONS OF ^{238}U, ^{234}U, ^{238}Pu AND $^{239+240}Pu$ AND ACTIVITY RATIOS OF $^{234}U/^{238}U$ AND $^{238}Pu/^{239+240}Pu$ MEASURED IN THE DU PENETRATORS FROM KUWAIT

Penetrator	Activity concentration (Bq/kg)				Activity ratio	
	^{238}U ($\times 10^6$)	^{234}U ($\times 10^6$)	$^{239+240}Pu$	^{238}Pu	$^{234}U/^{238}U$	$^{238}Pu/^{239+240}Pu$
P1 (N = 3)[a]	12.05 ± 0.55	1.57 ± 0.08	6.2 ± 0.4	0.45 ± 0.07	0.130 ± 0.006	0.072 ± 0.013
P2 (N = 6)	10.94 ± 0.47	1.39 ± 0.08	5.3 ± 0.2	0.13 ± 0.03	0.126 ± 0.002	0.025± 0.004
P3 (N = 4)	11.03 ± 0.47	1.50 ± 0.08	0.6 ± 0.1	0.06 ± 0.02	0.133 ± 0.007	0.10 ± 0.03

[a] N = number of independent determinations. The uncertainty in the activity ratios is expressed as the standard deviation of N measurements.

Isotopes of natural uranium decay mainly by emitting alpha particles. The emissions of beta particles and gamma radiation are low. Table III shows the average energies per transformation emitted by the three isotopes of natural uranium.

2.4. URANIUM IN NATURE

Uranium is found in trace amounts in all rocks and soil, in water and air and in materials made from natural substances. It is a reactive metal, and therefore it is not present as free uranium in the environment. In addition to the uranium naturally present in minerals, the uranium metal and compounds produced by industrial activities can also be released back to the environment.

Uranium can combine with other elements in the environment to form uranium compounds. The solubility of these uranium compounds varies greatly. Uranium in the environment is dominated by uranium oxides such as UO_2, which is an anoxic insoluble compound found in minerals, and UO_3, a moderately soluble compound found in surface waters. The chemical form of the uranium compound determines how easily the compound can move through the environment, as well as how chemically toxic it might be.

Table IV summarizes the activity concentrations of ^{238}U and ^{235}U of natural origin in some environmental materials [5].

TABLE III. AVERAGE ENERGY PER TRANSFORMATION OF THE URANIUM ISOTOPES ^{238}U, ^{235}U AND ^{234}U

Isotope	Average energy per transformation (MeV/Bq)		
	Alpha	Beta	Gamma
^{238}U	4.26	0.01	0.001
^{235}U	4.47	0.048	0.154
^{234}U	4.84	0.0013	0.002

2.5. EXPOSURE TO NATURAL URANIUM

Uranium is incorporated into the human body mainly through the ingestion of food and water and the inhalation of air.

TABLE IV. ACTIVITY CONCENTRATIONS OF NATURALLY OCCURRING ^{238}U AND ^{235}U IN SOME ENVIRONMENTAL MATERIALS

Material	Activity concentration			
	^{238}U		^{235}U	
	Reference value	Range	Reference value	Range
Soil (Bq/kg)	35	1–690	—	—
Air (μBq/m^3)	1	0.02–18	0.05	—
Drinking water (Bq/kg)	0.001	0.00009–150	0.00004	0.0004–0.5
Leafy vegetables (Bq/kg)	0.02	0.006–2.2	0.001	0.0007–0.0012
Root vegetables (Bq/kg)	0.003	0.0004–2.9	0.0001	0.00005–0.0006
Milk products (Bq/kg)	0.001	0.0001–0.017	0.00005	0.00005–0.0006
Meat products (Bq/kg)	0.002	0.0008–0.02	0.00005	0.00002–0.0005

UNSCEAR has estimated that the average person ingests 1.3 μg of uranium per day, corresponding to an annual intake of 0.46 mg, or 11.6 Bq [5], primarily through the consumption of drinking water. Typically, the average person receives an annual dose of less than 0.6 μSv from the ingestion of uranium; in addition, the average individual receives an annual dose of about 110 μSv from the ingestion of the decay products of uranium [5].

Uranium in air is associated with particles of dust. UNSCEAR has estimated that the average person inhales 0.6 μg of uranium (15 mBq) each year [5]. This gives rise to an annual dose of 0.048 μSv; the average total annual dose from the inhalation of all radionuclides of natural origin has been estimated to be 5.8 μSv [5]. The size of the uranium aerosols and the solubility of the uranium compounds in the lungs and gut influence the transport of uranium in the human body.

Most of the uranium ingested is excreted in faeces within a few days and never reaches the bloodstream. The remaining fraction will be transferred into the bloodstream. Most of the uranium in the bloodstream is excreted in urine within a few days, but a small fraction remains in the kidneys and other soft tissue, as well as in bones.

2.6. PATHWAYS OF EXPOSURE DUE TO DU

The radiation emitted from DU is predominantly alpha particles (see Table III). Alpha particles have a very limited range in tissue; they can barely penetrate the external layer of the skin, and hence do not pose a hazard in terms of external irradiation. However, alpha particles are very energetic, and if emitted inside the body can damage nearby cells. Consequently, internal irradiation is an important consideration. Uranium is not generally transferred effectively along food chains, and so in environmental assessments inhalation is usually the exposure pathway that merits primary attention. Processes such as migration through the soil, deposition of resuspended material onto crops and transfer to groundwater might be of greater interest in the longer term.

In a combat situation the main radiological hazard associated with DU munitions is the inhalation of the aerosols created when DU munitions hit an armoured target. Studies carried out at test ranges show that most of the DU aerosols created by the impact of penetrators against an armoured target settle within a short time of the impact and in close proximity to the site, although smaller particles may be carried a distance of several hundred metres by the wind [10]. However, the IAEA's investigation was concerned with the possible effects of DU on the population of Kuwait. Exposure of military personnel to DU in the immediate aftermath of an attack was not considered in this study.

A possible exposure pathway for those visiting or living in DU affected areas after the aerosols have settled is the inhalation of the DU particles in the soil that are resuspended through the action of the wind or human activities such as ploughing.

One possible pathway of exposure that merits consideration is the inadvertent or deliberate ingestion of soil. For example, farmers working in a field in which DU munitions were fired could inadvertently ingest small quantities of soil, while sometimes children deliberately eat soil. Doses from this exposure pathway were, however, found to be much lower than doses associated with other pathways.

Generally a large proportion of DU munitions fired from an aircraft miss their intended target. The physical state of these munitions once fired will vary from small fragments to whole intact penetrators, either totally or partially encased in their aluminium jackets. Individuals who find and handle such munitions could be exposed via external irradiation due to the beta particles and gamma rays emitted by the DU (Table III). However, the dose received would be significant only if a person were in contact with DU projectiles over a considerable period of time, since the contact dose to the skin from DU is about 2.3 mSv/h [11]. It is therefore unlikely that even prolonged contact with DU would lead to skin burns or any other acute radiation effect.

In addition, penetrators that do not hit the target corrode with time, forming fragments and particles containing DU oxides, which may range from several millimetres to less than a micrometre in size [12]. People could possibly ingest or inhale some of the uranium oxides formed through this weathering process.

2.7. USE OF DU IN KUWAIT

2.7.1. Military uses of DU

The physical and chemical properties of uranium make it very suitable for military uses. DU is used in the manufacture of munitions used to pierce armour plating, such as that in tanks, in missile nose cones and as a component of armour for tanks. Armour

made of DU is much more resistant to penetration by anti-armour munitions than conventional hard rolled steel armour plate.

Armour piercing munitions are generally referred to as 'kinetic energy penetrators'. DU is preferred to other metals, such as tungsten, for its high density, its pyrophoric nature (DU self-ignites when exposed to temperatures of 600–700°C and at high pressures) and its property of becoming 'sharper' as it penetrates armour plating. On impact against its target, a DU penetrator will ignite, breaking up into fragments and forming an aerosol of particles ('DU dust') whose size depends on the angle of impact, the velocity of the penetrator and the temperature. These fine dust particles can catch fire spontaneously in air. Small pieces may ignite in a fire and burn, but tests have shown that this does not normally apply for large pieces such as the penetrators used in anti-tank weapons or in aircraft balance weights.

2.7.2. Use of DU in the Gulf War

The Gulf War in 1991 was the first conflict in which extensive use was made of DU munitions. DU munitions were used by the US Army, Air Force, Navy and Marine Corps. The United Kingdom was the only other State involved in the war known to have used DU munitions. Table V gives a summary of the stated number and weight of DU rounds used during the Gulf War. According to information provided by the US Department of Defense (Office of the Special Assistant to the Secretary of Defense for Gulf War Illnesses (OSAGWI)) [13], the US Army used 105 mm (M900) and 120 mm (M829 and M829A1) DU rounds, which were fired from Abrams tanks. Each 105 mm round weighs about 3.83 kg, while the weight of the 120 mm tank ammunition varies between 3.94 kg for the M829 type and 4.64 kg for the M829A1 type. The figures for the US Army given in Table V include the ammunition supplied to the Marine Corps once its initial allocation had been used. This initial allocation is not included in the information provided by the US Department of Defense. The US Air Force used a stated total of 783 514 rounds of 30 mm API (Armor Piercing Incendiary), each containing about 302 g of DU, fired from its A-10 aircraft. Four or five DU rounds were accidentally fired from the 20 mm cannon of the Phalanx CIWS (Close-In Weapon System) on board a US Navy frigate. Finally the Marine Corps, in addition to an undisclosed number of DU tank munitions, fired a stated total of 67 436 rounds of 25 mm PGU/20 from its AV-8B Harrier jets, each containing 148 g of DU. According to information provided by the United Kingdom Ministry of Defence, the British Army fired fewer than one hundred 120 mm APFSDSs (Armor Piercing Fin Stabilized Discarding Sabot) from its Challenger

TABLE V. SUMMARY OF DU MUNITIONS USED DURING THE GULF WAR

DU munition type	Rounds used in the Gulf War	Weight of a DU round (kg)	Total weight of DU (t)
US Army			
M900 (105 mm)	504	3.83	1.93
M829 and M829A1 (120 mm)	9048	3.94/4.64	37.3
Total	9552	—	39.2
US Air Force			
API (30 mm)	783 514	0.302	237
US Navy			
20 mm from Phalanx CIWS	4–5	~0.1	~0.0005
US Marine Corps			
PGU/20 (25 mm)	67 436	0.148	10
British Army			
APFSDS (120 mm)	<100	4.85	<0.5
Total	~860 600	—	~286

tanks. The total number of rounds expended in the Gulf War is estimated to be about 860 600 for a total weight of DU of about 286 t. These figures, however, do not include the initial allocation of DU tank munitions expended by the US Marine Corps. According to Dunningam and Bay [14], of the 3700 tanks of Iraq's army destroyed during the Gulf War, DU munitions accounted for only around 500, 80% of which were destroyed by US tanks.

Unlike the Kosovo conflict, for which the North Atlantic Treaty Organization (NATO) provided detailed co-ordinates of the locations at which DU munitions were used, the US authorities have not released detailed information on the exact sites at which such munitions were fired during the Gulf War. The sites included in this study were suggested by the authorities of Kuwait, and their selection was based solely on information available to the authorities of Kuwait concerning the scenes of military action involving the use of DU munitions. No further investigation was carried out to verify the accuracy of this information or to locate other possible sites in Kuwait that might be affected by the presence of residues of DU.

3. METHODOLOGY USED FOR SITE INVESTIGATION AND RADIOLOGICAL ASSESSMENT

The investigation of the current situation in Kuwait was carried out by means of two missions of senior experts in radiological protection appointed by the IAEA: the first mission took place in September 2001 and was followed by a sampling campaign conducted in February 2002.

3.1. FIRST MISSION OF SENIOR EXPERTS: SEPTEMBER 2001

The aims of the mission by senior experts in September 2001 were to discuss the information then available with colleagues from Kuwait, visit the sites intended for study and develop a strategy for the subsequent sampling mission, analyses and assessment. This mission also provided an opportunity for the experts to become familiar with the types of environment and concerns to be considered in the subsequent assessment.

Data on the concentrations of uranium in various environmental materials had been collected by the authorities of Kuwait prior to this mission, although no specific data were available at that time on the amounts of DU present. Air had been sampled at four locations around Kuwait City since 1991; soil, vegetation and water samples had been collected from sites of interest. In addition, radiation in tanks struck by DU munitions had been measured using portable radiation monitors. The overall requirement was to produce an independent assessment considering the sites specified by the Government of Kuwait. However, the experts were of the opinion that the data already generated could form an important input to the final assessment, provided that they could demonstrate independently that the data were reliable. A protocol for assessing the reliability of the existing data was discussed and agreed upon by the senior experts and their colleagues from Kuwait during the mission in September 2001.

After the reliability assessment had been completed, a revised sampling and measurement programme was developed. In addition, the RPD selected some samples of soil, water and air filters that had already been collected and sent them to the IAEA for detailed analysis. The subsequent assessment was based on all the reliable data available.

3.2. EVALUATION OF THE RELIABILITY OF EXISTING DATA

This part of the study was carried out at the Agency's Laboratories at Seibersdorf, with the co-operation of the RPD. The detailed report is reproduced in Appendix I; only a brief summary and the conclusions are presented here.

In September 2001 the RPD provided the IAEA with a preliminary report entitled Concentration of Uranium in Soil from the Wafrah Region, which contained data on concentrations of uranium in air filters covering the period 1993–2000. A second report, dated 28 October 2001, was received in Seibersdorf on 5 November 2001. In addition to the data already supplied, this report contained information on the protocols, standards and background spectral data used by the RPD. These documents enabled the IAEA to audit the procedures in use at that time.

The samples of air filters and soil supplied by the RPD in September 2001 had already been analysed by the RPD using gamma spectrometry; measured values were known to be close to or below the limits of detection. These samples were subsequently analysed by the IAEA using gamma spectrometry as well as by the more sensitive techniques of alpha spectrometry and inductively coupled plasma mass spectrometry (ICP–MS).

A specific intercomparison exercise was also carried out. About 8.5 kg of soil from Al Doha, known to be contaminated with DU, was collected by the RPD and sent to the Agency's Laboratories at Seibersdorf, where it was dried, sieved and thoroughly mixed. Separate portions were then analysed by the IAEA and RPD. In addition, a reference material prepared and analysed previously by the IAEA was sent to the RPD for analysis. These samples enabled the IAEA to evaluate the ability of the RPD to measure DU and natural uranium in samples in which levels were elevated. For this exercise, measurements by the IAEA on both the reference material and the soil from Al Doha were confined to gamma spectrometry.

The evaluation at the Agency's Laboratories at Seibersdorf concluded that the calibration procedure used by the RPD had led to systematic error in the measurement of the soil and air filter samples;

actual values of activity concentration could be more than an order of magnitude higher than reported at the lower end of the range of measurement (see Appendix I). Advice was provided on how the procedure could be refined. The measurement technique adopted by the RPD requires the minimum of sample preparation and hence is attractive from the monitoring point of view when the throughput of samples is important. This approach cannot provide information on the isotopic composition of the radionuclides of interest though, and so cannot establish whether the uranium present is depleted or of natural origin. However, the detection limits that can be achieved are below the concentrations that would be of radiological concern. In the remainder of this report, concentrations of ^{238}U in soil measured by the RPD have been taken to be about 10 Bq/kg, unless otherwise stated. On the basis of the IAEA's data, this is around the value expected for the natural background radiation level in Kuwait.

The results of the intercomparison exercise were in agreement and demonstrated that the RPD could perform accurate measurements of uranium concentrations in soils using gamma spectrometry when the values exceed the detection limit.

3.3. SAMPLING CAMPAIGN: FEBRUARY 2002

During their mission in September 2001, the senior experts prepared a strategy for a subsequent sampling mission based on the assumption that the data already generated by the RPD could be used directly. However, since the reliability assessment subsequently indicated that the majority of the RPD's data, obtained by gamma spectrometry, were concentrations close to or below detection limits and no data had been made available to demonstrate the presence of DU in the environment, it was necessary to carry out a more extensive programme. The IAEA therefore prepared a revised sampling scheme that was then refined and agreed upon by correspondence with the senior experts.

The sampling campaign took place between 2 and 10 February 2002. The team that carried out the campaign included scientists from the IAEA, the Spiez Laboratory, Switzerland, representing the UNEP, and the RPD. All the 11 sites included in the study were inspected. Ad hoc resuspension experiments involving the dispersion of sand contaminated with DU by means of controlled explosions were also carried out (see Appendix III). In total, 206 samples were collected, including 163 samples of soil, water and vegetables with a total mass of over 400 kg, 11 swipes from DU contaminated tanks and 32 air filters collected during the resuspension experiments. Table VI provides a breakdown of the samples collected. Details of the sampling that took place at individual sites are provided in Section 4.

3.4. ANALYSIS OF THE SAMPLES COLLECTED DURING THE CAMPAIGN

The analytical work was divided between the Agency's Laboratories at Seibersdorf and the Spiez Laboratory, Switzerland. Some of the vegetation samples analysed by the Spiez Laboratory were also measured by the Nuclear Chemistry Laboratory of the Institute of Transuranium Elements of the European Commission in Karlsruhe, Germany. The results of these measurements confirmed the results of the analysis carried out by the Spiez Laboratory. Samples were analysed using gamma spectrometry, alpha spectrometry or ICP–MS, as appropriate. Gamma spectrometry requires minimum sample preparation. Methods based on alpha spectrometry or ICP–MS are more labour intensive but give much lower detection limits and provide information that can be used to determine whether DU is present in the sample. All measurements have uncertainties associated with them, and the level of uncertainty depends upon factors such as the method used and the amount of activity in the sample. Uncertainties have been estimated for all the measurements made in this study, and these have been taken into account in the interpretation of the results. The results presented in the main part of this report are confined mainly to concentrations of ^{238}U and the

TABLE VI. SUMMARY OF SAMPLES COLLECTED DURING THE SAMPLING CAMPAIGN OF FEBRUARY 2002

Sample type	Number of samples	Mass (kg)
Soil	125	357
Water	12	25
Water filters	12	—
Vegetables	14	24
Air filters	32	—
Swipes	11	—
Total	206	406

$^{235}U/^{238}U$ mass ratio. A summary of the results of the analyses carried out at the Agency's Laboratories at Seibersdorf and by the Spiez Laboratory in support of this study, and the relevant reports detailing the analyses, are provided in Appendix IV.

All the analytical methods used had been suitably validated and the analyses were carried out within formal systems of quality assurance.

3.5. ASSESSMENT OF DOSES THAT COULD ARISE OWING TO RESIDUES OF DU

A conservative approach was adopted to estimate the possible annual doses that could be associated with DU. The estimated doses in this assessment should be considered theoretical doses received by hypothetical individuals working or residing in the areas investigated. No persons who might receive doses from exposure to residues of DU have been identified, either by the authorities of Kuwait or in the IAEA's investigation. The estimated doses are committed effective doses from exposure to current levels of DU in the environment and were estimated using, as a basis, the radionuclide concentrations measured in samples of environmental media collected during this study. No attempt was made to assess doses at the time of the Gulf War in 1991 or to model the long term transport of uranium progeny in the environment. Only the three uranium isotopes of natural origin (^{238}U, ^{235}U and ^{234}U) were included in the assessment. Other radionuclides, such as ^{238}Pu and $^{239+240}Pu$, were found only in small amounts in DU residues (see Table II) and so were not included in the assessment. Similarly, ^{236}U was found only in small quantities in some samples and was not considered further. For comparative purposes, doses that could arise owing to natural uranium present at the sites were also calculated.

The exposure pathways included in the assessment were:

(a) Inhalation of soil resuspended by the action of the wind or by human activities.
(b) Ingestion of water.
(c) Ingestion of terrestrial foodstuffs:
    — Green vegetables;
    — Root vegetables;
    — Milk;
    — Meat.
(d) Ingestion of soil.

External exposure to DU in the soil was not included in the assessment. This pathway is of minor importance in the absence of the progeny of uranium isotopes, as is the case with DU.

Doses associated with all the exposure pathways considered were only calculated for hypothetical individuals residing at the farming areas of Al Wafrah and Al Abdali. For Al Rawdhatine only doses to hypothetical adults due to the ingestion of drinking water were calculated. For all the other sites doses that could arise owing to the inhalation of resuspended material and the ingestion of soil were estimated for adults and also for 10 year old children if it was considered appropriate.

The methods used for assessing the possible radiation doses that could arise owing to the various exposure pathways identified above are fully described in Appendix II.

4. RESULTS OF THE RADIOLOGICAL ASSESSMENT

4.1. RADIOLOGICAL CONDITIONS AT THE SITES INVESTIGATED

This section provides detailed results and assessments of the radiological conditions at each of the sites specified for study. Where appropriate, sites where conditions and requirements were similar have been grouped together. The locations studied are shown in Fig. 1. The list of sites was provided by the Government of Kuwait. The sites selected for investigation can be roughly divided into three groups:

(a) Sites where DU munitions were used during the Gulf War. Since no detailed information on the exact locations was available, the sites were chosen on the basis of local knowledge or where residues of DU munitions had been found.
(b) Sites where DU residues have been stored.
(c) Sites where concern has been raised about the possible contamination of water and foodstuffs with DU.

Results of the analysis of air filters collected by the RPD in Kuwait City and of the radiation hazards that could be associated with the handling of DU munitions are also presented in this section. Only activity concentrations of ^{238}U and isotopic ratios of $^{235}U/^{238}U$ by mass are presented in this section. More detailed information is provided in Appendix IV.

Based on the measurements made, an assessment of the possible doses that could be received by individuals at the sites investigated was carried out. The results of the assessment are summarized as appropriate in the remainder of this section.

In order to place the results from specific sites in context, the RPD provided the IAEA with samples of sand and soil from the offshore islands of Failaka and Bubyan, which had not been affected by DU. These were analysed using alpha spectrometry and ICP–MS; the results are shown in Table VII. Activity concentrations of ^{238}U were in the range of 9 to 25 Bq/kg.

4.1.1. Al Doha

Al Doha is a foreshore location close to the settlement of Suliabikhat and to Entertainment City, a recreation centre used extensively by both adults and children. The site is completely flooded by high tides about once or twice a year, generally in October or November. The area of interest is adjacent to the US military base of Camp Doha. A large quantity of DU munitions was on the site when a fire broke out on 11 July 1991. According to information provided by the US Army [13], it was discovered that about 660 rounds of DU munitions had been destroyed or damaged in the fire, of which about 360 were accounted for in the immediate cleanup operations. Around 300 DU penetrators, corresponding to a total of 1500 kg of DU, were missing. Shortly after the fire the US Army cleared the area of equipment, buildings and debris and also removed most of the contaminated soil. Some post-accident debris was discarded and stored at the site investigated; the area was fenced and access to it is restricted.

TABLE VII. ACTIVITY CONCENTRATIONS OF ^{238}U AND ISOTOPIC RATIOS IN SAND AND SOIL FROM LOCATIONS IN KUWAIT

Location and sample type	Activity concentration of ^{238}U (Bq/kg)	$^{234}U/^{238}U$ activity ratio	$^{235}U/^{238}U$ mass ratio
Failaka sand	17.6 ± 1.0	1.13 ± 0.09	0.0072
Failaka sand	19.5 ± 1.2	1.12 ± 0.09	0.0073
Failaka soil	15.9 ± 1.1	1.08 ± 0.10	0.0072
Failaka sand	18.9 ± 1.2	1.10 ± 0.10	0.0072
Bubyan soil and sand	9.9 ± 1.7	1.00 ± 0.11	0.0071
Bubyan soil and sand	23.8 ± 1.9	1.10 ± 0.08	0.0072
Bubyan soil and sand	21.9 ± 2.0	1.03 ± 0.11	0.0071
Bubyan soil	20.8 ± 1.3	1.10 ± 0.13	0.0072

The location is currently bare land with sparse vegetation. Surveys of the area conducted by the RPD after the location had been cleared by the US Army indicated one particular area that was contaminated, and a remediation programme was initiated. Contaminated debris was also found in 1995 at a nearby bird sanctuary. Access to both the foreshore area and the bird sanctuary remains restricted.

At the time of the first mission in September 2001 most of the surface soil from the contaminated area on the foreshore had been removed and taken to the military base at Um Al Kwaty, a restricted area where vehicles contaminated with DU were already being stored (see Section 4.1.8). At the request of the senior experts, the RPD collected a sample of highly contaminated soil from this site later in 2001 and sent it to the IAEA for analysis. There was clear evidence of the presence of DU, concentrations of ^{238}U being about 13 200 Bq/kg.

By the time of the sampling campaign of February 2002 (Fig. 3), part of this area had been covered with about 0.5 m of clean soil, the intention being eventually to treat the whole of the area in this manner. The requirement for this site was to assess the likely effectiveness of the remediation programme. Sampling was therefore mainly confined to that part of the area that had already been covered with clean soil. Eight samples of surface soil (0–5 cm) were taken from within an area of about 40 m^2 that had already been partially remediated. Two soil cores were taken to a depth of 35 cm and separated into four sections of 0–5, 5–15, 15–25 and 25–35 cm. Prior to the sampling mission the area had been partially flooded by the sea and had received heavy rainfall; samples were therefore also taken from nearby pools of surface water. For comparison, four samples were collected from the heaps of clean soil intended to be used later in the remediation operation. The results are shown in Table VIII.

FIG. 3. Collection of a sample of surface soil from Al Doha.

There was evidence of the presence of DU in the samples of surface water. Low concentrations of DU in some of the samples of surface soil were also found, and the results for one of the soil cores indicated an increasing proportion of DU with depth. In both cases, however, the concentrations of ^{238}U were more than two orders of magnitude less than the values observed in soil prior to remediation. In the case of the other soil core, there was some evidence of the presence of DU in the surface layer, but at greater depth the uranium was entirely of natural origin. In several of the samples of surface soil, however, there was no evidence of the presence of DU, and the concentrations of ^{238}U were close to the values found in the clean soil.

To place the observed concentrations of DU in the context of doses that could be received by people in Kuwait, someone spending several hours each day working on the site could receive a dose of 7.7 μSv over a year, based on cautious assumptions, mainly from the inhalation of resuspended material (see Appendix II). The same individual would receive an annual dose of 17 μSv from natural uranium. Individuals using the area for recreational purposes would receive doses about six times lower. While access to the area remains restricted, actual doses from DU to people working or spending time nearby would be very much less.

Overall, the results indicate that the chosen remediation option is effective. The presence of small amounts of DU in the surface soil may be due either to incomplete remediation at the time of sampling or to disturbance by large vehicles engaged in the remediation operation. In the longer term, disturbance of the clean soil could also take place during flooding by the sea. Consideration of simple ways in which the clean soil can be consolidated or stabilized could therefore be helpful.

Table VIII shows that concentrations of ^{238}U in the clean soil were close to the detection limit expected for the RPD's equipment, which is around 10 Bq/kg (Appendix I). For those soil samples in which DU was a significant contributor to the total uranium content, the corresponding values were higher and it should be readily detectable using the RPD's approach. Ongoing monitoring of the effectiveness of remediation at Al Doha by the RPD should therefore be reasonably straightforward. On

TABLE VIII. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SAMPLES FROM AL DOHA

Sample type and No.	Sample depth (cm)	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
Filtered surface water[a]	—	1.62 ± 0.050[b]	0.0031
Filtered surface water[a]	—	4.9 ± 0.12[b]	0.0024
Filtered surface water[a]	—	4.1 ± 0.12[b]	0.0027
Soil, prior to remediation	—	13 200 ± 400[b]	0.0020
Soil, after remediation			
Sample 1	0–5	30.5 ± 0.44	0.0066
Sample 2	0–5	87 ± 1.3	0.0036
Sample 3	0–5	22.2 ± 0.42	0.0058
Sample 4	0–5	14.9 ± 0.27	0.0072
Sample 5	0–5	14.6 ± 0.26	0.0072
Sample 6	0–5	17.6 ± 0.39	0.0064
Sample 7	0–5	14.4 ± 0.24	0.0071
Sample 8	0–5	80 ± 1.2	0.0035
Soil core 1			
Layer 1	0–5	30.9 ± 0.56	0.0066
Layer 2	5–15	31.7 ± 0.80	0.0071
Layer 3	15–25	40 ± 1.6	0.0071
Layer 4	25–35	42 ± 1.3	0.0071
Soil core 2			
Layer 1	0–5	21.9 ± 0.53	0.0063
Layer 2	5–15	23.6 ± 0.38	0.0064
Layer 3	15–25	45.0 ± 0.97	0.0042
Layer 4	25–35	121 ± 3.4	0.0029
Clean soil			
Sample 1	0–20	13.0 ± 0.25	0.0072
Sample 2	0–20	13.9 ± 0.27	0.0072
Sample 3	0–20	13.4 ± 0.29	0.0072
Sample 4	0–20	14.1 ± 0.25	0.0072

[a] There was some evidence of DU in the solid residues in the samples of surface water, the $^{235}U/^{238}U$ mass ratios being in the range of 0.0061 to 0.0064.

[b] Based on total uranium concentrations measured by ICP–MS.

the basis of the present evidence there is no justification for initiating a more comprehensive monitoring programme involving sampling outside the Al Doha site.

4.1.2. Al Jahra

Al Jahra is a major and expanding urban area with a population of between 40 000 and 50 000 people. The city is affected by desert winds that bring in fine sand, and is close to scenes of past military action, such as Al Mutlaa, where DU munitions were reported to have been used. Localized points of contamination would not be expected, and therefore in the past the RPD collected material from locations where windblown sand accumulated. The results of measurements of uranium concentrations were consistent with the values expected for natural uranium in Kuwait.

To confirm these findings, the IAEA team collected six samples of surface soil during the mission in February 2002. Three of these were within 5–10 km of the city; two were taken from flat, open areas in the city centre and one from within the grounds of the Al Jahra hospital. The results showed no evidence of the presence of DU (see Table IX).

TABLE IX. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SAMPLES OF SURFACE SOIL (0–5 cm) FROM AL JAHRA

Sample No.	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
1	9.7 ± 0.21	0.0073
2	11.8 ± 0.41	0.0073
3	10.8 ± 0.25	0.0072
4	10.9 ± 0.29	0.0072
5	11.0 ± 0.43	0.0072
6	11.2 ± 0.21	0.0072

The observed concentrations of ^{238}U were consistent with the background levels, and were around the detection limit that can be achieved by the RPD. In the future, the RPD should be able to provide sufficient reassurance to the public by occasionally sampling and measuring windblown material within the city.

4.1.3. Farming areas at Al Wafrah and Al Abdali

Most of the terrestrial foodstuffs consumed in Kuwait are imported. However, some farming areas, both in the north and in the south of the country, produce crops such as tomatoes and cucumbers, mostly grown in greenhouses, as well as fodder for animals kept at the farms which provide milk and meat. The areas under cultivation at the two sites considered in this report are increasing. The farming areas of Al Wafrah are located about 120 km south of Kuwait City, near the border with Saudi Arabia. The Al Abdali farms are situated in the northern part of the country, near the border with Iraq. Both farming areas are in flat regions surrounded by desert.

The foodstuffs produced in these farming areas are consumed by local people, and there has been some concern about possible contamination with DU of both the crops grown in the areas and the brackish water used for irrigation supplied by wells located on the farms. The farms are not entirely dependent on these wells, additional water supplies being brought in from desalination plants.

Measurements of uranium concentrations in soil samples were made by the RPD around Al Wafrah, and the values were consistent with those expected from the natural background level. No measurements on crops were available prior to the sampling mission in February 2002; the RPD had previously supplied the IAEA with three samples of soil from Al Wafrah for more detailed analysis.

Some farms were bombed and three Iraqi tanks were destroyed at Al Abdali during the Gulf War, although it was not clear whether DU munitions were used. The authorities of Kuwait surveyed the location where this attack took place, and no evidence of elevated levels of uranium in the soil was found.

Two or more farms were studied in each of these areas. Samples of crops were taken and the edible parts separated for analysis. Surface soil was taken from cultivated allotment areas (Fig. 4), while some soil cores were collected from areas that had not been disturbed to investigate the distribution of activity with depth. Samples of the brackish well water were also taken; these were filtered after collection and both the filtrate and the solid residue were analysed. The results for all these samples and those supplied by the RPD are shown in Tables X–XII.

There was no evidence of the presence of DU in any of the samples of soil. There was some variability across each site, but generally this was within the range observed at the offshore sites used as controls (Table VII). A sample of fertilizer used at Al Abdali was analysed, but concentrations of ^{238}U were below the detection limit of about 0.05 mg/kg (60 mBq/kg). The application of such fertilizer would not therefore have affected the overall levels of DU in the soil.

Concentrations of uranium isotopes in the samples of crops were very low. The apparent presence of DU in some crops was considered questionable, particularly since the absolute concentrations

FIG. 4. Collection of a sample of surface soil in a greenhouse at Al Abdali.

TABLE X. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SAMPLES OF SOIL FROM THE FARMS AT AL ABDALI AND AL WAFRAH

Sample type and No.	Sample depth (cm)	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
		Al Abdali	
Surface soil			
Sample 1	0–5	21.3 ± 0.39	0.0073
Sample 2	0–5	16.6 ± 0.32	0.0072
Sample 3	0–5	14.1 ± 0.42	0.0072
Sample 4	0–5	20.6 ± 0.39	0.0072
Sample 5	0–5	18.4 ± 0.42	0.0074
Sample 6	0–5	15.6 ± 0.33	0.0074
Soil core 1			
Layer 1	0–5	12.8 ± 0.50	0.0073
Layer 2	5–15	14.3 ± 0.27	0.0073
Layer 3	15–25	13.4 ± 0.52	0.0072
Layer 4	25–35	14.1 ± 0.26	0.0073
Soil core 2			
Layer 1	0–5	13.6 ± 0.25	0.0073
Layer 2	5–15	13.4 ± 0.35	0.0072
Layer 3	15–25	13.6 ± 0.24	0.0074
Layer 4	25–35	12.5 ± 0.41	0.0073
Soil core 3			
Layer 1	0–5	13.0 ± 0.42	0.0072
Layer 2	5–15	12.6 ± 0.25	0.0073
Layer 3	15–25	14.6 ± 0.26	0.0074
Layer 4	25–35	13.1 ± 0.28	0.0074
Soil core 4			
Layer 1	0–5	18.6 ± 0.38	0.0074
Layer 2	5–15	20.2 ± 0.40	0.0074
Layer 3	15–25	16.6 ± 0.32	0.0073
Layer 4	25–35	16.9 ± 0.42	0.0073
		Al Wafrah	
Surface soils			
Sample 1	0–5	11.7 ± 0.35	0.0072
Sample 2	0–5	11.2 ± 0.24	0.0073
Sample 3	0–5	10.0 ± 0.20	0.0073
Sample 4	0–5	13.6 ± 0.27	0.0074
Sample 5	0–5	11.0 ± 0.29	0.0073
Sample 6	0–5	9.8 ± 0.29	0.0075
Sample 7	0–5	10.0 ± 0.29	0.0074
Sample 8	0–5	10.2 ± 0.23	0.0073
Sample 9	0–5	13.4 ± 0.29	0.0073
Sample 10	0–5	12.4 ± 0.28	0.0074
Sample 11	0–5	11.3 ± 0.30	0.0074
Soil core 1			
Layer 1	0–5	11.7 ± 0.23	0.0073
Layer 2	5–15	8.8 ± 0.22	0.0073
Layer 3	15–25	8.4 ± 0.17	0.0072
Layer 4	25–35	7.6 ± 0.20	0.0074
		Soil samples supplied to the IAEA by the RPD	
Sample 1	Not specified	7.34 ± 0.25[a]	0.0073
Sample 2	Not specified	55.0 ± 1.6[a]	0.0072
Sample 3	Not specified	5.3 ± 0.12[a]	0.0073

[a] Based on total uranium concentrations measured by ICP–MS.

TABLE XI. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN CROPS FROM THE FARMS AT AL ABDALI AND AL WAFRAH

Sample type	^{238}U activity concentration (mBq/kg, fresh mass)	$^{235}U/^{238}U$ mass ratio
	Al Abdali	
Tomatoes	1.13 ± 0.06	0.0052
Cucumbers	1.82 ± 0.08	0.0070
Potatoes	2.6 ± 0.13	0.0070
Onions	20 ± 1.4	0.0072
Radishes	31 ± 1.5	0.0072
Beets	100 ± 12	0.0072
	Al Wafrah	
Lettuces	2.6 ± 0.28	0.0060
Cucumbers	0.97 ± 0.08	0.0038
Cabbages	3.3 ± 0.21	0.0063
Tomatoes	0.88 ± 0.05	0.0068
Carrots	13.6 ± 0.59	0.0071

TABLE XII. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN FILTERED WATER FROM THE FARMS AT AL ABDALI AND AL WAFRAH

Sample No.	^{238}U activity concentration (mBq/L)	$^{235}U/^{238}U$ mass ratio
	Al Abdali	
1	670 ± 32	0.0072
2	1430 ± 29	0.0073
3	95 ± 2.0	0.0073
	Al Wafrah	
1	103 ± 2.1	0.0072
2	2.7 ± 0.42	0.0066
3	149 ± 4.7	0.0072
4	24.8 ± 0.75	0.0072

of ^{238}U in these samples were among the lowest observed and no DU was detectable in the associated samples of soil. A possible explanation is cross-contamination of the samples at the time of packaging in Kuwait at the end of the sampling campaign. Even if these results were accurate, the exposure of local farmers due to DU would be, in any case, extremely low. Typical annual doses that could arise to farmers residing at Al Wafrah and Al Abdali and consuming local produce would be 0.090 μSv and 0.080 μSv, respectively (see Appendix II). The assessment of these doses took account of the consumption of animal products (meat and milk) because of the possibility that locally grown fodder crops could also have been affected, and is based on the assumption that the brackish water from the local wells was also given to cattle. Moreover, in the calculation of these doses it was assumed that water used for human consumption comes from Al Rawdhatine (see Section 4.1.4). The annual doses that could arise due to DU are only a small fraction of the doses typically received due to naturally occurring uranium isotopes, which for adults living at Al Wafrah and Al Abdali were estimated to be 19 μSv and 29 μSv, respectively.

This level of dose does not warrant an intensive monitoring programme. The collection of occasional samples for reassurance and to confirm or refute the presence of traces of DU in crops could be worthwhile. The collection of kidneys from slaughtered grazing animals could be useful for these purposes because these would provide an indication of intakes of uranium from a reasonably large area of land over a considerable period of time. However, on the basis

of the present results, any analyses of foodstuffs would need to be carried out by a suitably accredited laboratory having an ICP–MS facility.

4.1.4. Al Rawdhatine

More than 99% of the bottled drinking water consumed in Kuwait is imported. However, a private company extracts water from two deep wells at Al Rawdhatine, located around 80 km north of Kuwait City, to the east of the main highway to Iraq, where considerable military action took place in the Gulf War in 1991. The wells access the same groundwater body at depths of between about 45 and 57 m. The water is pumped from the wells, filtered, ozonized, bottled on the site and then distributed throughout the country.

The RPD took samples of water from this site and determined the total alpha activity by liquid scintillation counting. The results were within the reference concentration for routine screening of 0.1 Bq/L for drinking water recommended by the WHO, and the RPD considered that only about 40% of the total alpha activity was due to isotopes of uranium. After the expert mission in September 2001, the RPD dispatched three samples of water from these wells to the IAEA for more detailed analysis. In view of the widespread use of this water throughout Kuwait, in February 2002 the IAEA team collected two further samples for more detailed analysis. One sample was taken directly from the wells and the other at random from bottled water that was ready for sale. Both samples were filtered and then acidified before analysis. The results are given in Table XIII. No DU could be detected in any of the samples. The $^{235}U/^{238}U$ mass ratio in the solid residue from the sample taken directly from the wells was lower than the value for natural uranium. This value can be accounted for by the uncertainties in the measurements and is not indicative of the presence of DU in water extracted at Al Rawdhatine. Even if traces of DU were actually present in the water at the levels inferred from the estimate of the $^{235}U/^{238}U$ mass ratio in the solid residue, any possible radiological consequences would be extremely minor. On this basis a typical dose to an adult that could arise from the consumption of drinking water from Al Rawdhatine would be 0.072 μSv (see Appendix II).

4.1.5. Al Mutlaa

The site of Al Mutlaa is a few kilometres north of Al Jahra, where the land rises by about 100 m to a plateau that extends towards the border with Iraq. The main road to Iraq follows this route, passing through a gully before reaching the plateau. In the Gulf War a retreating convoy of Iraqi vehicles, including tanks, and troops was isolated in the gully and on the plateau, and was attacked. It has been reported that a large number of DU rounds were used in the air raid.

The vehicles destroyed in the attack have been removed and the road has been completely resurfaced. The area is popular with campers during the cooler months of the year. The RPD carried out an instrument survey and analysed five soil samples from the sandy areas close to the road. The results indicated that the levels of uranium were consistent with the background levels across Kuwait.

The IAEA team was requested to confine its attention to the areas close to the road. Eight samples of surface soil were collected in pairs, one on either side of the road, at intervals of 2.5 km. Two samples of vegetation (thorny bush and grass) were also collected. The results are shown in Table XIV. None of the samples of either soil or vegetation contained detectable amounts of DU, and the concentration of ^{238}U in the soil samples was consistent with the values expected generally in soil in Kuwait, in agreement with the RPD's findings. There seems little justification for continued monitoring in this area.

4.1.6. Al Sabhan and the Military Hospital storage ground

Both Al Sabhan and the Military Hospital storage ground are in the outskirts of Kuwait City, a

TABLE XIII. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN FILTERED WATER FROM AL RAWDHATINE

Sample No.	^{238}U activity concentration (mBq/L)	$^{235}U/^{238}U$ mass ratio
1	22.3 ± 0.80	0.0073
2	19.8 ± 0.83	0.0073

TABLE XIV. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SURFACE SOIL (0–5 cm) ALONGSIDE THE HIGHWAY AT AL MUTLAA

Sample No.	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
1	10.4 ± 0.25	0.0073
2	12.6 ± 0.24	0.0073
3	7.9 ± 0.27	0.0072
4	8.6 ± 0.21	0.0073
5	12.0 ± 0.30	0.0072
6	14.6 ± 0.25	0.0071
7	8.8 ± 0.17	0.0072
8	11.3 ± 0.20	0.0071

few kilometres south of the city centre, and since they are adjacent they were considered together. The sites are close to public amenities and public areas and buildings, including a hospital and a racetrack.

The site at Al Sabhan was used as an initial storage location for several thousand damaged and destroyed Iraqi vehicles, some of which were contaminated with DU. The contaminated vehicles were segregated into an area of about 100 m^2. After about 18 months the vehicles were moved to the storage area near the Military Hospital. No vehicles are currently kept in the area at Al Sabhan.

The Military Hospital storage ground has been used to store several thousand uncontaminated vehicles for around eight years. Originally, 53 vehicles contaminated with DU were also kept there in a segregated area, but these have now been transferred to Um Al Kwaty (Section 4.1.8). One tank showing contamination with DU, however, was found still to be at this location in the sampling campaign. Access to this site is restricted.

The requirement at both sites was to assess the possible radiological consequences of any residual DU. Four samples of surface soil were taken at Al Sabhan from within the area where contaminated tanks had been stored. The results are shown in Table XV. No DU could be detected in any of the samples, and again the concentrations of ^{238}U were consistent with what would be expected generally in Kuwait.

Four samples of soil were taken from the surface (0–5 cm) at the Military Hospital storage site, adjacent to the area where the contaminated tanks had

TABLE XV. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SOIL AT THE MILITARY HOSPITAL VEHICLE STORAGE GROUND AND AT AL SABHAN

Sample type and No.	Sample depth (cm)	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
	Military Hospital storage ground		
Surface soil			
Sample 1	0–5	12.0 ± 0.26	0.0072
Sample 2	0–5	16.5 ± 0.43	0.0072
Sample 3	0–5	16.9 ± 0.24	0.0066
Sample 4	0–5	41 ± 1.0	0.0038
Soil core 1			
Layer 1	0–5	10.8 ± 0.38	0.0070
Layer 2	5–15	12.3 ± 0.24	0.0071
Layer 3	15–25	11.2 ± 0.40	0.0071
Layer 4	25–35	10.3 ± 0.17	0.0071
	Al Sabhan		
Surface soil			
Sample 1	0–5	12.5 ± 0.25	0.0072
Sample 2	0–5	12.2 ± 0.27	0.0072
Sample 3	0–5	11.2 ± 0.23	0.0072
Sample 4	0–5	12.9 ± 0.19	0.0072

been stored; a soil core was also collected. One of the samples of surface soil was taken close to the DU contaminated tank that was still present. These results are given in Table XV. These samples indicated that some DU was present in some parts of the area formerly used to store contaminated tanks. However, the highest concentrations of ^{238}U observed were only about two to four times the value expected from the natural background levels across Kuwait. Someone who worked on this part of the site could, on the basis of cautious assumptions, receive an annual dose from DU of about 3.3 μSv (see Appendix II). Annual doses that could arise to any members of the public using the area for recreation would be less than 1 μSv. Doses to members of the public making use of nearby facilities would be lower still. While access remains restricted, there is little justification for continued monitoring. However, if in the future the site were to be developed for public use then some further measurement might be advisable. The facilities currently available at the RPD would be sufficient for this purpose.

4.1.7. Manageesh oilfields

The Manageesh oilfields cover a very large area southwest of Kuwait City. Owing to its strategic importance, the area was occupied by a large number of Iraqi troops with a great deal of military equipment, and was subjected to repeated air raids involving DU ammunition during the Gulf War. The area as a whole is still thought to contain several hundred unexploded landmines and cluster bombs. Access to this area is restricted, and field work can only be carried out at a few locations under the supervision of experts on explosives, who have been working to clear the area of landmines and other unexploded ordnance for over 10 years.

The locations specified for study were close to Manageesh Gathering Centre 28 (GC 28) and Umm Gudayar Gathering Centre 18 (GC 18). The area selected for study at Manageesh GC 28 was surveyed by the RPD in mid-2001, and all the penetrators located had been removed at the time of the survey. The approach adopted by the RPD to investigate the site would have detected penetrators to a depth of a few centimetres in the sand. When the senior experts visited the site in September 2001, further penetrators (Fig. 5) were visible on the sand surface, together with fragments of uranium oxide, which were clearly visible because of their yellow colouration. Further penetrators were found on the sand surface when the sampling teams visited the site in February 2002. This was a good illustration of the continual movement of sand in these areas, which results in the appearance of previously buried and undetected material.

The requirements at these sites were:

(a) To assess the doses that could arise under ambient and sandstorm conditions from the inhalation of resuspended material;
(b) To assess the doses that could arise if contaminated soil were resuspended after a conventional explosion.

This second requirement arose because of the occasional need for those people clearing the area of unexploded munitions to carry out controlled explosions. The possible presence of penetrators among the debris in destroyed buildings and facilities such as pumping equipment was not considered. The clearance of such areas will take a considerable period of time to complete, and will require health physics monitoring by the RPD as well as inspection by explosives experts.

To determine the distribution of DU in soil around and below where penetrators had been found, both surface soil samples and soil cores were collected at Manageesh GC 28. One soil core was taken where a penetrator was retrieved and a second core was collected a few metres away. The RPD had carried out a similar sampling exercise at Manageesh GC 28 in 2001, prior to the visit by the experts, and these samples had already been sent to the IAEA for detailed analysis. The results are given in Table XVI.

At the Umm Gudayar GC 18 site there are an oil pumping station and some related service buildings

FIG. 5. Penetrator found at the Manageesh GC 28 site.

TABLE XVI. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SOIL AT MANAGEESH GC 28

Sample type and No.	Sample depth (cm)	^{238}U activity concentration (Bq/kg)[a]	$^{235}U/^{238}U$ mass ratio
Samples collected during the February 2002 mission			
Surface soil			
Sample 1	0–5	13.8 ± 0.37	0.0044
Sample 2	0–5	24.6 ± 0.75	0.0034
Sample 3	0–5	5.8 ± 0.12	0.0065
Sample 4	0–5	8.8 ± 0.25	0.0051
Sample 5	0–5	6.3 ± 0.25	0.0064
Sample 6	0–5	8.5 ± 0.25	0.0054
Sample 7	0–5	6.0 ± 0.12	0.0066
Soil core 1, just below corroded penetrators			
Layer 1	0–5	49 000 ± 1500	0.0021
Layer 2	5–15	101 ± 2.5	0.0023
Layer 3	15–25	45 ± 1.2	0.0027
Layer 4	25–35	26.1 ± 0.75	0.0031
Layer 5	35–45	21.1 ± 0.62	0.0033
Soil core 2, away from corroded penetrators			
Layer 1	0–5	5.7 ± 0.12	0.0066
Layer 2	5–15	5.7 ± 0.12	0.0066
Layer 3	15–25	5.7 ± 0.12	0.0070
Layer 4	25–35	6.5 ± 0.25	0.0059
Samples collected previously by the RPD			
Surface soil			
Sample 1	Not specified	1220 ± 36	0.0022
Sample 2	Not specified	91 ± 2.7	0.0023
Sample 3	Not specified	960 ± 29	0.0022
Sample 4	Not specified	180 ± 5.0	0.0021
Sample 5	Not specified	7.46 ± 0.25	0.0066
Soil core 1, just below a penetrator			
Layer 1	0–5	19 700 ± 600	0.0021
Layer 2	5–15	820 ± 25	0.0020
Layer 3	15–25	34.1 ± 0.99	0.0032
Layer 4	25–35	29 ± 1.2	0.0035
Soil core 2, just below a penetrator			
Layer 1	0–5	94 000 ± 2800	0.0020
Layer 2	5–15	78 ± 2.5	0.0026
Layer 3	15–25	27.4 ± 0.87	0.0035

[a] Based on total uranium concentrations measured by ICP–MS.

that were destroyed by air raids in which DU munitions were fired. The area surrounding the site has not been cleared of unexploded landmines and cluster bombs and, consequently, samples could be collected only in the area adjacent to the destroyed pumping equipment and buildings. Five surface soil samples and two soil cores were collected during the February 2002 mission. The results are shown in Table XVII.

Some DU was present in all samples of surface soil collected from around Manageesh GC 28. Concentrations of ^{238}U in soil underneath a penetrator were high, but decreased rapidly with depth and with distance from the penetrator. In many cases,

TABLE XVII. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SOIL AT UMM GUDAYAR GC 18

Sample type and No.	Sample depth (cm)	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
Surface soil			
Sample 1	0–5	9.7 ± 0.23	0.0071
Sample 2	0–5	20.2 ± 0.32	0.0072
Sample 3	0–5	8.1 ± 0.19	0.0066
Sample 4	0–5	8.1 ± 0.19	0.0071
Sample 5	0–5	5.8 ± 0.11	0.0070
Soil core 1			
Layer 1	0–5	10.5 ± 0.18	0.0069
Layer 2	5–15	10.7 ± 0.17	0.0072
Layer 3	15–25	9.5 ± 0.44	0.0073
Layer 4	25–35	10.8 ± 0.26	0.0071
Soil core 2			
Layer 1	0–5	15.0 ± 0.23	0.0071
Layer 2	5–15	14.4 ± 0.27	0.0072
Layer 3	15–25	14.6 ± 0.22	0.0071
Layer 4	25–35	18.7 ± 0.49	0.0073

even though DU was detectable, the concentrations of ^{238}U were around the natural background levels expected in Kuwait.

The results at Manageesh GC 28 indicated that it would not be appropriate to assess the radiological conditions simply on the basis of the highest observed activity concentrations in the surface soil (i.e. those in the immediate vicinity of a penetrator), because resuspended dust derives from a wide area. For this reason, the evaluation of doses from resuspension under ambient conditions was based on the average concentrations of uranium isotopes in the surface soil samples collected during the campaign of February 2002 and shown in Table XVI. In ambient conditions it was estimated that annual doses to hypothetical adults and 10 year old children living and working in the Manageesh GC 28 area would be about 13 μSv and 6.0 μSv, respectively (see Appendix II). Estimated annual doses for Umm Gudayar GC 18 would be significantly lower (0.27 μSv and 0.1 μSv for hypothetical adults and 10 year old children, respectively). Although the amount of dust resuspended during a sandstorm could be high, it is unlikely that a person would spend a long time in such conditions without some form of protection. Doses received during sandstorms are therefore unlikely to exceed the doses received in normal conditions or to affect significantly the doses calculated for ambient conditions.

To assess the likely doses resulting from controlled explosions, two experiments were carried out within the restricted area at Um Al Kwaty using soil collected from around Manageesh GC 28. The experiments are described in detail in Appendix III. Although the results of these experiments should be interpreted with caution, since they followed a protocol that may only approximately represent real conditions, and any extrapolation to different conditions may not be justified, the experiments provided some useful information on the behaviour of DU resuspended by means of an explosion.

A composite sample of about 900 kg of sand was collected from an area of about 200 m in diameter at Manageesh GC 28. A small sample was taken for analysis. The activity concentration of ^{238}U in this soil was about 9.7 Bq/kg, with a $^{235}U/^{238}U$ mass ratio of 0.0050, indicating that 43% by mass of the uranium in the sample was depleted. These values are similar to the average total activity concentration of uranium (10.8 Bq/kg) and percentage of DU by mass (47%) used in the assessment of doses at this site (see Appendix II).

The quantity of explosive used replicated the explosion of a landmine, and a series of air samplers was placed at various distances downwind. Air sampling began before the explosion took place and continued for about 1 h afterwards, with filters being changed at intervals of about 20 min. In one

experiment the resuspended material reached an altitude of about 50 m, but after about 12 s no dust was visible. In the second experiment more explosive was used and the dust reached an altitude of about 70 m, but no dust was visible after about 20 s. Most of the air filters did not contain detectable uranium. The most notable exception was during the period immediately after the explosion, when activity was only detectable in the filter situated 25 m from the explosion. The $^{235}U/^{238}U$ mass ratio was 0.0022, which corresponds to a fraction of DU by mass of around 96%. This result may indicate that DU is associated with lighter fractions than the natural uranium in the soil. However, the amount of uranium that might be inhaled was estimated to be less than 1 ng (see Appendix III), which corresponds to 0.0012 mBq. This activity is 2000 times lower than the activity of natural uranium inhaled annually by a typical adult living in Kuwait City (see Appendix II). The absence of any measurable quantity of DU in the airborne dust collected by the samplers positioned at distances of 50 m and further from the explosion indicates that transport of resuspended DU over such distances is very unlikely.

The radiological consequences of DU in the soil for people working in the area are therefore likely to be minor. The widespread presence of unexploded ordnance means that access to this area will be restricted for a considerable period of time.

4.1.8. Um Al Kwaty

This site is within the perimeter of the Ali Salem air force base, and access to it is restricted. This site is used to store several thousand Iraqi military vehicles destroyed during the war, among them 105 tanks contaminated with DU. The 53 vehicles formerly kept at the Military Hospital storage site are in a designated area. The remainder were recovered from different parts of Kuwait and are stored alongside uncontaminated tanks in different parts of the site. The tanks had been surveyed and marked by the RPD and the holes caused by DU munitions in a number of tanks were counted and measured.

The site also contains 366 heaps of contaminated soil from Al Doha (Section 4.1.1), each heap being a single truckload of about 10 t (Fig. 6). These heaps contain ash from the fire at Camp Doha, fragments of ammunition and other metallic debris, and are contaminated with DU in the form of uranium oxides.

The requirements at this site were to make an estimate of the total amount of DU in the soil removed from Al Doha, estimate the amount of DU that could be lost readily from the outside of tanks during storage and during any subsequent disposal owing to the corroded DU contaminated holes caused by the impact of DU munitions, and estimate the amount of DU that might still be inside the tanks.

Samples were taken from 11 of the heaps of contaminated soil. The results are given in Table XVIII. These indicated that, as expected, concentrations of ^{238}U were very variable, but an average value would be about 5000 Bq/kg. This represents a total inventory of about 1.8×10^{10} Bq of ^{238}U, which corresponds to around 1.5 t of DU. In terms of waste management, the stability of the soil is a primary concern, given that material can be dispersed during sandstorms. Consideration therefore needs to be given to simple, cost effective ways in which such dispersion could be prevented.

If all the DU in the heaps of contaminated soil originated from 120 mm penetrators, the number of penetrators giving rise to this quantity of DU would be about 300. This number is consistent with the information provided by the US Army (see Section 4.1.1).

Swipe samples were taken from around and within penetrator holes in 11 contaminated tanks, six in the designated area and five stored elsewhere on the site. No more than about 100 Bq of ^{238}U was transferred to any of the swipes. The swipes were taken using 100 cm^2 clean cotton cloths, as used by the IAEA's safeguards inspectors to collect environmental samples on solid surfaces.

With some cautious assumptions about the amount that might be lost from each tank, further

FIG. 6. Heaps of debris containing DU at Um Al Kwaty.

TABLE XVIII. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN SOIL AT UM AL KWATY

Sample No.	^{238}U activity concentration (Bq/kg)	$^{235}U/^{238}U$ mass ratio
1[a]	54 ± 4	Not measured
2[a]	84 ± 6	Not measured
3[b]	224 ± 6.2	0.0029
4[a]	15 000 ± 300	Not measured
5[b]	15 100 ± 450	0.0021
6[a]	117 ± 7	Not measured
7[a]	15 800 ± 300	Not measured
8[b]	63.0 ± 2.5	0.0047
9[b]	940 ± 29	0.0022
10[b]	2570 ± 75	0.0021
11[b]	241 ± 7.5	0.0028

[a] The activity concentration of ^{238}U was measured by gamma spectrometry.

[b] Based on total uranium concentrations measured by ICP–MS.

movement could give rise to localized concentrations of ^{238}U in soil of only around three times the value considered typical of the natural background levels in Kuwait, which is reasonably consistent with the values observed in surface soil at the former storage site at the Military Hospital.

The amount of DU remaining in the tanks was estimated on the basis of the number of holes in each tank (Fig. 7) and of published information on the types of munitions used. In 2001 the RPD carried out a survey of the number of holes found in tanks stored at Um Al Kwaty, which is summarized in Table XIX. The RPD's survey indicated that typically two penetrators were used against a single tank and that the holes were mostly caused by 120 mm penetrators containing about 4.64 kg of DU. On about 40 tanks contamination was detected, but no holes were found because of the effects of explosions, and about one third of the tanks had more than 10 holes, probably caused by fragments of DU munitions created by the impact. The survey also indicated that dose rates on the surface of the contaminated tanks near the holes were in the range of 1.1 to 1.4 μSv/h.

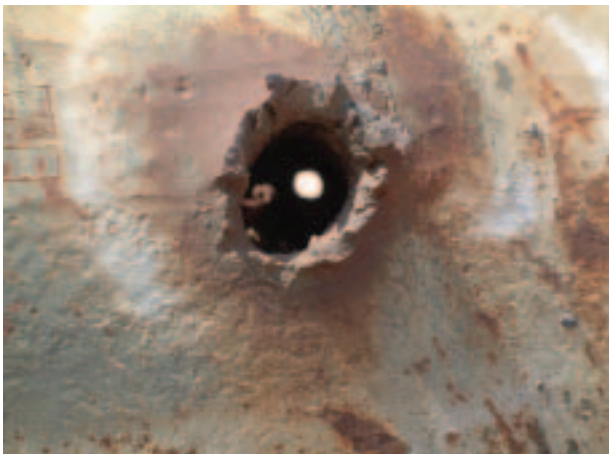

FIG. 7. Hole caused by the impact of a DU munition in a tank stored at Um Al Kwaty.

A certain amount of DU is aerosolized after impact, but information collated by the United Kingdom's Royal Society indicates that the proportion is variable; a value of 2–3% was considered typical for a 4 kg penetrator [8]. Since the aim of this study was to provide a broad estimate of the inventory on the site, it was cautiously assumed that all the DU in each penetrator remained in the tank. On this basis, the total amount of DU remaining in the contaminated tanks would be of the order of 1 t.

There seems little justification in taking special, expensive measures to reclaim the materials in these vehicles, given that the number of tanks contaminated with DU is small compared with the total number of vehicles at this site. The transfer of all the contaminated tanks to the segregated area would be warranted, after which consideration needs to be given to cost effective ways in which they can be stored or disposed of without further treatment. Burial would be a cost effective option provided that steps were taken to ensure that the overlying sand is kept in place, for example by the use of retaining walls.

4.1.9. Kuwait City

Kuwait City is the main centre of population in Kuwait. The RPD has carried out monitoring of airborne dust at various locations in the city for several years. Some samples of air filters collected during 2001 were sent to the IAEA for detailed analysis after the first expert mission. The glass fibre filters used by the RPD contained small and variable amounts of naturally occurring uranium. Caution is therefore required in using these data to estimate activity concentrations in air. More importantly, the $^{235}U/^{238}U$ mass ratios indicated that no DU was present. During the second mission a further four samples were collected using Teflon or cellulose filters that do not contain uranium. The results for

TABLE XIX. NUMBER AND SIZE OF HOLES DUE TO DU PENETRATORS IN TANKS STORED AT UM AL KWATY

Tank No.	No. of holes	Shape of holes	Size of holes (cm)			
1	1	Elliptic	4 × 6	—	—	—
15	3	Elliptic	3.5 × 4	3.5 × 5	4 × 5	—
—	3	Circular	5.8 × 5.8	5.8 × 5.8	5.8 × 5.8	—
27	2	Circular, elliptic	7 × 7	6.5 × 10	—	—
33	1	Circular	10 × 10	—	—	—
34	1	Elliptic	9.5 × 22	—	—	—
35	2	Elliptic	7.5 × 8.5	6.5 × 8.5	—	—
36	1	Elliptic	7.5 × 9.5	—	—	—
37	1	Circular	6.4 × 6.4	—	—	—
38	2	Elliptic	6.5 × 11	3.5 × 4.5	—	—
39	>10	Elliptic	4.4 × 6.2	5 × 10	—	—
45	1	Elliptic	5.7 × 7	—	—	—
48	2	Elliptic	7 × 8	4 × 5	—	—
51	>10	Elliptic	8 × 10	—	—	—
52	1	Elliptic	6.5 × 18	—	—	—
53	>10	Circular, elliptic	6.7 × 6.7	—	—	—
54	>10	Circular, elliptic	4.5 × 6.5	7.5 × 7.5	8 × 9	6 × 10
55	>10	Circular, elliptic	6.7 × 6.7	—	—	—
59	1	Elliptic	4.4 × 5	—	—	—
60	>10	Circular, elliptic	5.5 × 6	6 × 11	6.5 × 9	6 × 8
61	>10	Circular, elliptic	5 × 7	5.5 × 7	—	—
62	1	Elliptic	6.3 × 6.6	—	—	—
64	2	Elliptic	5.5 × 9	5.9 × 13	—	—
65	1	Elliptic	4.5 × 5	—	—	—
67	>10	Circular, elliptic	6 × 8	6 × 6	5.5 × 6	—
69	>10	Circular, elliptic	5.5 × 6	5.5 × 6	4.7 × 4.7	—
70	>10	Circular, elliptic	6.4 × 7.5	6 × 6	5 × 6	—
86	1	Elliptic	3.5 × 10.5	—	—	—
88	2	Elliptic	3.7 × 7.3	12 × 16	—	—
89	2	Circular, elliptic	7 × 7	7.5 × 8.5	—	—
91	2	Elliptic	14.1 × 6	6 × 6.2	—	—

these samples are shown in Table XX. The values would correspond to an annual dose of less than 2 μSv (see Appendix II).

These results are consistent with the data published by UNSCEAR [5] (see Table IV), and showed no evidence of the presence of DU. In terms of the total activity on individual filters, the values measured by the IAEA using sensitive analytical techniques were below the detection limits that could be achieved by the equipment at the RPD. However, the RPD's equipment would be sufficient to detect any concentrations that would give cause for radiological concern. A change to filters free of uranium would be advisable.

4.2. GENERAL ASSESSMENT OF EXTERNAL EXPOSURE DUE TO DU MUNITIONS

DU munitions were found both by the RPD and by the senior experts and members of the IAEA sampling team during this study. It cannot be excluded therefore that fragments of DU penetrators or entire munitions might still be found and collected by members of the public at locations in Kuwait where DU munitions were used in the Gulf War. Individuals who might handle DU munitions could be exposed to external radiation emitted by DU. The main radiation emitted by isotopes of

TABLE XX. ACTIVITY CONCENTRATIONS OF ^{238}U AND $^{235}U/^{238}U$ MASS RATIOS IN AIR IN KUWAIT CITY

Sample No.	^{238}U activity concentration ($\mu Bq/m^3$)	$^{235}U/^{238}U$ mass ratio
1	1.60 ± 0.05	0.0072
2	1.73 ± 0.06	0.0072
3	1.85 ± 0.06	0.0072
4	1.36 ± 0.04	0.0072

uranium is alpha particles, which have a range in air of the order of one centimetre; in the case of tissue, they can barely penetrate the external dead layer of the skin. Therefore, the dose due to external exposure to the radiation emitted by uranium isotopes in DU would be significant only if the person exposed were in contact with DU munitions or fragments. This is not the case, however, with natural uranium, as people are also exposed to the more penetrating beta and gamma radiation emitted by the decay products of uranium that are normally found in equilibrium with the uranium isotopes. In the case of DU, the only beta emitting decay products present are ^{234}Th, ^{234m}Pa and ^{231}Th, all of which emit low intensity gamma radiation, and thus the risk from external exposure to DU is considerably lower than that from exposure to natural uranium. The contact dose rate to the skin from a DU penetrator has been estimated to be about 2.3 mSv/h, primarily from beta particle decay of DU progeny [11]. At this dose rate it is unlikely that even prolonged contact with a DU penetrator would lead to skin burns (erythema) or any other acute radiation effect. Nevertheless, the dose that could be delivered from handling DU munitions is such that the exposure and handling time should be kept to a minimum, and protective gloves should be worn when DU munitions are being handled.

5. FINDINGS AND CONCLUSIONS

5.1. OVERALL FINDINGS AND CONCLUSIONS

On the basis of the measurements carried out for the sites investigated during the study and summarized in this report, DU does not pose a radiological hazard to the population of Kuwait. Estimated annual radiation doses that could arise from exposure to DU residues are very low and of little radiological concern. Estimated annual radiation doses that could arise in the areas where residues do exist are of the order of a few microsieverts, well below the annual doses received by the population of Kuwait from natural sources of radiation in the environment and far below the action level of 10 mSv suggested by the ICRP as a criterion to establish whether remedial actions are necessary.

Complete DU penetrators or fragments can still be found at some locations where these weapons were used in the Gulf War, such as at the oilfields at Manageesh. Prolonged contact with these DU residues is the only possible exposure pathway that could result in exposures of radiological significance. As long as access to the areas remains restricted, the likelihood that members of the public could pick up or otherwise come into contact with these residues is low.

The authorities of Kuwait have the competence and equipment to carry out the necessary monitoring and survey activities in relation to DU. The gamma spectrometry analysis technique used by the RPD is sufficient to determine whether concentrations of uranium in environmental samples give cause for radiological concern.

5.2. SITE SPECIFIC FINDINGS AND CONCLUSIONS

This section describes the findings and conclusions reached regarding the radiological conditions at the sites investigated in this study. The locations selected for investigation include sites at which DU munitions were used in the Gulf War, sites at which DU residues have been stored and sites for which concern has been expressed about the possible contamination of water and foodstuffs with DU. Results are presented for each site investigated; locations with similar characteristics have been grouped together. Findings based on the analysis of air samples provided by the RPD for Kuwait City are also presented.

5.2.1. Al Doha

Concentrations of DU in the soil collected from Al Doha were low and the values for total uranium were within the range expected for naturally occurring uranium in the soils of Kuwait. Remediation at this site has been effective in reducing environmental levels of DU. The maximum possible annual dose now due to exposure to DU for an individual working at the site was calculated to be less than 8 μSv, almost entirely from the inhalation of resuspended material.

5.2.2. Al Jahra and Al Mutlaa

There was no evidence of DU in the samples of soil collected from the city of Al Jahra. The main road leading from Al Jahra to the border with Iraq has been resurfaced since 1991. There was no evidence of DU in soil taken from areas on either side of the road in the vicinity of Al Mutlaa.

5.2.3. Al Sabhan and the Military Hospital storage ground

These locations were used in the past to store DU contaminated tanks and military vehicles. No DU was measured in samples of soil taken from Al Sabhan, but there was evidence of the presence of DU at the Military Hospital storage ground. Estimated doses that could arise owing to exposure to DU at the Military Hospital storage area are low; the maximum possible annual dose was calculated to be 3.3 μSv, almost entirely from the inhalation of resuspended material.

5.2.4. Al Rawdhatine

No DU was measured in the samples of filtered water extracted from the deep wells at Al Rawdhatine. However, the $^{235}U/^{238}U$ mass ratio measured in the solid residue on a water filter was lower than the value expected for natural uranium, but this can be accounted for by the uncertainties in the measurements. Even if this lower ratio were indicative of the presence of DU, the estimated

annual dose that could arise from the ingestion of DU in drinking water would be very low (less than 0.08 μSv).

5.2.5. Farming areas at Al Wafrah and Al Abdali

Concentrations of uranium in the foodstuff samples collected at the farms were low and of little radiological significance; possible annual doses that could arise for people living in these areas were estimated to be less than 0.1 μSv. However, uncertainty remains as to whether the $^{235}U/^{238}U$ mass ratio measured in some of the vegetables collected at the farms at Al Wafrah and Al Abdali can be attributed to the presence of DU, as no evidence of DU could be found in the corresponding soil samples. There was an indication of the possible presence of DU in the brackish water from wells at the farms at Al Wafrah, but not in the water from wells at the farms at Al Abdali.

5.2.6. Manageesh oilfields

DU was readily detectable in many of the samples of soil taken from the oilfields at Manageesh. Activity concentrations were variable, but the annual radiation doses that could be received by people working in the area are small. The annual doses due to exposure to DU that could be received by hypothetical adults assumed to work and live in the vicinity of Manageesh GC 28 were estimated to be about 13 μSv, almost entirely from the inhalation of resuspended material. The corresponding values for Umm Gudayar GC 18 were much lower (less than 0.3 μSv).

Inhalation of DU is not expected to pose any radiological hazard to people who carry out controlled explosions in situ. The resuspension experiments carried out at Um Al Kwaty using sand from Manageesh GC 28 indicate that an adult standing in the proximity of the explosion would inhale less than 1 ng of DU, corresponding to 0.0012 mBq, which is about 2000 times lower than the activity of natural uranium inhaled annually by a typical adult living in Kuwait City.

5.2.7. Um Al Kwaty

The debris removed from Al Doha and stored at Um Al Kwaty is estimated to contain about 1.5 t of DU. The tanks stored at the site are estimated to contain a total of about 1 t of DU. The investigation also showed that surface contamination of DU on the tanks is not readily removable.

The transfer of all the contaminated tanks to the segregated area would be warranted, after which consideration needs to be given to cost effective ways in which they can be stored or disposed of without further treatment.

5.2.8. Kuwait City

No specific areas in Kuwait City were investigated in this study. Analysis of air samples provided by the RPD shows that there is no evidence of any ingress of DU into Kuwait City.

6. RECOMMENDATIONS

(1) The results of this study indicate that no remedial measures are necessary at any of the sites investigated other than those that are currently being implemented at Al Doha and those required to deal with the residues of DU currently stored at Um Al Kwaty.

(2) The approach to remediation being adopted at Al Doha, which involves the removal of all the remaining debris to the Um Al Kwaty military base and the covering of the contaminated area with fresh, uncontaminated soil, is effective. Since the sea occasionally floods the area, it would be advisable to consider simple ways in which the clean soil could be stabilized. Monitoring to assess the effectiveness of further remediation can be carried out by the RPD using existing equipment. On the basis of the present evidence, monitoring further away from the site is not warranted.

(3) The authorities of Kuwait should give consideration to ways in which the residues of DU from Al Doha currently stored at Um Al Kwaty can be stabilized, since sandstorms are common and could result in the dispersal of the material[3].

(4) The group of experts considered that efforts to decontaminate the tanks stored at Um Al Kwaty would not be warranted, in view of the small but significant radiation hazards that would be involved in the decontamination process, and because of the management problems that would be associated with the radioactive waste generated. Storage or disposal of the tanks without further treatment should instead be considered. Burial would be a cost effective option provided that steps were taken to ensure that the overlying sand is kept in place.

(5) An intensive monitoring programme at the farming areas of Al Wafrah and Al Abdali and at the water extraction facility of Al Rawdhatine is not warranted on the basis of radiological protection considerations, although, in view of public concern about the possible contamination of foodstuffs, occasional measurements may be justified. However, the analysis of the samples would need to be carried out by a laboratory at which ICP–MS was operational on a regular basis.

(6) While restrictions remain in place, there is little justification for continued monitoring at the Military Hospital storage ground. However, if the site were to be developed for future use then some further measurements might be warranted. The facilities currently available at the RPD would be adequate for this purpose. The tank contaminated with DU uncovered during the sampling campaign of February 2001 should be moved to the designated area at the Um Al Kwaty military base.

(7) The authorities of Kuwait should ensure the safe removal of DU munitions from the sites where DU penetrators were found in the investigation and from any other areas of the country where significant numbers of DU munitions are found in the future. The authorities of Kuwait should also consider informing the local residents and workers at such sites of the possible hazards associated with collecting DU munitions or fragments.

[3] It is understood that since the expert mission to Kuwait the authorities of Kuwait have taken appropriate steps to ensure that the residues of DU from Al Doha currently stored at Um Al Kwaty are stabilized.

Appendix I

EVALUATION OF THE RELIABILITY OF THE DATA ON DU PROVIDED BY THE RPD OF THE MINISTRY OF HEALTH OF KUWAIT

I.1. INTRODUCTION

This appendix is divided into two parts. Section I.2 deals with the evaluation of the data on uranium concentrations in soil samples and air filters provided to the IAEA by the RPD. Section I.3 deals with an intercomparison exercise organized by the RPD and the Agency's Laboratories at Seibersdorf. This intercomparison involved the analysis of three soil samples, three air filters, an IAEA reference material and a DU contaminated soil sample from Al Doha, one of the sites investigated.

I.2. EVALUATION OF THE DATA PROVIDED BY THE RPD

During the mission of the senior experts to Kuwait in September 2001, it was noted that the RPD had carried out a considerable number of analyses for uranium in soil samples and air filters, for which an extensive database existed. To make maximum use of the resources available for the environmental assessment and to minimize the need for additional sampling and analysis, the senior experts recommended that the database be reviewed to determine whether the existing RPD data could be used as a basis for the assessment.

In September 2001 the RPD provided the IAEA with a preliminary report entitled Concentration of Uranium in Soil from the Wafrah Region, which contained data on uranium levels in eight sets of air filters and a number of soil samples from various regions. A second report, dated 28 October 2001, was received at the Agency's Laboratories at Seibersdorf on 5 November 2001. This latter report contained almost the same data on uranium concentrations in air filters and soil as the first report but also included information on the protocols, standards used and background spectral data needed for a thorough evaluation. These reports were evaluated by specialists at the Agency's Laboratories at Seibersdorf with expertise in the relevant area. The results of the evaluation are summarized below.

I.2.1. Air filter data

Both reports provided by the RPD contained eight tables on uranium activity concentrations in air derived from gamma spectrometric measurements of air filters spanning the period 1993–2000 (one table for each year). Comparison of the eight tables in both reports indicated that, with the exception of the data table for 2000, the number and identification of filters in corresponding tables were the same. For 2000, each report listed results for a different number and set of filters. As the information on air filters was more comprehensive in the report dated 28 October 2001, the evaluation of air filter data was mainly based on that report.

Each of the eight tables listed the air filter sample number, collection date, mass of deposit, net counts in the ^{234}Th photopeak at 63.3 keV, the volume of air sampled and the calculated uranium activity concentration in the air during the sampling period. These data were evaluated together with details of the measurement protocol (i.e. the counting period, specifications of the gamma spectrometer used, background spectral information and standards used as well as corrections applied).

The conclusions reached were that most of the values reported for the air filters appear to be well below the detection limit expected for the measurement conditions and the gamma spectrometry system in use. To determine whether the reported results were realistic, the air filter samples sent from Kuwait for the intercomparison exercise were measured again by the IAEA using a gamma spectrometer at the Agency's Laboratories at Seibersdorf specifically designed for the measurement of the low energy gamma rays from ^{234}Th. For comparison, the specifications of the gamma spectrometers and the details of the measurement parameters are listed in Table XXI.

With the longer counting period and higher measurement efficiency, the IAEA's minimum detectable activities (MDAs) should be three to four times lower than those quoted by the RPD. Based on the specifications of the RPD's gamma spectrometry

TABLE XXI. COMPARISON OF RPD AND IAEA GAMMA SPECTROMETER SPECIFICATIONS AND MEASUREMENT PARAMETERS FOR AIR FILTER SAMPLES

Parameter	RPD	IAEA
Gamma spectrometer specifications	P-type; 26% relative efficiency	N-type; 35% relative efficiency
Counting period	50 000 s	246 000–346 000 s
Efficiency at 63.3 keV	8%	18%
Efficiency at 92.8 keV	10%	20%

system and measurement conditions, a more realistic evaluation of the MDAs for the RPD data is shown in Table XXII.

It can be concluded that most of the RPD's data for air filters are below the actual MDAs, indicating that the total uranium concentration generally does not exceed approximately 1.0 Bq per filter.

Evaluation of the RPD's air filter data also revealed the following:

(a) There are data reported (table of 1997 data in the first report) for which the net number of counts in the ^{234}Th photopeak at 63.3 keV was negative after background subtraction. Nevertheless, the final activity concentrations of ^{234}Th in air (in Bq/m^3) were calculated as positive values.
(b) Apparently the same detector efficiency was used for more than six years. The example provided of a full efficiency calibration was dated January 1995. Generally, gamma spectrometers should be calibrated for efficiency response every year, as their characteristics change with time and they are subject to loss of vacuum, which degrades the detection efficiency, especially in the low energy region.
(c) The uncertainty associated with the variation in the background and peak area (counting statistics) does not appear to have been taken properly into account.
(d) Evaluation of the printouts of reports on the peak area evaluation for two filters, identified as 18-T and 19-T, indicated that different backgrounds were used for each filter to calculate the net peak areas even though the filters were measured within one day of each other. Owing to the measurement time (50 000 s for each filter), it appears unlikely that sufficient time between measurements was available to make separate background measurements. Thus the same background spectrum should have been used for both air filters.
(e) The use of 92.6 keV gamma rays to determine ^{234}Th is not optimal, as this gamma ray in reality is composed of a doublet (92.4 keV and 92.8 keV) and is interfered with by two X rays at 89.8 keV and 93.4 keV from ^{228}Ac in the ^{232}Th series.
(f) Analysis of blank glass fibre air filters sent to the Agency's Laboratories at Seibersdorf has shown a large variation of a factor of two in the natural uranium content of these filters. Moreover, the levels of natural uranium present in the blank filters represent a significant fraction (between 0.5 and 0.8) of the uranium levels reported by the RPD for samples trapped on glass fibre. Therefore the data based on the use of these filters should be considered with extra caution.

I.2.2. Soil data

The MDA reported by the RPD for ^{238}U, based on the measurement of the activity of its decay product ^{234}Th at 92.8 keV (0.37 Bq/kg), also seems to be too low. It appears that the estimate by the RPD of the MDA was based on a measurement of the

TABLE XXII. COMPARISON BETWEEN MDAs FOR AIR FILTERS

Gamma ray line used by the RPD	MDA values reported in the RPD report	Realistic MDA values for the RPD data according to the IAEA evaluation	MDA values obtained by the IAEA using the IAEA gamma spectrometer
MDA at 63.3.keV	0.14 Bq per filter	~0.7 Bq per filter	0.22 Bq per filter
MDA at 92.8 keV	0.15 Bq per filter	~1.0 Bq per filter	0.35 Bq per filter

background level recorded without a sample present. The background and resultant MDA is therefore unrealistically low, owing to the absence of the contribution to the Compton background from ^{40}K, which is present in most environmental samples and is usually the major contributor to the background of the gamma ray spectra. The MDA should have been assessed using a blank containing a typical level of ^{40}K found in the soil of Kuwait. The IAEA's estimate of the MDA, based on the evaluation of the data and measurement conditions used by the RPD, would be approximately 20 times larger (6–12 Bq/kg, equivalent to 0.5–1.0 mg/kg). Thus the data reported to be lower than approximately 10 Bq/kg (the majority) should be considered an MDA. Comparisons between the specifications of the gamma spectrometers of the RPD and of the Agency's Laboratories at Seibersdorf and of the conditions used to measure soil samples for the intercomparison are provided in Table XXIII.

The measurement efficiency of the system at the Agency's Laboratories at Seibersdorf is approximately 1.8 times greater than that of the RPD's system. Thus the MDA for the RPD's system is expected to be greater than that of the system at the Agency's Laboratories at Seibersdorf. A more realistic evaluation of the MDA for the RPD's data is shown in Table XXIV.

The uncertainties in the results of the measurements carried out by the RPD also appear to be underestimated. They should range from 30 to 100% instead of the 5 to 10% quoted in the reports. Some discrepancies in the information provided were also identified: namely, in one report the amount of uranium contained in the standard used was quoted as 0.7968 g, while in a second report the amount quoted was 0.996 g. Some problems may also have been caused by the lack of facilities to process and homogenize soil samples in the RPD.

I.2.3. General remarks

The data supplied by the RPD for air filters and soil samples, together with the measurement conditions and detector specifications, indicate that the majority of the RPD's data are very close to or below the actual MDAs. Therefore the RPD's results have a very large associated uncertainty. Moreover, the RPD does not provide any information on the isotopic abundances of the uranium isotopes of interest (^{235}U and ^{238}U), which is necessary to establish whether the uranium present in the sample is natural or DU. Nevertheless, the data can still prove useful to indicate that the uranium concentrations in the soil of the areas sampled are below the level at which remedial measures would be warranted.

I.3. INTERCOMPARISON EXERCISE

To supplement the evaluation of the RPD's data, an intercomparison exercise was organized between the RPD and the Agency's Laboratories at Seibersdorf. The intercomparison was in two parts. The first part involved the measurement of the uranium concentration in six samples by both the RPD and the Agency's Laboratories at Seibersdorf. The six samples, collected by the RPD in Kuwait, consisted of three air filters and three soil samples. The results of the RPD, provided to the IAEA in a report, were obtained by gamma spectrometry. The three filters and three soil samples were analysed at

TABLE XXIII. COMPARISON OF RPD AND IAEA GAMMA SPECTROMETER SPECIFICATIONS AND MEASUREMENT PARAMETERS FOR SOIL SAMPLES

Parameter	RPD	IAEA
Gamma spectrometer specifications	P-type; 26% relative efficiency	P-type; 70% relative efficiency
Counting period	72 000 s	50 000 s
Efficiency at 92.8 keV	2.0%	3.6%

TABLE XXIV. COMPARISON BETWEEN MDAs FOR SOIL SAMPLES

Energy of gamma ray transition used to establish the MDA	Values reported in the RPD report	Realistic values for the RPD data according to the IAEA evaluation	Values obtained by the IAEA
MDA at 92.8 keV	0.37 Bq/kg	~9 Bq/kg	5 Bq/kg

TABLE XXV. COMPARISON BETWEEN THE MEASUREMENTS BY THE RPD AND THOSE OF THE IAEA OF URANIUM ACTIVITY IN AIR FILTERS AND ACTIVITY CONCENTRATIONS IN SOIL SAMPLES

Sample	RPD data	Data of the Agency's Laboratories at Seibersdorf		
	Gamma spectrometry	Gamma spectrometry	Alpha spectrometry	ICP–MS
Air filter 18-T	<0.15 Bq	<0.3 Bq	0.26 ± 0.02 Bq	0.15 ± 0.05 Bq
Air filter 19-T	0.21 Bq	<0.3 Bq	0.20 ± 0.02 Bq	0.12 ± 0.05 Bq
Air filter 20-T	<0.15 Bq	<0.3 Bq	0.036 ± 0.004 Bq	0.031 ± 0.009 Bq
Soil W1	9.46 ± 0.87 Bq/kg	<19 Bq/kg	8.6 ± 0.5 Bq/kg	7.4 ± 0.8 Bq/kg
Soil W2	64 ± 3 Bq/kg	50 ± 10 Bq/kg	68 ± 4 Bq/kg	54 ± 5 Bq/kg
Soil W3	15.43 ± 1.24 Bq/kg	<23 Bq/kg	7.7 ± 0.5 Bq/kg	5.3 ± 0.7 Bq/kg

the Agency's Laboratories at Seibersdorf directly by gamma spectrometry and, after dissolution, by both alpha spectrometry and ICP–MS. The results of the RPD and those of the Agency's Laboratories at Seibersdorf are shown in Table XXV.

The second part of the exercise consisted of the analysis by the RPD of an IAEA Analytical Quality Control Services natural uranium reference material and a 1.5 kg sample of soil from the Al Doha site containing elevated levels of DU, sent as two unknowns. This permitted the IAEA to evaluate the accuracy of the RPD's measurements for samples containing elevated levels of both natural uranium and DU. The sample collected by the RPD at Al Doha consisted of approximately 8.5 kg of raw soil. This was sent to the Agency's Laboratories at Seibersdorf, where it was processed (dried and sieved), thoroughly mixed and analysed using gamma spectrometry. A representative 1.5 kg aliquot was sent back to the RPD for analysis. The results of this exercise are shown in Table XXVI.

The results of the intercomparison indicate that, for air filters, the MDAs of the RPD are somewhat underestimated. In the case of the soil samples W1 and W3 the RPD's results should have been reported as equal to or below the detection limit for the conditions under which the RPD made the gamma spectrometric measurements. That the MDAs were underestimated by the RPD is clearly indicated by comparing the RPD's data with those obtained by the IAEA using more sensitive, destructive techniques (ICP–MS and alpha spectrometry). In the case of soil sample W2, the IAEA reference material (RGU) and the soil from Al Doha, the RPD's results are in very good agreement with the IAEA's results and the reference value. This indicates that the RPD can perform accurate measurements of uranium concentrations in soil by gamma spectrometry whenever the uranium concentration exceeds the MDA expected for the operating conditions. A realistic MDA for the RPD's measurements on soil samples has been estimated by the IAEA to be about 10 Bq/kg, while for filters it was estimated to be between 0.7 and 1.0 Bq per filter.

TABLE XXVI. COMPARISON BETWEEN ACTIVITY CONCENTRATIONS OF URANIUM AS MEASURED BY THE RPD AND BY THE IAEA IN TWO SOIL SAMPLES

Sample	RPD (Bq/kg)	IAEA (Bq/kg)
IAEA reference material (RGU)	4950 ± 100	4940 ± 15 (reference value)
Soil from Al Doha	12 300 ± 200	11 500 ± 500

Appendix II

ASSESSMENT OF DOSES THAT COULD ARISE OWING TO RESIDUES OF DU IN AREAS OF KUWAIT

II.1. INTRODUCTION

This appendix describes the assessment of the doses that could be received by individuals at locations investigated as part of this study on the radiological conditions in areas of Kuwait with residues of DU.

To estimate the annual doses that could arise owing to residues of DU a conservative approach based on cautious assumptions was adopted with the proviso that, should the assessment indicate that the radiological conditions in Kuwait were of some concern, more refined calculations would be required. Doses calculated in this assessment should be considered doses that could be received by hypothetical individuals who work or reside in the areas investigated. No persons who might receive doses from exposure to residues of DU have been identified, either by the authorities of Kuwait or in the IAEA's investigation. Estimated doses presented in this appendix are committed effective doses from exposure to DU at current levels in the environment and were estimated using radionuclide concentrations measured in samples of environmental media collected during this study. No attempt was made to assess doses at the time of the Gulf War in 1991 or to model the long term transport of uranium progeny in the environment. Only the three uranium isotopes of natural origin (^{238}U, ^{235}U and ^{234}U) were included in the assessment. Other radionuclides, such as ^{238}Pu and $^{239+240}$Pu, were only found in small amounts in DU residues (see Table II) and so were not included in the assessment. Similarly, ^{236}U was only found in small amounts in some samples and was not considered further. For comparative purposes doses that could arise owing to exposure to natural uranium present at the sites were also calculated.

II.2. METHODOLOGY ADOPTED IN THE ASSESSMENT

II.2.1. Exposure pathways and age groups considered

The exposure pathways included in the assessment were:

(a) Inhalation of soil resuspended by the action of the wind or by human activities.
(b) Ingestion of water.
(c) Ingestion of terrestrial foodstuffs:
  — Green vegetables;
  — Root vegetables;
  — Milk;
  — Meat.
(d) Ingestion of soil.

External exposure to DU in the soil was not included in the assessment. This pathway is of minor importance in the absence of the progeny of uranium isotopes, as is the case with DU. Doses caused by handling DU munitions are considered in Section 4.2.

Doses associated with all the exposure pathways considered were calculated only for hypothetical individuals residing at the farming areas of Al Wafrah and Al Abdali. For Al Rawdhatine only doses to hypothetical adults due to the ingestion of drinking water were calculated. For all the other sites doses that could arise owing to the inhalation of resuspended material and the ingestion of soil were estimated for adults and also for 10 year old children if it was considered appropriate.

II.2.2. Activity concentrations used in the assessment

The calculation of doses made use primarily of the measurements of activity concentrations in environmental samples collected during the sampling campaign conducted in February 2002. More than 200 samples of soil, water and vegetables were collected during the campaign, and about 90% of

them were analysed for DU. For each sample analysed, the fraction of DU was determined using the following relation:

$$R_{\text{U-235,U-238}} = \frac{F^{\text{Nat}}_{\text{U-235}} - (F^{\text{Nat}}_{\text{U-235}} - F^{\text{Dep}}_{\text{U-235}})\,x}{F^{\text{Nat}}_{\text{U-238}} - (F^{\text{Nat}}_{\text{U-238}} - F^{\text{Dep}}_{\text{U-238}})\,x}$$

where x is the fraction by mass of DU; $R_{\text{U-235, U-238}}$ is the isotopic ratio by mass of $^{235}\text{U}/^{238}\text{U}$ measured in the sample; and $F^{\text{Nat}}_{\text{U-235}}$, $F^{\text{Nat}}_{\text{U-238}}$, $F^{\text{Dep}}_{\text{U-235}}$ and $F^{\text{Dep}}_{\text{U-238}}$ are the isotopic abundances by mass of ^{235}U and ^{238}U in natural uranium and in DU, respectively (see Table I).

Activity concentrations were then obtained by multiplying the concentrations in terms of mass by the specific activities given in Table I.

The calculation of doses from the inhalation of resuspended material and the ingestion of milk and meat requires the use of activity concentrations in air, milk and meat. These activity concentrations were not measured during the investigation and were therefore derived using simple generic models of environmental transfer, which are briefly described below.

Radionuclide concentrations in air due to resuspension were determined using a simple dust loading approach:

$$C_{\text{air},i} = S_E C_{\text{soil},i}$$

where

$C_{\text{air},i}$ is the activity concentration of radionuclide i in air (Bq/m^3);
S_E is the dust loading factor (kg/m^3);
$C_{\text{soil},i}$ is the activity concentration of radionuclide i in soil (Bq/kg).

The dust loading approach has the advantage of using activity concentrations per unit mass rather than activity depositions. However, it implies that the radionuclides inhaled are closely associated with the soil and assumes that the size distribution of the DU particles associated with the soil is in the respirable range. Analyses of the size distribution of DU particles in samples collected in Kosovo indicate that most of the DU particles were less than 5 μm in diameter and that about 50% of them had a diameter of less than 1.5 μm [12]. It is therefore reasonable to assume that, once resuspended, DU particles in the soil can be inhaled.

Typical dust loading factors for wind driven resuspension in the European environment are in the range of 5×10^{-9} to 2.0×10^{-7} kg/m^3 [15], while for human-made resuspension created by such activities as digging and general agricultural activities, dust loading factors are higher. The European Commission [15] recommends a dust loading factor for human-made resuspension of 1×10^{-5} kg/m^3 for assessments of the radiological consequences of routine releases of radionuclides to the environment, which is appropriate for the north European environment. For arid environments similar to the one in Kuwait, higher values should be used. In its assessment of the health hazard associated with DU munitions, the United Kingdom's Royal Society [8] adopted dust loading factors of 2.0×10^{-6} kg/m^3 for wind driven resuspension and 3.0×10^{-5} kg/m^3 for human-made resuspension based on measurements taken at the Emu and Maralinga test sites [16]. The value for human-made resuspension was retained for this assessment, while the value for wind driven resuspension was increased to 5.0×10^{-6} kg/m^3 to take account of the sandstorms that are a common feature of the weather conditions found in Kuwait.

Radionuclide activity concentrations in milk were determined using the following equation:

$$C_{\text{milk},i} = F_{\text{milk}}\,(C_{f,i}\,Q_{f,\text{milk}} + C_{w,i}\,Q_{w,\text{milk}})$$

where

$C_{\text{milk},i}$ is the activity concentration of radionuclide i in milk (Bq/L);
F_{milk} is the uranium transfer factor for milk (d/L) (fraction of the animal's daily intake of uranium that can be found in a litre of milk);
$C_{f,i}$ and $C_{w,i}$ are the activity concentrations of radionuclide i in animal feed (Bq/kg, dry weight) and water (Bq/L), respectively;
$Q_{f,\text{milk}}$ and $Q_{w,\text{milk}}$ are the daily intakes of animal feed (kg/d, dry weight) and water (L/d) of milk producing cattle.

Radionuclide concentrations in meat were determined using a similar equation:

$$C_{\text{meat},i} = F_{\text{meat}}\,(C_{f,i}\,Q_{f,\text{meat}} + \text{C}_{w,i}\,Q_{w,\text{meat}})$$

where

$C_{\text{meat},i}$ is the activity concentration of radionuclide i in meat (Bq/kg);

F_{meat} is the uranium transfer factor for meat (d/kg) (fraction of the animal's daily intake of uranium that can be found in a kilogram of meat);

$C_{f,i}$ and $C_{w,i}$ are the activity concentrations of radionuclide i in animal feed (Bq/kg, dry weight) and water (Bq/L), respectively;

$Q_{f,\text{meat}}$ and $Q_{w,\text{meat}}$ are the daily intakes of animal feed (kg/d, dry weight) and water (L/d) of meat producing cattle.

No samples of animal feed were collected during the campaign of February 2002 or by the RPD. Green vegetables collected at the farms at Al Wafrah and Al Abdali were considered a suitable equivalent for grass and activity concentrations in these materials were used instead. The estimation of activity concentrations in milk and meat was based on a fresh to dry mass ratio for fodder of 5. Uranium transfer factors and daily intakes of animal feed and water used in the assessment, shown in Table XXVII, were taken from Ref. [17] and are generally appropriate for cattle. Uranium transfer factors for sheep meat are in general higher than for beef. For example, in its assessments the United Kingdom's National Radiological Protection Board uses values of 2×10^{-4} d/kg for beef and 2×10^{-3} d/kg for sheep meat [18]. The transfer factor suggested in Ref. [17] is higher than both these values and was therefore applied to both cattle and sheep. Table XXVII provides values of parameters used in the calculation of activity concentrations in air, milk and meat, while Table XXVIII summarizes the activity concentrations of isotopes of uranium in environmental media used in the calculation of doses.

II.2.3. Dose coefficients

The dose coefficients for ingestion and inhalation used in the calculations were taken from the Basic Safety Standards [1] and are shown in Table XXIX. Dose coefficients for inhalation are calculated for three types of material, classified as type F, M and S, according to whether the absorption rate of the material into body fluids from the respiratory tract is considered to be fast (very soluble compounds), moderate or slow (insoluble compounds). The chemical composition of the uranium particles in the environment was not determined in this study. It was conservatively assumed that the uranium oxides in the soil produced from the oxidation of uranium in the DU munitions were quite insoluble. Consequently, in this assessment the inhalation dose coefficients used were those for compounds with a slow absorption rate (type S). Dose coefficients provided are those calculated using a gut transfer factor (f_1) value of 0.04.

II.2.4. Habit data

The consumption rates of drinking water and terrestrial foods for adults used in the assessment were the generic values considered appropriate for the West Asia region, as reported in Ref. [17], which gives a single consumption rate for vegetables (i.e. green and root vegetables are combined into one group). For the purpose of this assessment the consumption rate was divided equally between the two types of vegetable. Ingestion rates of soil were taken from Ref. [19] and are given as hourly rates. To calculate doses due to the ingestion of soil, the time

TABLE XXVII. PARAMETER VALUES ADOPTED IN THE CALCULATION OF ACTIVITY CONCENTRATIONS OF URANIUM ISOTOPES IN AIR, MILK AND MEAT

Parameter	Value	
Dust loading factor, human-made resuspension (kg/m^3)	3.0×10^{-5}	
Dust loading factor, wind driven resuspension (kg/m^3)	5.0×10^{-6}	
	Milk	Meat
Animal intake of water (L/d)	60	40
Animal intake of feed (kg/d, dry mass)	16	12
Transfer factor (d/L)	6.0×10^{-4}	3.0×10^{-3}
Ratio of fresh to dry matter (mass)	5	

TABLE XXVIII. ACTIVITY CONCENTRATIONS OF URANIUM ISOTOPES (DEPLETED AND NATURAL) IN ENVIRONMENTAL MEDIA USED IN THE ASSESSMENT OF DOSES DUE TO DU IN KUWAIT

Environmental medium	Activity concentration					
	DU			Natural uranium		
	^{238}U	^{235}U	^{234}U	^{238}U	^{235}U	^{234}U
Al Doha						
Air (human-made resuspension) (Bq/m^3)	4.9×10^{-4}	6.4×10^{-6}	6.4×10^{-5}	5.6×10^{-4}	2.6×10^{-5}	5.6×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	8.2×10^{-5}	1.1×10^{-6}	1.1×10^{-5}	9.4×10^{-5}	4.4×10^{-6}	9.3×10^{-5}
Soil, dry (Bq/kg)	1.6×10^{1}	2.1×10^{-1}	2.1×10^{0}	1.9×10^{1}	8.7×10^{-1}	1.8×10^{1}
Al Jahra						
Air (wind driven resuspension) (Bq/m^3)	—	—	—	5.5×10^{-5}	2.5×10^{-6}	5.4×10^{-5}
Soil, dry (Bq/kg)	—	—	—	1.1×10^{1}	5.1×10^{-1}	1.1×10^{1}
Al Mutlaa						
Air (wind driven resuspension) (Bq/m^3)	—	—	—	8.9×10^{-5}	4.2×10^{-6}	9.6×10^{-5}
Soil, dry (Bq/kg)	—	—	—	1.8×10^{1}	8.4×10^{-1}	1.9×10^{1}
Al Rawdhatine						
Water (Bq/L)	2.4×10^{-3}	3.1×10^{-5}	3.1×10^{-4}	2.1×10^{-2}	9.8×10^{-4}	3.2×10^{-2}
Al Wafrah						
Air (human-made resuspension) (Bq/m^3)	—	—	—	3.4×10^{-4}	1.6×10^{-5}	3.7×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	—	—	—	5.7×10^{-5}	2.7×10^{-6}	6.2×10^{-5}
Soil, dry (Bq/kg)	—	—	—	1.1×10^{1}	5.4×10^{-1}	1.2×10^{1}
Water (Bq/L)	2.4×10^{-3}	3.1×10^{-5}	3.1×10^{-4}	2.1×10^{-2}	9.8×10^{-4}	3.2×10^{-2}
Green vegetables, fresh (Bq/kg)	4.9×10^{-4}	6.3×10^{-6}	9.1×10^{-5}	1.4×10^{-3}	6.8×10^{-5}	1.6×10^{-3}
Root vegetables, fresh (Bq/kg)	5.5×10^{-4}	7.1×10^{-6}	1.0×10^{-4}	1.3×10^{-2}	6.1×10^{-4}	1.8×10^{-2}
Grass, fresh (Bq/kg)	4.9×10^{-4}	6.3×10^{-6}	9.1×10^{-5}	1.4×10^{-3}	6.8×10^{-5}	1.6×10^{-3}
Milk (Bq/L)	1.8×10^{-5}	2.3×10^{-7}	3.3×10^{-6}	2.5×10^{-3}	1.2×10^{-4}	3.2×10^{-3}
Meat (Bq/kg)	1.3×10^{-4}	1.7×10^{-6}	2.4×10^{-5}	8.6×10^{-3}	4.0×10^{-4}	1.1×10^{-2}
Al Abdali						
Air (human-made resuspension) (Bq/m^3)	—	—	—	5.4×10^{-4}	2.5×10^{-5}	5.8×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	—	—	—	8.9×10^{-5}	4.2×10^{-6}	9.6×10^{-5}
Soil, dry (Bq/kg)	—	—	—	1.8×10^{1}	8.4×10^{-1}	1.9×10^{1}
Water (Bq/L)	2.4×10^{-3}	3.1×10^{-5}	3.1×10^{-4}	2.1×10^{-2}	9.8×10^{-4}	3.2×10^{-2}
Green vegetables, fresh (Bq/kg)	2.7×10^{-4}	3.5×10^{-6}	5.0×10^{-5}	1.2×10^{-3}	5.6×10^{-5}	1.4×10^{-3}
Root vegetables, fresh (Bq/kg)	2.0×10^{-4}	2.5×10^{-6}	3.7×10^{-5}	3.8×10^{-2}	1.8×10^{-3}	5.3×10^{-2}
Grass, fresh (Bq/kg)	2.7×10^{-4}	3.5×10^{-6}	5.0×10^{-5}	1.2×10^{-3}	5.6×10^{-5}	1.4×10^{-3}
Milk (Bq/L)	1.3×10^{-5}	1.7×10^{-7}	2.4×10^{-6}	2.6×10^{-2}	1.2×10^{-3}	3.2×10^{-2}
Meat (Bq/kg)	4.9×10^{-5}	6.3×10^{-7}	9.1×10^{-6}	8.8×10^{-2}	4.1×10^{-3}	1.1×10^{-1}
Military Hospital storage ground						
Air (human-made resuspension) (Bq/m^3)	2.2×10^{-4}	2.8×10^{-6}	2.8×10^{-5}	4.3×10^{-4}	2.0×10^{-5}	4.4×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	3.6×10^{-5}	4.7×10^{-7}	4.7×10^{-6}	7.2×10^{-5}	3.4×10^{-6}	7.3×10^{-5}
Soil, dry (Bq/kg)	7.3×10^{0}	9.4×10^{-2}	9.5×10^{-1}	1.4×10^{1}	6.7×10^{-1}	1.5×10^{1}
Al Sabhan						
Air (human-made resuspension) (Bq/m^3)	—	—	—	3.7×10^{-4}	1.7×10^{-5}	3.6×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	—	—	—	6.1×10^{-5}	2.8×10^{-6}	6.0×10^{-5}
Soil, dry (Bq/kg)	—	—	—	1.2×10^{1}	5.7×10^{-1}	1.2×10^{1}

TABLE XXVIII. (cont.)

Environmental medium	Activity concentration					
	DU			Natural uranium		
	^{238}U	^{235}U	^{234}U	^{238}U	^{235}U	^{234}U
Manageesh GC 28						
Air (human-made resuspension) (Bq/m^3)	5.4×10^{-4}	7.0×10^{-6}	7.0×10^{-5}	1.7×10^{-4}	7.8×10^{-6}	1.5×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	9.0×10^{-5}	1.2×10^{-6}	1.2×10^{-5}	2.8×10^{-5}	1.3×10^{-6}	2.5×10^{-5}
Soil, dry (Bq/kg)	1.8×10^{1}	2.3×10^{-1}	2.3×10^{0}	5.6×10^{0}	2.6×10^{-1}	5.0×10^{0}
Umm Gudayar GC 18						
Air (human-made resuspension) (Bq/m^3)	1.1×10^{-5}	1.4×10^{-7}	1.4×10^{-6}	3.0×10^{-4}	1.4×10^{-5}	3.0×10^{-4}
Air (wind driven resuspension) (Bq/m^3)	1.9×10^{-6}	2.4×10^{-8}	2.4×10^{-7}	5.0×10^{-5}	2.3×10^{-6}	5.0×10^{-5}
Soil, dry (Bq/kg)	3.7×10^{-1}	4.8×10^{-3}	4.8×10^{-2}	1.0×10^{1}	4.7×10^{-1}	1.0×10^{1}
Kuwait City						
Air (Bq/m^3)	—	—	—	1.6×10^{-6}	7.6×10^{-8}	1.7×10^{-6}

TABLE XXIX. DOSE COEFFICIENTS FOR INGESTION AND INHALATION USED IN THE ASSESSMENT

Exposure pathway	Dose coefficient (Sv/Bq)					
	Adults			Children (10 years old)		
	^{238}U	^{235}U	^{234}U	^{238}U	^{235}U	^{234}U
Inhalation (type S)	8.0×10^{-6}	8.4×10^{-6}	9.3×10^{-6}	1.0×10^{-5}	1.1×10^{-5}	1.2×10^{-5}
Ingestion ($f_1 = 0.04$)	4.4×10^{-8}	4.6×10^{-8}	4.9×10^{-8}	6.6×10^{-8}	7.0×10^{-8}	7.4×10^{-8}

spent in the exposed areas must be taken into account. The breathing rates adopted in the calculation were taken from Ref. [5]. The calculation of doses from the inhalation of resuspended material and the ingestion of soil require an estimate of the time spent by hypothetical individuals exposed in the area under consideration. Three values were adopted in this assessment: a work related occupancy rate of 2000 h/a, only applicable to adults; a recreational occupancy rate of the same value (2000 h/a); and a residential occupancy rate of 8760 h/a equally applicable to both adults and children. The work related value corresponds to a working week of 40 h and is commonly used for standard assessments carried out in Europe. In general, recreational occupancy rates are lower than the value used in this assessment. However, the value adopted was the same as the work related rate so as to take account of the time spent by many people camping, a highly popular activity among the population of Kuwait. An occupancy rate of 2000 h/a corresponds to a period of about 3 months, which is a reasonable assumption for the time spent by people camping. The residential occupancy rate corresponds to full time occupancy. For the calculation of doses due to the ingestion of soil it was assumed that individuals spent their entire time outdoors when working or camping, while it was assumed that they spent only 50% of the time outdoors in residential areas. The habit data adopted in the assessment are given in Table XXX.

II.3. RESULTS OF THE ASSESSMENT OF DOSES THAT COULD ARISE OWING TO DU RESIDUES IN AREAS OF KUWAIT

This section illustrates the results and radiological consequences for the sites included in this study and for Kuwait City. Results are presented for each site investigated; locations with similar characteristics have been grouped together. A description of the locations studied is given in the main part of this report.

TABLE XXX. HABIT DATA USED IN THE ASSESSMENT

Quantity	Age group	Value
Inhalation rate (m^3/a)	Adults	7300
Inhalation rate (m^3/a)	Children	5600
Ingestion rate of water (L/a)	Adults	600
Ingestion rate of green vegetables (kg/a)	Adults	300
Ingestion rate of root vegetables (kg/a)	Adults	300
Ingestion rate of milk (kg/a)	Adults	140
Ingestion rate of meat (kg/a)	Adults	55
Ingestion rate of soil (mg/h)	Adults	5
Ingestion rate of soil (mg/h)	Children	10
Work related occupancy (h/a)	Adults	2000
Recreational occupancy (h/a)	Adults, children	2000
Residential occupancy (h/a)	Adults, children	8760
Fraction spent outdoors	Adults, children	0.5

II.3.1. Al Doha

The site investigated at Al Doha is a field next to the US Army base of Camp Doha. Some debris of the fire at the base (see Section 4.1.1) in July 1991 had been dumped in the area of interest. The debris included residues of DU munitions and contaminated soil. The location is fenced and access to it is restricted. The area is currently subject to a remediation programme, which involves removing all the remaining debris to the Um Al Kwaty military base and covering the contaminated area at Al Doha with fresh, uncontaminated soil. The main purpose of the assessment was to estimate doses that could be received by individuals working on the site or using the site for recreation in order to determine the effectiveness of the remedial measures. The site is not used for farming; therefore only hypothetical doses from the inhalation of resuspended material and the ingestion of soil were calculated.

The activity concentrations in the soil used in the assessment were the average values for the eight surface soil samples collected during the sampling campaign conducted in February 2002 (see Table XXVIII). The resultant doses are shown in Table XXXI.

The annual dose from DU that could be received by a hypothetical individual working at the site is 7.7 μSv, while people using the site for recreational purposes could receive doses of the order of 1 μSv. Doses that could arise from natural uranium are about a factor of two to three higher than those from DU.

The results of the assessment indicate that the remedial measures taken are effective. Since access to the area remains restricted, actual doses to any people in the vicinity would be very much less than those given in Table XXXI.

II.3.2. Al Jahra and Al Mutlaa

Al Jahra and Al Mutlaa are situated in areas close to scenes of military action in which DU munitions were reported to have been used in the Gulf War. The purpose of the assessment was to calculate doses that could arise to people residing in Al Jahra and people using the area at Al Mutlaa for camping.

TABLE XXXI. ESTIMATED ANNUAL DOSES TO HYPOTHETICAL INDIVIDUALS AT AL DOHA

Group	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Adults working on the site	6.6	0.089	1.0	7.7	7.5	0.37	8.2	17
Adults using the site for recreation	1.1	0.015	0.17	1.3	1.3	0.062	1.5	2.8
Children (10 years old) using the site for recreation	0.86	0.012	0.13	1.0	1.2	0.063	1.5	2.7

Activity concentrations in the soil used in the calculations were the average values of the measurements in the samples of surface soil collected during the mission in February 2002. For both sites only doses that could arise owing to the inhalation of uranium in material resuspended by the action of the wind and the ingestion of soil were calculated. It was assumed for Al Jahra that the individuals exposed lived in the city, while doses that could arise for Al Mutlaa were calculated for individuals using the location for recreational purposes. The results are given in Table XXXII.

No DU could be measured in any of the samples collected at these locations, and the calculations were therefore confined to uranium of natural origin. Doses that could arise to 10 year old children differ very little from those to adults. Individuals residing at Al Jahra could receive an annual dose of 7.0 μSv from natural uranium; the corresponding value for people using the area at Al Mutlaa for camping is less than 3 μSv.

II.3.3. Al Rawdhatine

Estimated annual doses to adults from the ingestion of water extracted at Al Rawdhatine are shown in Table XXXIII. No DU could be detected in either the samples collected during the February 2002 mission or those dispatched by the RPD (see Table X). No doses would be expected to arise owing to the ingestion of water extracted from Al Rawdhatine. However, analysis of the solid residue from one of the samples collected during the IAEA sampling campaign indicated a $^{235}U/^{238}U$ mass ratio lower than the value for natural uranium. This value can be accounted for by the uncertainties in the measurements and is not indicative of the presence of DU in water extracted at Al Rawdhatine. However, as a conservative approach doses that could arise from the ingestion of DU in drinking water were also calculated based on the cautious assumption that the percentage of DU in the water extracted at Al Rawdhatine was equal to the value implied by the $^{235}U/^{238}U$ mass ratio measured in the solid residue. The resulting dose to a hypothetical adult that could arise from the consumption of drinking water from Al Rawdhatine was 0.072 μSv. The corresponding value for natural uranium, which was based on measurements in filtered water, was 1.5 μSv.

II.3.4. Farming areas at Al Wafrah and Al Abdali

Most of the terrestrial foodstuffs consumed in Kuwait are imported. However, crops as well as fodder for animals are grown in two farming areas, Al Wafrah in the south of Kuwait and Al Abdali in the northern part of the country near the border

TABLE XXXII. CALCULATED ANNUAL DOSES TO INDIVIDUALS AT AL JAHRA AND AL MUTLAA

Group	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Al Jahra								
Adults residing in the area	—	—	—	—	3.2	0.16	3.7	7.0
Children (10 years old) residing in the area	—	—	—	—	3.1	0.16	3.6	6.9
Al Mutlaa								
Adults camping in the area	—	—	—	—	1.2	0.059	1.5	2.8
Children (10 years old) camping in the area	—	—	—	—	1.2	0.060	1.5	2.7

TABLE XXXIII. CALCULATED ANNUAL DOSES TO HYPOTHETICAL ADULTS FROM THE INGESTION OF WATER EXTRACTED AT AL RAWDHATINE

Group	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Adults drinking water from Al Rawdhatine	0.062	0.00084	0.0091	0.072	0.55	0.027	0.94	1.5

with Iraq. The foodstuffs produced on the farms in these areas are intended for the local market. Concern was also raised about the possibility that locally grown fodder crops could have been affected.

Doses were calculated for adults working at the farms and consuming foodstuffs entirely produced there. The assessment was based on the activity concentrations in crops that were collected during the sampling campaign of February 2002. At Al Wafrah the mean values of the measurements taken in lettuces, cucumbers, tomatoes and cabbages were used to estimate the dose from the consumption of green vegetables, while the activity concentrations in carrots were applied to all root vegetables. For Al Abdali, concentrations in green vegetables were taken to be the mean of the values for tomatoes and cucumbers, while those for root vegetables were derived from the measured values for potatoes, onions, radishes and beets.

The brackish water supplied by wells at the farms is used only for irrigation and is not intended for human consumption. In the assessment it was assumed that this water is also given to cattle. Activity concentrations in milk and meat were calculated using the method described in Section II.2.2, based on the assumption that activity concentrations in animal fodder were the same as those in green vegetables. Annual doses that could arise from the consumption of drinking water were cautiously based on the activity concentrations of DU used in the calculation of doses for Al Rawdhatine (Section II.3.3).

Annual doses that could arise to farmers at Al Wafrah and Al Abdali are given in Table XXXIV. Given the number of exposure pathways included in the calculation, a breakdown of doses by exposure pathway is provided. No DU was measured in soil samples taken at the farms, and hence doses from the inhalation of DU in resuspended soil have been taken to be zero. Total doses from exposure to DU that could be received by any farmers residing at Al Wafrah and Al Abdali and consuming local produce are 0.090 μSv and 0.080 μSv, respectively. The main contribution to the dose is the ingestion of drinking water, which accounts for about 81% of the dose at Al Wafrah and about 90% of the dose at Al Abdali. It should be noted that doses from drinking water were calculated by assuming that the water consumed by these individuals comes from Al Rawdhatine. These annual doses from DU are only a small fraction of the doses that could be received from naturally occurring uranium isotopes, which were estimated to be 19 μSv and 29 μSv for farmers living at Al Wafrah and Al Abdali, respectively. The

TABLE XXXIV. CALCULATED ANNUAL DOSES TO ADULT FARMERS AT AL WAFRAH AND AL ABDALI

Exposure pathway	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Al Wafrah								
Inhalation (resuspension)	—	—	—	—	7.1	0.35	8.9	16
Ingestion of water	0.062	0.00084	0.0091	0.072	0.55	0.027	0.94	1.5
Ingestion of green vegetables	0.0065	0.000087	0.0013	0.0079	0.019	0.00093	0.024	0.044
Ingestion of root vegetables	0.0073	0.0000098	0.0015	0.0089	0.17	0.0085	0.27	0.45
Ingestion of milk	0.00011	0.0000015	0.000023	0.00013	0.015	0.00075	0.022	0.038
Ingestion of meat	0.00032	0.0000043	0.000066	0.00039	0.021	0.0010	0.029	0.051
Ingestion of soil	—	—	—	—	0.013	0.00066	0.016	0.030
Total	0.077	0.0010	0.012	0.090	7.9	0.39	10	19
Al Abdali								
Inhalation (resuspension)	—	—	—	—	11	0.52	14	26
Ingestion of water	0.062	0.00084	0.0091	0.072	0.55	0.027	0.94	1.5
Ingestion of green vegetables	0.0036	0.000048	0.00074	0.0044	0.016	0.00078	0.021	0.038
Ingestion of root vegetables	0.0026	0.000035	0.00054	0.0032	0.50	0.024	0.79	1.3
Ingestion of milk	0.000080	0.0000011	0.000017	0.000098	0.16	0.0079	0.22	0.39
Ingestion of meat	0.00012	0.0000016	0.000024	0.00014	0.21	0.010	0.28	0.51
Ingestion of soil	—	—	—	—	0.021	0.0010	0.025	0.048
Total	0.069	0.00093	0.010	0.080	13	0.65	16	29

most significant exposure pathway in this case would be the inhalation of resuspended material, which contributes almost 90% of the calculated dose.

II.3.5. Al Sabhan and the Military Hospital storage ground

The sites at Al Sabhan and the Military Hospital storage ground were used as initial storage areas for Iraqi military vehicles recovered in Kuwait. Some of these vehicles were found to be contaminated with DU. Contaminated vehicles were eventually moved to the military base at Um Al Kwaty, although one tank showing contamination with DU was still at the Military Hospital storage ground.

Access to both sites is currently restricted; the purpose of the assessment for these two sites was to estimate doses that could arise to people who might work at this location or use it for recreational purposes if the restriction were lifted. Doses were estimated for a hypothetical worker spending 2000 h a year at these sites and engaged in activities that might require disturbance of the soil, and to members of the public who might spend the same amount of time in these areas for recreation. The assessment was based on the mean of the measured values in samples of surface soil collected at these sites during the IAEA sampling campaign of February 2002. The resultant doses are given in Table XXXV. No DU could be measured in any of the samples collected at Al Sabhan, and therefore only doses that could arise owing to natural uranium are presented for this site. The annual dose from DU that would be received by an individual working at the Military Hospital storage ground is 3.3 μSv, while people using the site for recreational purposes would receive doses of the order of 1 μSv. Doses from natural uranium are about a factor of two to three higher than those from DU.

II.3.6. Manageesh oilfields

The areas investigated at Manageesh GC 28 and Umm Gudayar GC 18 were of particular strategic importance during the Gulf War and were subjected to numerous air raids involving DU munitions. DU penetrators can still be found at these locations. No agricultural activities are carried out in this area and therefore the assessment was limited to the calculation of doses that could be received by adults from the inhalation of resuspended material.

The area is under the control of the Kuwait Oil Company and not readily accessible by members of the public. It is therefore unlikely that any member of the public would spend a significant length of time at these sites. However, the situation at the Manageesh oilfields may be representative of other areas in Kuwait affected by the presence of DU residues where people do live. Conservatively, doses were therefore calculated for a hypothetical adult both working for 2000 h a year and residing for the remainder of the year at the same location.

The activity concentrations in soil used in the calculations were the mean values of the measurements in samples collected in February 2002. The activity concentrations for Manageesh GC 28 agree well with the activity concentrations in the soil collected at the same site and used for the resuspension experiments conducted at Um Al Kwaty. Higher concentrations were measured in proximity to penetrators found at the site. However, it would be inappropriate to base the assessment simply on the

TABLE XXXV. CALCULATED DOSES TO HYPOTHETICAL INDIVIDUALS AT THE MILITARY HOSPITAL STORAGE GROUND AND AT AL SABHAN

Group	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Military Hospital storage area								
Adults working on the site	2.9	0.038	0.38	3.3	5.8	0.28	6.8	13
Adults using the site for recreation	0.49	0.0063	0.064	0.56	0.97	0.048	1.1	2.2
Children (10 years old) using the site for recreation	0.47	0.0067	0.074	0.56	0.94	0.048	1.1	2.1
Al Sabhan								
Adults working on the site	—	—	—	—	4.9	0.24	5.6	11
Adults using the site for recreation	—	—	—	—	0.82	0.040	0.94	1.8
Children (10 years old) using the site for recreation	—	—	—	—	0.80	0.041	0.94	1.8

highest measured activity concentrations in the surface soil collected near a penetrator because resuspended dust derives from a wide area.

The results of the dose assessment are shown in Table XXXVI. In ambient conditions, the doses that could be received by hypothetical adults and 10 year old children from DU would be about 13 μSv and 6 μSv, respectively, at Manageesh GC 28, and 0.27 μSv and 0.12 μSv at Umm Gudayar GC 18. The corresponding calculated doses from natural uranium are 7.3 μSv and 3.4 μSv at Manageesh GC 28 and 14 μSv and 6.4 μSv at Umm Gudayar GC 18 for adults and children, respectively. Manageesh GC 28 is the only site among those investigated where doses that could arise from DU would be higher than those associated with naturally occurring uranium. As noted in Section II.2.2, a conservative dust loading factor for wind driven resuspension has been adopted to take account of possible sandstorms. Although the amount of material resuspended during a sandstorm could be high, and activity concentrations in air higher than those estimated for the dose calculations, the duration of such storms is limited and it is unlikely that a person would spend a considerable amount of time in such conditions without some form of protection. Doses that could be received during sandstorms are therefore unlikely to exceed the doses that could be received in normal conditions or to affect significantly the doses shown in Table XXXVI.

II.3.7. Kuwait City

Activity concentrations in airborne dust in Kuwait City have been measured by the RPD for a number of years. As part of the investigation of the radiological conditions, samples of air filters collected during 2001 and during the sampling campaign of February 2002 were analysed. The $^{235}U/^{238}U$ mass ratios in these samples indicated that no DU was present. Average activity concentrations of isotopes of naturally occurring uranium measured in the samples collected in Kuwait City are shown in Table XXXVII and are consistent with the average concentrations of natural uranium in air published by UNSCEAR [5]. The annual dose from the inhalation of natural uranium in dust was calculated to be 0.21 μSv (Table XXXVII).

TABLE XXXVI. CALCULATED ANNUAL DOSES TO HYPOTHETICAL INDIVIDUALS AT MANAGEESH GC 28 AND AT UMM GUDAYAR GC 18

Group	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Manageesh GC 28								
Adults working and residing in the area	11	0.15	1.7	13	3.5	0.17	3.6	7.3
Children (10 years old) residing in the area	5.1	0.072	0.79	6.0	1.6	0.081	1.7	3.4
Umm Gudayar GC 18								
Adults working and residing in the area	0.23	0.0031	0.035	0.27	6.3	0.31	7.3	14
Children (10 years old) residing in the area	0.10	0.0015	0.016	0.12	2.8	0.14	3.4	6.4

TABLE XXXVII. CALCULATED ANNUAL DOSES TO INDIVIDUALS FROM THE INHALATION OF DUST IN KUWAIT CITY

Group	Annual dose (μSv)							
	DU				Natural uranium			
	^{238}U	^{235}U	^{234}U	Total	^{238}U	^{235}U	^{234}U	Total
Adults residing in Kuwait City	—	—	—	—	0.095	0.0047	0.11	0.21
Children (10 years old) residing in Kuwait City	—	—	—	—	0.092	0.0047	0.11	0.21

Appendix III

EXPERIMENTS TO EVALUATE THE RESUSPENSION OF RESIDUES OF DU

III.1. INTRODUCTION

In the sampling campaign of February 2002 two experiments were carried out to evaluate the consequences of a possible resuspension of DU particles resulting from the accidental or intentional explosion of landmines or bombs. For these experiments sand collected from the Manageesh GC 28 site was dispersed in the air by means of two controlled explosions; the dust thus dispersed was collected and analysed for DU content. The explosions were carried out under the supervision of Lieutenant Col. Al Haddad of the Chemical Defence Directorate of the Army of Kuwait at the Ali Salem air force base at Um Al Kwaty.

Manageesh GC 28 is one of the sites included in the IAEA's study. It was decided to use sand from this site for the experiments because the conditions at Manageesh GC 28 can be considered typical of locations in Kuwait affected by DU residues. A description of this area is given in Section 4.1.7.

The results of these experiments should be interpreted with caution and any extrapolation to different conditions may not be justified since they were conducted with a specific DU contaminated soil and followed a protocol that may only approximately represent real conditions. The experiments, however, provided some useful information on the behaviour of DU resuspended by means of an explosion.

III.2. COLLECTION AND ANALYSIS OF THE MATERIAL USED IN THE RESUSPENSION EXPERIMENTS

The material used in the experiments was collected at random over a relatively large area (a circle of about 200 m in diameter) of Manageesh GC 28. A total of around 900 kg of sandy soil was collected and placed in 15 metal boxes. The sand in each box was thoroughly mixed and from each box a sample of about 100 g was placed in an appropriate container, in which it was again very well mixed.

The sandy soil was analysed at the Agency's Laboratories at Seibersdorf by both ICP–MS and alpha spectroscopy. The results obtained with the two techniques were in reasonable agreement; the concentration measured by ICP–MS was 0.73 mg/kg, while the alpha spectroscopy analysis gave a value of 0.78 mg/kg. The $^{235}U/^{238}U$ isotopic mass ratio determined by ICP–MS was 0.0050, indicating that around 43% of the uranium in the sand was depleted.

A sample of the soil collected for the experiments was also analysed by a scanning electron microscope equipped with an X ray energy dispersion device (SEM–EDXRF). Pictures of this soil at different magnifications are shown in Fig. 8. The images were taken in the backscattering mode and the presence of uranium is visible in the two pictures taken at higher magnification as small white dots covering sand grains having an approximate diameter of 200 μm.

III.3. DESCRIPTION OF THE EXPERIMENTS

The two resuspension experiments required the use of explosives and therefore were conducted inside the perimeter of the Ali Salem air force base, at Um Al Kwaty, parts of which are used frequently by Kuwait's army for test explosions.

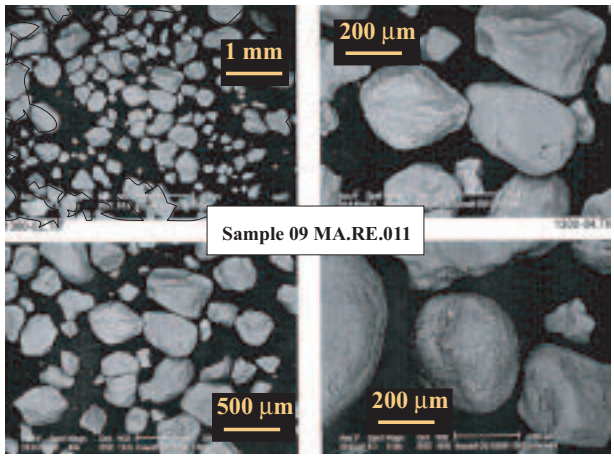

FIG. 8. SEM–EDXRF images of the sample of sand collected at Manageesh GC 28 and used in the resuspension experiments.

In the first experiment about 420 kg of the DU contaminated sandy soil was resuspended in the air by 0.5 kg of Semtex explosive. The quantity of explosive was chosen to simulate the explosion of a landmine. To perform the experiment a 0.05 m deep square trench of 2 m × 2 m (Fig. 9) was excavated in the terrain. Sandbags about 0.30 m high surrounded the trench. The explosive was placed in a hole in the centre of the trench at a depth of about 0.40 m. The middle of the trench was then covered with the sand collected at Manageesh GC 28. Four air samplers were placed downwind at distances of 25, 50, 150 and 250 m from the centre of the trench.

The scheme of the experiments is shown in Fig. 10. Before the explosion an air filter blank was collected by operating the air samplers for 30 min. After the explosion the filters were changed three times at about 20 min intervals. At the time of the explosion the wind speed was about 25 km/h and its direction was north–north–east, approximately along the axis of the four air samplers. The resuspended material reached a height of about 50 m immediately after the explosion and moved rapidly along the axis of the samplers at decreasing height. After about 12 s no dust was visible. Sequential pictures of the explosion are shown in Fig. 11.

The experiment was repeated using the remaining 480 kg of sand from Manageesh GC 28, dispersed in the air by means of 1.8 kg of Semtex explosive. To avoid cross-contamination, the second experiment was carried out along an axis parallel to the first one, at a distance of about 300 m. The height reached by the sand after the explosion was about 70 m. After about 20 s no dust was visible.

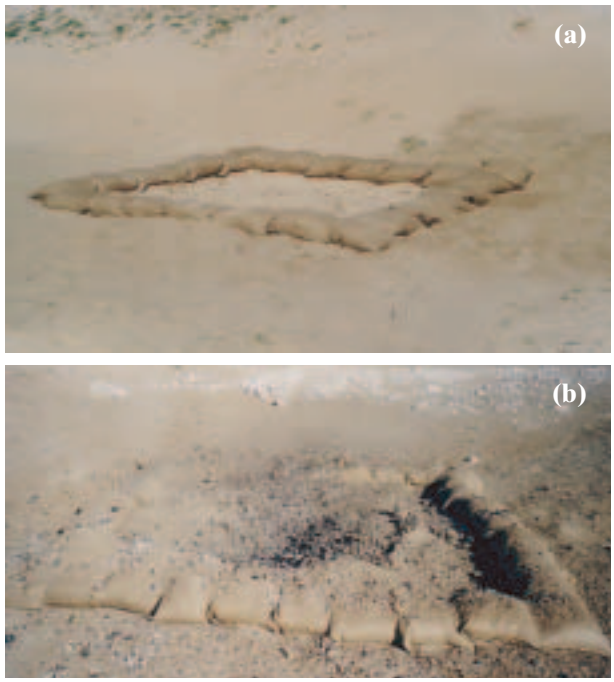

FIG. 9. Trench of an area of 2 m × 2 m containing 420 kg of sandy soil from Manageesh GC 28: (a) before the resuspension experiment and (b) afterwards.

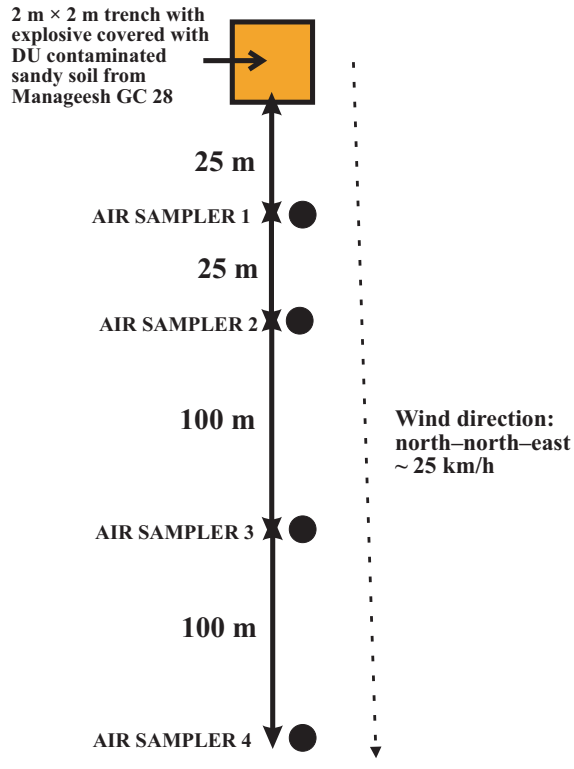

FIG. 10. Scheme of the resuspension experiments conducted at Um Al Kwaty.

III.4. AIR SAMPLERS

The air samplers (Staplex Company, model TFIA-4BC) were powered by 24 V DC drawing 16 A and mounted on a tripod at about 1 m above the ground (Fig. 12). They were connected to car batteries by clamps. The samplers had a filter holder of 20 cm × 25 cm and were operated at a flow rate of 2 m^3/min. The filter material was cellulose, with a pore size of 1.1 μm; the filter had the same dimensions as the holder.

III.5. ANALYSIS OF THE AIR FILTERS

The results of the analyses are shown in Appendix IV, Table XXXIX. The blank filters were analysed and found to contain no measurable amount of uranium (less than 0.01 μg). Almost all the filters collected and measured after the first explosion contained extremely small amounts of

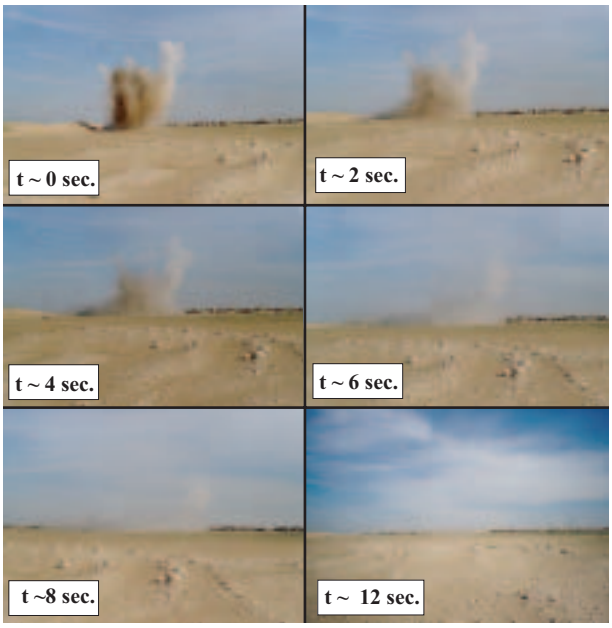

FIG. 11. Time sequence of the resuspension experiment carried out at Um Al Kwaty.

FIG. 12. Air sampler with filter holder and filter.

uranium (0.01 µg or less). The exception was the filter located 25 m from the explosion and collected 23 min after the explosion. The total quantity of uranium collected was 0.12 µg. The isotopic mass ratio of $^{235}U/^{238}U$ measured by ICP–MS was 0.0022, indicating that the uranium in the air collected was almost entirely (~96%) DU. The presence of almost only DU in the airborne dust collected indicates that it was associated with material lighter than natural uranium. This can be explained by the difference in speciation between natural uranium, which is associated with the soil itself, and DU, which would be present mainly as oxide particles formed by the corrosion of the DU penetrators. The absence of any measurable quantity of DU in the airborne dust collected by the samplers positioned at distances of 50 m and beyond from the explosion indicates that transport of resuspended DU over such distances is unlikely.

As the sequential pictures of the explosion in Fig. 11 show, after about 12 s no dust was visible. Therefore it was assumed that all uranium was deposited on the filters over this initial period of 12 s. Using the flow rate of 2 m^3/min, the integrated concentration of uranium in the air collected was calculated to be 0.3 µg/m^3.

On the assumption that all DU present in the air consists of inhalable particles (<10 µm), an individual standing 25 m from the explosion would inhale less than 1 ng of DU, corresponding to 0.0012 mBq. This is 2000 times lower than the activity of natural uranium inhaled annually by a typical adult living in Kuwait City (see Appendix II).

In the second experiment, no soil or dust could be collected on any of the air filters following the explosion, probably because of a change in wind direction.

Appendix IV

SUMMARY OF THE ANALYTICAL RESULTS

This appendix provides a summary of the results of the analyses of the environmental samples collected as part of the IAEA's study on the radiological conditions in areas of Kuwait arising from the presence of DU. The data presented are the results of the analyses carried out at the Agency's Laboratories at Seibersdorf and the Spiez Laboratory on the environmental samples collected in the sampling campaign of February 2002, as well as on those taken as part of the evaluation of the reliability of data on DU provided by the RPD.

Table XXXVIII gives concentrations of ^{238}U, ^{234}U, ^{235}U and total uranium, as well as the isotopic ratio $^{235}U/^{238}U$ by mass and the fraction of DU by mass present in each sample. Table XXXIX gives activity concentrations of ^{238}U, ^{234}U and ^{235}U in the samples. Additional information on the sampling (date, co-ordinates of the sampling location, equipment used and group that collected the sample) and the analysis (laboratory at which the analysis was performed and method used) are also provided in the tables.

TABLE XXXVIII. MASS CONCENTRATIONS OF URANIUM ISOTOPES MEASURED IN ENVIRONMENTAL SAMPLES COLLECTED AS PART OF THE IAEA STUDY ON DU IN KUWAIT

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
Al Doha										
01DO.Blank.01	N 29°21'40.9" E 47°48'57.0"	Soil (0-2)	Spiez	ICP-MS	1.05 ± 0.020 mg/kg	58 ± 7.9 ng/kg	7.6 ± 0.38 µg/kg	1.06 ± 0.021 mg/kg	0.724	<2
01DO.Blank.02	N 29°21'41.2" E 47°48'56.7"	Soil (0-2)	Spiez	ICP-MS	1.12 ± 0.022 mg/kg	61 ± 7.6 ng/kg	8.1 ± 0.35 µg/kg	1.13 ± 0.023 mg/kg	0.723	<2
01DO.Blank.03	N 29°21'41.5" E 47°48'56.4"	Soil (0-2)	Spiez	ICP-MS	1.08 ± 0.023 mg/kg	59 ± 6.8 ng/kg	7.8 ± 0.45 µg/kg	1.09 ± 0.024 mg/kg	0.722	<2
01DO.Blank.04	N 29°21'41.7" E 47°48'57.0"	Soil (0-2)	Spiez	ICP-MS	1.14 ± 0.020 mg/kg	60 ± 7.6 ng/kg	8.2 ± 0.23 µg/kg	1.15 ± 0.020 mg/kg	0.719	<2
01DO.P.01	N 29°21'40.2" E 47°48'57.1"	Soil (0-5)	Spiez	ICP-MS	2.49 ± 0.045 mg/kg	139 ± 18 ng/kg	16.5 ± 0.78 µg/kg	2.51 ± 0.046 mg/kg	0.663	12
01DO.P.02		Soil (5-15)	Spiez	ICP-MS	2.56 ± 0.065 mg/kg	154 ± 18 ng/kg	18.2 ± 0.91 µg/kg	2.58 ± 0.065 mg/kg	0.711	2.7
01DO.P.03		Soil (15-25)	Spiez	ICP-MS	3.23 ± 0.13 mg/kg	196 ± 27 ng/kg	22.9 ± 1.2 µg/kg	3.3 ± 0.13 mg/kg	0.709	3.1
01DO.P.04		Soil (25-35)	Spiez	ICP-MS	3.36 ± 0.10 mg/kg	203 ± 23 ng/kg	23.8 ± 1.0 µg/kg	3.4 ± 0.11 mg/kg	0.708	3.2
01DO.P.05	N 29°21'40.5" E 47°48'56.4"	Soil (0-5)	Spiez	ICP-MS	1.77 ± 0.042 mg/kg	87 ± 10 ng/kg	11.2 ± 0.38 µg/kg	1.78 ± 0.043 mg/kg	0.633	18
01DO.P.06		Soil (5-15)	Spiez	ICP-MS	1.90 ± 0.030 mg/kg	97 ± 11 ng/kg	12.2 ± 0.28 µg/kg	1.91 ± 0.031 mg/kg	0.642	16
01DO.P.07		Soil (15-25)	Spiez	ICP-MS	3.63 ± 0.078 mg/kg	102 ± 11 ng/kg	15.4 ± 0.38 µg/kg	3.65 ± 0.078 mg/kg	0.424	57
01DO.P.08		Soil (25-35)	Spiez	ICP-MS	9.77 ± 0.27 mg/kg	143 ± 19 ng/kg	28.0 ± 0.90 µg/kg	9.8 ± 0.27 mg/kg	0.287	84
01DO.S.01	N 29°21'40.1" E 47°48'57.2"	Soil (0-5)	Spiez	ICP-MS	2.46 ± 0.035 mg/kg	129 ± 16 ng/kg	16.2 ± 0.84 µg/kg	2.48 ± 0.036 mg/kg	0.659	13
01DO.S.02	N 29°21'40.0" E 47°48'57.1"	Soil (0-5)	Spiez	ICP-MS	7.04 ± 0.10 mg/kg	160 ± 20 ng/kg	25.5 ± 0.64 µg/kg	7.1 ± 0.10 mg/kg	0.362	69
01DO.S.03	N 29°21'40.5" E 47°48'57.1"	Soil (0-5)	Spiez	ICP-MS	1.79 ± 0.034 mg/kg	66 ± 8.0 ng/kg	10.4 ± 0.27 µg/kg	1.80 ± 0.034 mg/kg	0.581	27
01DO.S.04	N 29°21'40.5" E 47°48'56.7"	Soil (0-5)	Spiez	ICP-MS	1.20 ± 0.021 mg/kg	56 ± 7.3 ng/kg	8.6 ± 0.26 µg/kg	1.21 ± 0.022 mg/kg	0.717	<2
01DO.S.05	N 29°21'40.5" E 47°48'56.4"	Soil (0-5)	Spiez	ICP-MS	1.18 ± 0.021 mg/kg	58 ± 6.7 ng/kg	8.5 ± 0.30 µg/kg	1.19 ± 0.021 mg/kg	0.720	<2
01DO.S.06	N 29°21'40.2" E 47°48'56.3"	Soil (0-5)	Spiez	ICP-MS	1.42 ± 0.032 mg/kg	61 ± 7.1 ng/kg	9.1 ± 0.30 µg/kg	1.43 ± 0.032 mg/kg	0.641	16
01DO.S.07	N 29°21'39.9" E 47°48'56.4'	Soil (0-5)	Spiez	ICP-MS	1.16 ± 0.020 mg/kg	57 ± 6.7 ng/kg	8.2 ± 0.31 µg/kg	1.17 ± 0.020 mg/kg	0.707	3.5
01DO.S.08	N 29°21'40.3" E 47°48'56.4"	Soil (0-5)	Spiez	ICP-MS	6.42 ± 0.10 mg/kg	135 ± 14 ng/kg	22.2 ± 0.46 µg/kg	6.44 ± 0.100 mg/kg	0.346	72

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
DOHA	—	Soil	IAEA	ICP-MS				1065 ± 32 mg/kg	0.200	100
				α-spec	1231 ± 104 mg/kg					
				γ-spec	565 ± 1565 mg/kg					
01DO.W.01	N 29°21'40.2" E 47°48'56.6"	Water	IAEA	ICP-MS				130 ± 4 µg/kg	0.310	79
				α-spec	110 ± 10 µg/kg					
		Water filter		ICP-MS				2.7 ± 0.10 µg/kg	0.638	17
01DO.W.02	N 29°21'39.3" E 47°48'56.2"	Water	IAEA	ICP-MS				390 ± 10 µg/kg	0.240	92
				α-spec	360 ± 20 µg/kg					
		Water filter		ICP-MS				0.81 ± 0.026 µg/kg	0.614	21
01DO.W.03	N 29°21'39.4" E 47°48'55.0"	Water	IAEA	ICP-MS				330 ± 10 µg/kg	0.270	87
				α-spec	285 ± 20 µg/kg					
		Water filter		ICP-MS				1.17 ± 0.035 µg/kg	0.613	21
Al Jahra										
02JA.S.01	N 29°21'50.0" E 47°39'57.2"	Soil (0-5)	Spiez	ICP-MS	0.78 ± 0.017 mg/kg	41 ± 4.7 ng/kg	5.7 ± 0.20 µg/kg	0.79 ± 0.017 mg/kg	0.731	<2
02JA.S.02	N 29°21'34.4" E 47°39'46.8"	Soil (0-5)	Spiez	ICP-MS	0.95 ± 0.033 mg/kg	52 ± 6.1 ng/kg	6.9 ± 0.29 µg/kg	0.96 ± 0.033 mg/kg	0.726	<2
02JA.S.03	N 29°21'34.4" E 47°39'46.8"	Soil (0-2)	Spiez	ICP-MS	0.87 ± 0.020 mg/kg	47 ± 5.2 ng/kg	6.3 ± 0.25 µg/kg	0.88 ± 0.020 mg/kg	0.724	<2
02JA.S.04	N 29°21'16.5" E 47°40'11.6"	Soil (0-5)	Spiez	ICP-MS	0.88 ± 0.023 mg/kg	47 ± 5.4 ng/kg	6.3 ± 0.26 µg/kg	0.89 ± 0.024 mg/kg	0.716	<2
02JA.S.05	N 29°20'37.2" E 47°40'38.9"	Soil (0-5)	Spiez	ICP-MS	0.89 ± 0.035 mg/kg	47 ± 5.4 ng/kg	6.4 ± 0.34 µg/kg	0.90 ± 0.035 mg/kg	0.719	<2
02JA.S.06	N 29°20'08.0" E 47°40'54.7"	Soil (0-5)	Spiez	ICP-MS	0.90 ± 0.017 mg/kg	45 ± 5.7 ng/kg	6.5 ± 0.32 µg/kg	0.91 ± 0.017 mg/kg	0.722	<2
Al Wafrah										
04WA.P.06	N 28°33'95.3" E 48°04'06.3"	Soil (0-5)	Spiez	ICP-MS	0.94 ± 0.019 mg/kg	56 ± 8.0 ng/kg	6.9 ± 0.18 µg/kg	0.95 ± 0.019 mg/kg	0.734	<2
04WA.P.07		Soil (5-15)	Spiez	ICP-MS	0.71 ± 0.018 mg/kg	40 ± 5.9 ng/kg	5.2 ± 0.17 µg/kg	0.72 ± 0.018 mg/kg	0.732	<2
04WA.P.08		Soil (15-25)	Spiez	ICP-MS	0.68 ± 0.014 mg/kg	35 ± 8.4 ng/kg	4.9 ± 0.15 µg/kg	0.68 ± 0.014 mg/kg	0.721	<2
04WA.P.09		Soil (25-35)	Spiez	ICP-MS	0.61 ± 0.016 mg/kg	36 ± 6.3 ng/kg	4.5 ± 0.17 µg/kg	0.61 ± 0.017 mg/kg	0.738	<2
04WA.S.01	N 28°33'52.8" E 48°00'22.5"	Soil (0-5)	Spiez	ICP-MS	0.94 ± 0.028 mg/kg	58 ± 13 ng/kg	6.8 ± 0.23 µg/kg	0.95 ± 0.029 mg/kg	0.723	<2
04WA.S.02	N 28°33'54.2" E 48°00'20.3"	Soil (0-5)	Spiez	ICP-MS	0.90 ± 0.020 mg/kg	50 ± 6.8 ng/kg	6.6 ± 0.18 µg/kg	0.91 ± 0.020 mg/kg	0.733	<2
04WA.S.03	N 28°33'54.8" E 48°00'20.4"	Soil (0-5)	Spiez	ICP-MS	0.81 ± 0.016 mg/kg	45 ± 8.2 ng/kg	5.9 ± 0.15 µg/kg	0.82 ± 0.016 mg/kg	0.728	<2

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
04WA.S.04	N 28°33'58.2" E 48°00'21.3"	Soil (0-5)	Spiez	ICP-MS	1.10 ± 0.022 mg/kg	63 ± 9.7 ng/kg	8.1 ± 0.22 µg/kg	1.11 ± 0.022 mg/kg	0.736	<2
04WA.S.05	N 28°33'57.6" E 48°00'23.8"	Soil (0-5)	Spiez	ICP-MS	0.89 ± 0.024 mg/kg	48 ± 6.6 ng/kg	6.5 ± 0.19 µg/kg	0.90 ± 0.024 mg/kg	0.730	<2
04WA.S.06	N 28°33'58.7" E 48°04'11.7"	Soil (0-5)	Spiez	ICP-MS	0.79 ± 0.023 mg/kg	46 ± 9.6 ng/kg	5.9 ± 0.20 µg/kg	0.80 ± 0.023 mg/kg	0.747	<2
04WA.S.07	N 28°33'58.8" E 48°04'13.2"	Soil (0-5)	Spiez	ICP-MS	0.81 ± 0.023 mg/kg	49 ± 9.8 ng/kg	6.0 ± 0.20 µg/kg	0.82 ± 0.023 mg/kg	0.741	<2
04WA.S.08	N 28°33'59.5" E 48°04'15.0"	Soil (0-5)	Spiez	ICP-MS	0.82 ± 0.019 mg/kg	48 ± 7.4 ng/kg	6.0 ± 0.16 µg/kg	0.83 ± 0.019 mg/kg	0.732	<2
04WA.S.11	N 28°33'94.5" E 48°00'31.1"	Soil (0-5)	Spiez	ICP-MS	1.08 ± 0.024 mg/kg	68 ± 9.0 ng/kg	7.9 ± 0.20 µg/kg	1.09 ± 0.024 mg/kg	0.731	<2
04WA.S.12	N 28°33'99.7" E 48°00'36.1"	Soil (0-5)	Spiez	ICP-MS	1.00 ± 0.023 mg/kg	60 ± 9.0 ng/kg	7.4 ± 0.20 µg/kg	1.01 ± 0.023 mg/kg	0.740	<2
04WA.S.13	N 28°34'00.4" E 48°00'40.1"	Soil (0-5)	Spiez	ICP-MS	0.91 ± 0.024 mg/kg	52 ± 7.3 ng/kg	6.7 ± 0.21 µg/kg	0.92 ± 0.024 mg/kg	0.736	<2
W1	—	Soil	IAEA	ICP-MS				0.59 ± 0.02 mg/kg	0.730	<2
				α-spec	0.69 ± 0.05 mg/kg					
				γ-spec	<1.5 mg/kg					
W2	—	Soil	IAEA	ICP-MS				4.42 ± 0.13 mg/kg	0.720	<2
				α-spec	5.7 ± 0.4 mg/kg					
				γ-spec	4.0 mg/kg					
W3	—	Soil	IAEA	ICP-MS				0.43 ± 0.01 mg/kg	0.730	<2
				α-spec	0.69 ± 0.10 mg/kg					
				γ-spec	<1.9 mg/kg					
04WA.W.01	N 28°33'58.8" E 48°00'15.6"	Water	Spiez	ICP-MS	8.3 ± 0.17 µg/L	449 ± 56 pg/L	60 ± 1.5 ng/L	8.4 ± 0.17 µg/L	0.723	<2
		Water filter		ICP-MS	15.1 ± 0.36 ng/kg	0.78 ± 0.096 pg/kg	0.105 ± 0.0037 ng/kg	15.2 ± 0.36 ng/kg	0.697	5.4
04WA.W.02	N 28°34'02.0" E 48°00'46.0"	Water	Spiez	ICP-MS	0.22 ± 0.034 µg/L	25 ± 4.6 pg/L	1.5 ± 0.23 ng/L	0.22 ± 0.034 µg/L	0.658	13
		Water filter		ICP-MS	6.5 ± 0.11 ng/kg	0.36 ± 0.046 pg/kg	0.046 ± 0.0017 ng/kg	6.5 ± 0.11 ng/kg	0.714	2.1
04WA.W.03	N 28°33'55.8" E 48°04'11.4"	Water	Spiez	ICP-MS	12 ± 0.38 µg/L	875 ± 98 pg/L	85 ± 3.4 ng/L	12.1 ± 0.39 µg/L	0.723	<2
		Water filter		ICP-MS	43 ± 1.1 ng/kg	2.7 ± 0.30 pg/kg	0.30 ± 0.011 ng/kg	43 ± 1.1 ng/kg	0.693	6.1
04WA.W.04	N 28°34'01.3" E 48°04'04.7"	Water	Spiez	ICP-MS	2.0 ± 0.060 µg/L	169 ± 22 pg/L	14 ± 0.69 ng/L	2.01 ± 0.061 µg/L	0.720	<2
		Water filter		ICP-MS	1.39 ± 0.041 ng/kg	0.10 ± 0.018 pg/kg	0.0098 ± 0.00039 ng/kg	1.40 ± 0.042 ng/kg	0.700	4.8
04WA.V.01	N 28°33'51.8" E 48°00'23.3"	Lettuce	Spiez	ICP-MS	0.206 ± 0.022 µg/kg	0.011 ± 0.0017 ng/kg	1.23 ± 0.15 ng/kg	0.21 ± 0.023 µg/kg	0.597	24.3
04WA.V.02	N 28°33'51.1" E 48°00'20.8"	Cucumbers	Spiez	ICP-MS	0.078 ± 0.006 µg/kg	0.0020 ± 0.00061 ng/kg	0.294 ± 0.053 ng/kg	0.078 ± 0.0061 µg/kg	0.377	66.2

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
04WA.V.03	N 28°33'54.9" E 48°00'20.5"	Cabbage	Spiez	ICP-MS	0.269 ± 0.017 µg/kg	0.014 ± 0.0020 ng/kg	1.69 ± 0.106 ng/kg	0.27 ± 0.017 µg/kg	0.628	18.4
04WA.V.04	N 28°33'58.3" E 48°00'21.4"	Tomatoes	Spiez	ICP-MS	0.071 ± 0.004 µg/kg	0.0039 ± 0.00076 ng/kg	0.485 ± 0.032 ng/kg	0.071 ± 0.0043 µg/kg	0.683	8.0
04WA.V.05	N 28°33'54.7" E 48°04'14.0"	Carrots	Spiez	ICP-MS	1.10 ± 0.048 µg/kg	0.080 ± 0.0090 ng/kg	7.76 ± 0.376 ng/kg	1.11 ± 0.048 µg/kg	0.705	3.7
Al Mutlaa										
06MU.S.01	N 29°27'13.3" E 47°39'05.4"	Soil (0-5)	Spiez	ICP-MS	0.84 ± 0.020 mg/kg	46 ± 5.3 ng/kg	6.1 ± 0.27 µg/kg	0.85 ± 0.020 mg/kg	0.726	<2
06MU.S.02	N 29°27'16.4" E 47°38'36.8"	Soil (0-5)	Spiez	ICP-MS	1.02 ± 0.019 mg/kg	57 ± 6.8 ng/kg	7.4 ± 0.22 µg/kg	1.03 ± 0.019 mg/kg	0.725	<2
06MU.S.03	N 29°26'29.2" E 47°38'20.1"	Soil (0-5)	Spiez	ICP-MS	0.64 ± 0.021 mg/kg	35 ± 4.1 ng/kg	4.6 ± 0.18 µg/kg	0.64 ± 0.022 mg/kg	0.719	<2
06MU.S.04	N 29°26'18.8" E 47°38'29.3"	Soil (0-5)	Spiez	ICP-MS	0.69 ± 0.017 mg/kg	38 ± 4.6 ng/kg	5.0 ± 0.23 µg/kg	0.70 ± 0.017 mg/kg	0.725	<2
06MU.S.05	N 29°23'00.0" E 47°39'05.2"	Soil (0-5)	Spiez	ICP-MS	0.97 ± 0.024 mg/kg	51 ± 6.1 ng/kg	7.0 ± 0.34 µg/kg	0.98 ± 0.025 mg/kg	0.722	<2
06MU.S.06	N 29°22'54.9" E 47°39'04.2"	Soil (0-5)	Spiez	ICP-MS	1.18 ± 0.021 mg/kg	69 ± 8.5 ng/kg	8.4 ± 0.29 µg/kg	1.19 ± 0.021 mg/kg	0.712	2.5
06MU.S.07	N 29°23'07.7" E 47°39'09.3"	Soil (0-5)	Spiez	ICP-MS	0.71 ± 0.014 mg/kg	36 ± 4.6 ng/kg	5.1 ± 0.19 µg/kg	0.72 ± 0.014 mg/kg	0.718	<2
06MU.S.08	N 29°23'07.7" E 47°39'39.3"	Soil (0-5)	Spiez	ICP-MS	0.91 ± 0.016 mg/kg	47 ± 5.5 ng/kg	6.5 ± 0.28 µg/kg	0.92 ± 0.016 mg/kg	0.714	2.1
06MU.V.01	N 29°26'28.3" E 47°38'20.6"	Stems	Spiez	ICP-MS	142 ± 2.4 µg/kg	7.5 ± 0.80 ng/kg	1014 ± 22 ng/kg	143 ± 2.4 µg/kg	0.714	2.1
06MU.V.02	N 29°26'18.9" E 47°38'29.3"	Vegetation	Spiez	ICP-MS	29.0 ± 0.6 µg/kg	1.5 ± 0.16 ng/kg	208 ± 5 ng/kg	29.2 ± 0.63 µg/kg	0.717	<2
Um Al Kwaty										
07KW.S.01	N 29°25'01.2" E 47°30'44.8"	Soil (0-10)	IAEA	γ-spec	4.4 ± 0.3 mg/kg				—	—
07KW.S.02	N 29°25'01.7" E 47°30'44.1"	Soil (0-10)	IAEA	γ-spec	6.8 ± 0.5 mg/kg				—	—
07KW.S.03	N 29°25'02.4" E 47°30'43.4"	Soil (0-10)	IAEA	ICP-MS				18.0 ± 0.5 mg/kg	0.286	84
				α-spec	20.3 ± 0.9 mg/kg					
				γ-spec	15.7 ± 0.7 mg/kg					
07KW.S.04	N 29°25'03.4" E 47°30'43.2"	Soil (0-10)	IAEA	γ-spec	1207 ± 24 mg/kg				—	—
07KW.S.05	N 29°25'04.0" E 47°30'43.4"	Soil (0-10)	IAEA	ICP-MS				1214 ± 36 mg/kg	0.208	99
				α-spec	1126 ± 119 mg/kg					

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
				γ-spec	1210 mg/kg					
07KW.S.06	N 29°25'05.4" E 47°30'42.9"	Soil (0-10)	IAEA	γ-spec	9.4 ± 0.6 mg/kg				—	—
07KW.S.07	N 29°25'07.9" E 47°30'42.6"	Soil (0-10)	IAEA	γ-spec	1274 ± 24 mg/kg				—	—
07KW.S.08	N 29°25'07.1" E 47°30'43.9"	Soil (0-10)	IAEA	ICP-MS				5.23 ± 0.2 mg/kg	0.469	49
				α-spec	5.1 ± 0.3 mg/kg					
				γ-spec	4.9 ± 0.5 mg/kg					
07KW.S.09	N 29°25'06.7" E 47°30'44.9"	Soil (0-10)	IAEA	ICP-MS				75.8 ± 2.3 mg/kg	0.222	96
				α-spec	93 ± 5 mg/kg					
				γ-spec	88 ± 24 mg/kg					
07KW.S.10	N 29°25'05.9" E 47°30'45.7"	Soil (0-10)	IAEA	ICP-MS				207 ± 6 mg/kg	0.211	98
				α-spec	227 ± 11 mg/kg					
				γ-spec	145 mg/kg					
07KW.S.11	N 29°25'05.5" E 47°30'44.3"	Soil (0-10)	IAEA	ICP-MS				19.4 ± 0.6 mg/kg	0.278	85
				α-spec	22 ± 1 mg/kg					
				γ-spec	48.1 ± 1.1 mg/kg					
Military Hospital storage ground										
08HO.P.01	N 29°14'36.7" E 48°01'03.6"	Soil (0-5)	Spiez	ICP-MS	0.87 ± 0.030 mg/kg	44 ± 5.2 ng/kg	6.1 ± 0.31 µg/kg	0.88 ± 0.031 mg/kg	0.701	4.6
08HO.P.02		Soil (5-15)	Spiez	ICP-MS	0.99 ± 0.020 mg/kg	50 ± 6.5 ng/kg	7.0 ± 0.38 µg/kg	1.00 ± 0.020 mg/kg	0.707	3.4
08HO.P.03		Soil (15-25)	Spiez	ICP-MS	0.90 ± 0.032 mg/kg	45 ± 5.2 ng/kg	6.4 ± 0.42 µg/kg	0.91 ± 0.033 mg/kg	0.711	2.7
08HO.P.04		Soil (25-35)	Spiez	ICP-MS	0.83 ± 0.014 mg/kg	41 ± 5.2 ng/kg	5.9 ± 0.28 µg/kg	0.84 ± 0.014 mg/kg	0.711	2.7
08HO.S.01	N 29°14'36.7" E 48°01'03.3"	Soil (0-5)	Spiez	ICP-MS	0.97 ± 0.021 mg/kg	51 ± 5.7 ng/kg	7.0 ± 0.19 µg/kg	0.98 ± 0.021 mg/kg	0.722	<2
08HO.S.02	N 29°14'37.3" E 48°01'02.5"	Soil (0-5)	Spiez	ICP-MS	1.33 ± 0.035 mg/kg	73 ± 8.8 ng/kg	9.6 ± 0.36 µg/kg	1.34 ± 0.035 mg/kg	0.722	<2
08HO.S.03	N 29°14'37.9" E 48°01'02.8"	Soil (0-5)	Spiez	ICP-MS	1.36 ± 0.020 mg/kg	65 ± 7.2 ng/kg	9.0 ± 0.34 µg/kg	1.37 ± 0.020 mg/kg	0.662	12
08HO.S.04	N 29°14'38.9" E 48°01'03.3"	Soil (0-5)	Spiez	ICP-MS	3.34 ± 0.081 mg/kg	79 ± 8.5 ng/kg	12.8 ± 0.37 µg/kg	3.35 ± 0.082 mg/kg	0.383	65
Umm Gudayar GC 18										
09GU.P.01	N 28°55'03.1" E 47°40'02.0"	Soil (0-5)	Spiez	ICP-MS	0.85 ± 0.014 mg/kg	41 ± 8.7 ng/kg	5.9 ± 0.29 µg/kg	0.86 ± 0.015 mg/kg	0.694	5.9
09GU.P.02		Soil (5-10)	Spiez	ICP-MS	0.86 ± 0.013 mg/kg	42 ± 5.6 ng/kg	6.2 ± 0.23 µg/kg	0.87 ± 0.014 mg/kg	0.721	<2
09GU.P.03		Soil (10-15)	Spiez	ICP-MS	0.77 ± 0.036 mg/kg	37 ± 4.8 ng/kg	5.6 ± 0.30 µg/kg	0.78 ± 0.036 mg/kg	0.727	<2
09GU.P.04		Soil (15-20)	Spiez	ICP-MS	0.87 ± 0.021 mg/kg	40 ± 5.2 ng/kg	6.2 ± 0.23 µg/kg	0.88 ± 0.021 mg/kg	0.713	2.4

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
09GU.P.05	N 28°55'03.2" E 47°40'02.7"	Soil (0-5)	Spiez	ICP-MS	1.21 ± 0.019 mg/kg	62 ± 7.6 ng/kg	8.6 ± 0.44 µg/kg	1.22 ± 0.019 mg/kg	0.711	2.7
09GU.P.06		Soil (5-10)	Spiez	ICP-MS	1.16 ± 0.021 mg/kg	58 ± 9.2 ng/kg	8.3 ± 0.55 µg/kg	1.17 ± 0.022 mg/kg	0.716	<2
09GU.P.07		Soil (10-15)	Spiez	ICP-MS	1.18 ± 0.018 mg/kg	60 ± 6.4 ng/kg	8.4 ± 0.21 µg/kg	1.19 ± 0.018 mg/kg	0.712	2.5
09GU.P.08		Soil (15-20)	Spiez	ICP-MS	1.51 ± 0.039 mg/kg	82 ± 9.6 ng/kg	11.0 ± 0.46 µg/kg	1.52 ± 0.040 mg/kg	0.728	<2
09GU.S.01	N 28°55'04.1" E 47°40'02.2"	Soil (0-5)	Spiez	ICP-MS	0.78 ± 0.018 mg/kg	41 ± 5.8 ng/kg	5.5 ± 0.40 µg/kg	0.79 ± 0.019 mg/kg	0.705	3.8
09GU.S.02	N 28°55'04.0" E 47°40'01.6"	Soil (0-5)	Spiez	ICP-MS	1.63 ± 0.026 mg/kg	93 ± 10 ng/kg	11.7 ± 0.60 µg/kg	1.64 ± 0.026 mg/kg	0.718	<2
09GU.S.03	N 28°55'04.0" E 47°40'01.2"	Soil (0-5)	Spiez	ICP-MS	0.65 ± 0.015 mg/kg	30 ± 3.8 ng/kg	4.3 ± 0.23 µg/kg	0.65 ± 0.016 mg/kg	0.662	12
09GU.S.04	N 28°55'05.0" E 47°40'00.8"	Soil (0-5)	Spiez	ICP-MS	0.65 ± 0.015 mg/kg	32 ± 4.2 ng/kg	4.6 ± 0.40 µg/kg	0.65 ± 0.015 mg/kg	0.708	3.3
09GU.S.05	N 28°55'05.0" E 47°40'04.5"	Soil (0-5)	Spiez	ICP-MS	0.47 ± 0.009 mg/kg	20 ± 3.4 ng/kg	3.3 ± 0.17 µg/kg	0.473 ± 0.009 mg/kg	0.702	4.4
Manageesh GC 28										
09MA.S.01	N 29°01'19.9" E 47°36'01.1"	Soil (0-5)	IAEA	ICP-MS				1.11 ± 0.03 mg/kg	0.440	54
				α-spec	1.27 ± 0.07 mg/kg					
				γ-spec	2.3 ± 0.3 mg/kg					
09MA.S.02	N 29°01'20.2" E 47°36'00.9"	Soil (0-5)	IAEA	ICP-MS				1.98 ± 0.06 mg/kg	0.340	73
				α-spec	2.0 ± 0.1 mg/kg					
				γ-spec	2.3 ± 0.4 mg/kg					
09MA.S.06	N 29°01'19.8" E 47°36'01.3"	Soil (0-5)	IAEA	ICP-MS				0.47 ± 0.01 mg/kg	0.650	14
				α-spec	0.7 ± 0.1 mg/kg					
				γ-spec	<2.1 mg/kg					
09MA.S.07	N 29°01'16.8" E 47°36'04.0"	Soil (0-5)	IAEA	ICP-MS				0.71 ± 0.02 mg/kg	0.510	41
				α-spec	0.88 ± 0.06 mg/kg					
				γ-spec	<2.0 mg/kg					
09MA.S.08	N 29°01'16.8" E 47°35'58.3"	Soil (0-5)	IAEA	ICP-MS				0.51 ± 0.02 mg/kg	0.640	16
				α-spec	0.53 ± 0.04 mg/kg					
				γ-spec	<2.2 mg/kg					
09MA.S.09	N 29°01'22.8" E 47°36'04.3"	Soil (0-5)	IAEA	ICP-MS				0.68 ± 0.02 mg/kg	0.540	35
				α-spec	0.65 ± 0.04 mg/kg					
				γ-spec	<1.6 mg/kg					
09MA.S.10	N 29°01'22.8" E 47°35'58.3"	Soil (0-5)	IAEA	ICP-MS				0.48 ± 0.01 mg/kg	0.660	12
				α-spec	0.6 ± 0.1 mg/kg					
				γ-spec	<1.8 mg/kg					

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
09MA.RE.01	N 29°01'20.5" E 47°36'00.5"	Soil	IAEA	ICP-MS				0.73 ± 0.02 mg/kg	0.500	43
				α-spec	0.78 ± 0.04 mg/kg					
				γ-spec	0.8 ± 0.3 mg/kg					
09MA.P.01	N 29°01'19.8" E 47°36'00.7"	Soil (0-5)	IAEA	ICP-MS				3931 ± 118 mg/kg	0.207	99
				α-spec	4180 ± 250 mg/kg					
				γ-spec	7185 ± 137 mg/kg					
09MA.P.02		Soil (5-10)	IAEA	ICP-MS				8.1 ± 0.2 mg/kg	0.229	95
				α-spec	9.3 ± 0.5 mg/kg					
				γ-spec	7.3 ± 0.9 mg/kg					
09MA.P.03		Soil (10-15)	IAEA	ICP-MS				3.6 ± 0.1 mg/kg	0.270	87
				α-spec	3.6 ± 0.2 mg/kg					
				γ-spec	<5.0 mg/kg					
09MA.P.04		Soil (15-20)	IAEA	ICP-MS				2.10 ± 0.06 mg/kg	0.310	79
				α-spec	2.4 ± 0.1 mg/kg					
				γ-spec	<4.2 mg/kg					
09MA.P.05		Soil (20-25)	IAEA	ICP-MS				1.70 ± 0.05 mg/kg	0.330	75
				α-spec	2.5 ± 0.1 mg/kg					
				γ-spec	1.2 ± 0.7 mg/kg					
09MA.P.06	N 29°01'19.7" E 47°36'01.1"	Soil (0-5)	IAEA	ICP-MS				0.46 ± 0.01 mg/kg	0.660	12
				α-spec	0.53 ± 0.04 mg/kg					
				γ-spec	<4.1 mg/kg					
09MA.P.07		Soil (5-10)	IAEA	ICP-MS				0.46 ± 0.01 mg/kg	0.660	12
				α-spec	0.64 ± 0.04 mg/kg					
				γ-spec	<3.5 mg/kg					
09MA.P.08		Soil (10-15)	IAEA	ICP-MS				0.46 ± 0.01 mg/kg	0.700	5
				α-spec	0.70 ± 0.05 mg/kg					
				γ-spec	<4.1 mg/kg					
09MA.P.09		Soil (15-20)	IAEA	ICP-MS				0.52 ± 0.02 mg/kg	0.590	26
				α-spec	0.68 ± 0.04 mg/kg					
				γ-spec	<4.0 mg/kg					
09MA.U.01	N 29°01'19.8" E 47°36'00.7"	Soil	IAEA		—				—	—
GC28#1	—	Soil	IAEA	ICP-MS				98.0 ± 2.9 mg/kg	0.220	96
				α-spec	103 ± 6 mg/kg					
				γ-spec	159 mg/kg					

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
GC28#2	—	Soil	IAEA	ICP-MS				7.28 ± 0.22 mg/kg	0.230	94
				α-spec	7.4 ± 0.8 mg/kg					
				γ-spec	6.0 mg/kg					
GC28#3	—	Soil	IAEA	ICP-MS				77.5 ± 2.3 mg/kg	0.220	96
				α-spec	85 ± 5 mg/kg					
				γ-spec	94 mg/kg					
GC28#4	—	Soil	IAEA	ICP-MS				14.5 ± 0.4 mg/kg	0.210	98
				α-spec	13.5 ± 0.6 mg/kg					
				γ-spec	5.2 mg/kg					
GC28#5	—	Soil	IAEA	ICP-MS				0.60 ± 0.02 mg/kg	0.660	12
				α-spec	0.54 ± 0.04 mg/kg					
				γ-spec	<1.5 mg/kg					
Soil/GC 28 1D	—	Soil (0-5)	IAEA	ICP-MS				1585 ± 48 mg/kg	0.210	98
				α-spec	1536 ± 370 mg/kg					
				γ-spec	4597 mg/kg					
		Soil (5-15)	IAEA	ICP-MS				65.7 ± 2.0 mg/kg	0.200	100
				α-spec	67 ± 4 mg/kg					
				γ-spec	46 mg/kg					
		Soil (15-25)	IAEA	ICP-MS				2.74 ± 0.08 mg/kg	0.320	77
				α-spec	2.7 ± 0.2 mg/kg					
				γ-spec	<2.5 mg/kg					
		Soil (25-35)	IAEA	ICP-MS				2.3 ± 0.1 mg/kg	0.350	71
				α-spec	2.1 ± 0.1 mg/kg					
				γ-spec	<1.7 mg/kg					
GC 28 1D	—	Soil (0-5)	IAEA	ICP-MS				7530 ± 226 mg/kg	0.202	100
				α-spec	8500 ± 500 mg/kg					
				γ-spec	4702 ± 48 mg/kg					
GC 28 2D	—	Soil (5-15)	IAEA	ICP-MS				6.3 ± 0.2 mg/kg	0.260	89
				α-spec	7.7 ± 0.5 mg/kg					
				γ-spec	38 ± 1.8 mg/kg					
GC 28 3D	—	Soil (15-25)	IAEA	γ-spec	<5.1 mg/kg				—	—
GC 28 4D	—	Soil (25-35)	IAEA	ICP-MS				2.20 ± 0.07 mg/kg	0.354	71
				α-spec	2.6 ± 0.1 mg/kg					
				γ-spec	<4.8 mg/kg					

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
Al Sabhan										
09SA.S.01	N 29°14'43.1" E 48°01'50.2"	Soil (0-5)	Spiez	ICP-MS	1.01 ± 0.020 mg/kg	53 ± 5.9 ng/kg	7.3 ± 0.26 µg/kg	1.02 ± 0.020 mg/kg	0.723	<2
09SA.S.02	N 29°14'41.5" E 48°01'50.2"	Soil (0-5)	Spiez	ICP-MS	0.98 ± 0.022 mg/kg	52 ± 6.2 ng/kg	7.1 ± 0.26 µg/kg	0.99 ± 0.022 mg/kg	0.724	<2
09SA.S.03	N 29°14'45.0" E 48°01'50.4"	Soil (0-5)	Spiez	ICP-MS	0.90 ± 0.019 mg/kg	48 ± 5.6 ng/kg	6.5 ± 0.20 µg/kg	0.91 ± 0.019 mg/kg	0.722	<2
09SA.S.04	N 29°14'43.2" E 48°01'48.1"	Soil (0-5)	Spiez	ICP-MS	1.04 ± 0.015 mg/kg	55 ± 6.1 ng/kg	7.5 ± 0.20 µg/kg	1.05 ± 0.016 mg/kg	0.721	<2
Al Abdali										
10AB.FE.01	N 30°01'42.4" E 47°44'35.7"	Soil	Spiez	ICP-MS	<0.005 mg/kg					
10AB.P.01	N 30°01'29.4" E 47°44'29.4"	Soil (0-5)	Spiez	ICP-MS	1.03 ± 0.040 mg/kg	56 ± 6.5 ng/kg	7.5 ± 0.34 µg/kg	1.04 ± 0.041 mg/kg	0.728	<2
10AB.P.02		Soil (5-15)	Spiez	ICP-MS	1.15 ± 0.022 mg/kg	63 ± 7.1 ng/kg	8.4 ± 0.29 µg/kg	1.16 ± 0.022 mg/kg	0.730	<2
10AB.P.03		Soil (15-25)	Spiez	ICP-MS	1.08 ± 0.042 mg/kg	61 ± 6.8 ng/kg	7.8 ± 0.38 µg/kg	1.09 ± 0.042 mg/kg	0.722	<2
10AB.P.04		Soil (25-35)	Spiez	ICP-MS	1.14 ± 0.021 mg/kg	65 ± 7.8 ng/kg	8.3 ± 0.34 µg/kg	1.15 ± 0.021 mg/kg	0.728	<2
10AB.P.05	N 30°01'36.0" E 47°44'28.6"	Soil (0-5)	Spiez	ICP-MS	1.10 ± 0.020 mg/kg	62 ± 6.9 ng/kg	8.0 ± 0.34 µg/kg	1.11 ± 0.021 mg/kg	0.727	<2
10AB.P.06		Soil (5-15)	Spiez	ICP-MS	1.08 ± 0.028 mg/kg	61 ± 7.8 ng/kg	7.8 ± 0.39 µg/kg	1.09 ± 0.029 mg/kg	0.722	<2
10AB.P.07		Soil (15-25)	Spiez	ICP-MS	1.10 ± 0.019 mg/kg	61 ± 8.0 ng/kg	8.1 ± 0.29 µg/kg	1.11 ± 0.020 mg/kg	0.736	<2
10AB.P.08		Soil (25-35)	Spiez	ICP-MS	1.01 ± 0.033 mg/kg	55 ± 6.8 ng/kg	7.4 ± 0.33 µg/kg	1.02 ± 0.034 mg/kg	0.733	<2
10AB.P.09	N 30°01'35.0" E 47°42'46.9"	Soil (0-5)	Spiez	ICP-MS	1.05 ± 0.033 mg/kg	57 ± 6.7 ng/kg	7.6 ± 0.35 µg/kg	1.06 ± 0.034 mg/kg	0.724	<2
10AB.P.10		Soil (5-15)	Spiez	ICP-MS	1.02 ± 0.020 mg/kg	60 ± 7.0 ng/kg	7.4 ± 0.29 µg/kg	1.03 ± 0.020 mg/kg	0.725	<2
10AB.P.11		Soil (15-25)	Spiez	ICP-MS	1.18 ± 0.021 mg/kg	67 ± 7.7 ng/kg	8.7 ± 0.23 µg/kg	1.19 ± 0.021 mg/kg	0.737	<2
10AB.P.12		Soil (25-35)	Spiez	ICP-MS	1.06 ± 0.023 mg/kg	58 ± 6.3 ng/kg	7.8 ± 0.21 µg/kg	1.07 ± 0.023 mg/kg	0.736	<2
10AB.P.13	N 30°01'27.7" E 47°42'56.6"	Soil (0-5)	Spiez	ICP-MS	1.50 ± 0.030 mg/kg	91 ± 9.7 ng/kg	11.1 ± 0.29 µg/kg	1.51 ± 0.031 mg/kg	0.740	<2
10AB.P.14		Soil (5-15)	Spiez	ICP-MS	1.63 ± 0.032 mg/kg	101 ± 12 ng/kg	12.0 ± 0.36 µg/kg	1.64 ± 0.033 mg/kg	0.736	<2
10AB.P.15		Soil (15-25)	Spiez	ICP-MS	1.34 ± 0.026 mg/kg	79 ± 9.4 ng/kg	9.8 ± 0.36 µg/kg	1.35 ± 0.026 mg/kg	0.731	<2
10AB.P.16		Soil (25-35)	Spiez	ICP-MS	1.36 ± 0.034 mg/kg	82 ± 9.7 ng/kg	9.9 ± 0.41 µg/kg	1.37 ± 0.035 mg/kg	0.728	<2
10AB.S.10	N 30°01'42.4" E 47°44'35.7"	Soil (0-5)	Spiez	ICP-MS	1.72 ± 0.032 mg/kg	100 ± 11 ng/kg	12.6 ± 0.36 µg/kg	1.73 ± 0.032 mg/kg	0.733	<2
10AB.S.11	N 30°01'41.9" E 47°44'36.0"	Soil (0-5)	Spiez	ICP-MS	1.34 ± 0.026 mg/kg	76 ± 8.3 ng/kg	9.7 ± 0.30 µg/kg	1.35 ± 0.026 mg/kg	0.724	<2
10AB.S.12	N 30°01'45.7" E 47°44'40.2"	Soil (0-5)	Spiez	ICP-MS	1.14 ± 0.034 mg/kg	63 ± 7.4 ng/kg	8.2 ± 0.39 µg/kg	1.15 ± 0.034 mg/kg	0.719	<2
10AB.S.13	N 30°01'29.7" E 47°42'53.3"	Soil (0-5)	Spiez	ICP-MS	1.66 ± 0.032 mg/kg	101 ± 11 ng/kg	12.0 ± 0.57 µg/kg	1.67 ± 0.032 mg/kg	0.723	<2

TABLE XXXVIII. (cont.)

Sample field code	Co-ordinates	Sample type (depth, cm)	Analysed by	Method	^{238}U	^{234}U	^{235}U	U_{total}	$^{235}U/^{238}U$ by mass (×100)	Fraction of DU by mass (%)
10AB.S.14	N 30°01'30.3" E 47°42'54.5"	Soil (0-5)	Spiez	ICP-MS	1.48 ± 0.034 mg/kg	89 ± 10 ng/kg	10.9 ± 0.34 µg/kg	1.49 ± 0.034 mg/kg	0.736	<2
10AB.S.15	N 30°01'32.9" E 47°42'57.0"	Soil (0-5)	Spiez	ICP-MS	1.26 ± 0.026 mg/kg	70 ± 7.8 ng/kg	9.3 ± 0.24 µg/kg	1.27 ± 0.027 mg/kg	0.738	<2
10AB.W.03	N 30°01'41.8" E 47°44'31.4"	Water	Spiez	ICP-MS	54 ± 2.6 µg/L	3518 ± 415 pg/L	391 ± 20 ng/L	54 ± 2.6 µg/L	0.724	<2
		Water filter		ICP-MS	12.5 ± 0.26 ng/kg	0.79 ± 0.090 pg/kg	0.088 ± 0.0024 ng/kg	12.6 ± 0.26 ng/kg	0.704	4.1
10AB.W.04	N 30°01'35.7" E 47°44'43.2"	Water	Spiez	ICP-MS	115 ± 2.3 µg/L	7247 ± 797 pg/L	835 ± 19 ng/L	116 ± 2.3 µg/L	0.726	<2
		Water filter		ICP-MS	31.3 ± 0.77 ng/kg	1.9 ± 0.22 pg/kg	0.224 ± 0.0086 ng/kg	31.5 ± 0.78 ng/kg	0.716	<2
10AB.W.05	N 30°01'36.7" E 47°42'50.3"	Water	Spiez	ICP-MS	7.7 ± 0.16 µg/L	634 ± 67 pg/L	56 ± 1.45 ng/L	7.8 ± 0.17 µg/L	0.727	<2
		Water filter		ICP-MS	1.9 ± 0.033 ng/kg	0.16 ± 0.026 pg/kg	0.0133 ± 0.00049 ng/kg	1.92 ± 0.033 ng/kg	0.700	4.8
#1	N 30°01'45.6" E 47°46'18.1"	Water	IAEA	ICP-MS				47.0 ± 1.4 µg/L	0.730	<2
				α-spec	47.0 ± 1.0 µg/L					
				γ-spec	<310 µg/kg					
#2	N 29°59'35.6" E 47°47'01.1"	Water	IAEA	ICP-MS				10.5 ± 0.3 µg/L	0.750	<2
				α-spec	8.7 ± 0.3 µg/L					
#3	N 30°04'19.1" E 47°43'53.41"	Water	IAEA	ICP-MS				60.5 ± 1.8 µg/L	0.730	<2
				α-spec	58.6 ± 1.3 µg/L					
10AB.V.01	N 30°01'42.4" E 47°44'35.7"	Tomatoes	Spiez	ICP-MS	0.091 ± 0.004 µg/kg	0.004 ± 0.0015 ng/kg	0.469 ± 0.12 ng/kg	0.091 ± 0.0046 µg/kg	0.515	39.9
10AB.V.02	N 30°01'41.9" E 47°44'36.0"	Cucumbers	Spiez	ICP-MS	0.147 ± 0.006 µg/kg	0.009 ± 0.0014 ng/kg	1.03 ± 0.06 ng/kg	0.148 ± 0.0064 µg/kg	0.701	4.7
10AB.V.03	N 30°01'45.7" E 47°44'40.2"	Potatoes	Spiez	ICP-MS	0.210 ± 0.011 µg/kg	0.013 ± 0.0020 ng/kg	1.46 ± 0.08 ng/kg	0.21 ± 0.011 µg/kg	0.695	5.7
10AB.V.04	N 30°01'29.7" E 47°42'53.3"	Onions	Spiez	ICP-MS	1.60 ± 0.11 µg/kg	0.11 ± 0.014 ng/kg	11.5 ± 0.84 ng/kg	1.6 ± 0.11 µg/kg	0.719	<2
10AB.V.05	N 30°01'30.3" E 47°42'54.5"	Radishes	Spiez	ICP-MS	2.50 ± 0.12 µg/kg	0.19 ± 0.022 ng/kg	17.9 ± 0.92 ng/kg	2.5 ± 0.12 µg/kg	0.716	<2
10AB.V.06	N 30°01'32.9" E 47°42'57.0"	Beets	Spiez	ICP-MS	7.94 ± 0.94 µg/kg	0.6 ± 0.10 ng/kg	57.0 ± 6.8 ng/kg	8.0 ± 0.94 µg/kg	0.718	<2
Al Rawdhatine										
10AB.W.01	N 29°55'01.8" E 47°39'44.9"	Water	Spiez	ICP-MS	1.8 ± 0.064 µg/L	148 ± 16 pg/L	13 ± 0.54 ng/L	1.81 ± 0.065 µg/L	0.729	<2
		Water filter		ICP-MS	0.33 ± 0.018 ng/kg	<0.037 pg/kg	0.0023 ± 0.00014 ng/kg	0.33 ± 0.019 ng/kg	0.697	5.6
10AB.W.02	N 29°55'01.8" E 47°39'44.9"	Water	Spiez	ICP-MS	1.6 ± 0.067 µg/L	128 ± 14 pg/L	11 ± 0.52 ng/L	1.61 ± 0.068 µg/L	0.726	<2
		Water filter		ICP-MS	<0.32 ng/kg			<0.32 ng/kg		

TABLE XXXIX. ACTIVITY CONCENTRATIONS OF URANIUM ISOTOPES MEASURED IN ENVIRONMENTAL SAMPLES COLLECTED AS PART OF THE IAEA STUDY ON DU IN KUWAIT

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
Al Doha										
01DO.Blank.01	3-Feb-02	N 29°21'40.9" E 47°48'57.0"	Soil (0-2)	Scraper	IAEA team	Spiez	ICP-MS	13.0 ± 0.25 Bq/kg	13 ± 1.8 Bq/kg	0.61 ± 0.030 Bq/kg
01DO.Blank.02	3-Feb-02	N 29°21'41.2" E 47°48'56.7"	Soil (0-2)	Scraper	IAEA team	Spiez	ICP-MS	13.9 ± 0.27 Bq/kg	14 ± 1.7 Bq/kg	0.65 ± 0.028 Bq/kg
01DO.Blank.03	3-Feb-02	N 29°21'41.5" E 47°48'56.4"	Soil (0-2)	Scraper	IAEA team	Spiez	ICP-MS	13.4 ± 0.29 Bq/kg	14 ± 1.6 Bq/kg	0.62 ± 0.036 Bq/kg
01DO.Blank.04	3-Feb-02	N 29°21'41.7" E 47°48'57.0"	Soil (0-2)	Scraper	IAEA team	Spiez	ICP-MS	14.1 ± 0.25 Bq/kg	14 ± 1.8 Bq/kg	0.66 ± 0.018 Bq/kg
01DO.P.01	3-Feb-02	N 29°21'40.2" E 47°48'57.1"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	30.9 ± 0.56 Bq/kg	32 ± 4.0 Bq/kg	1.32 ± 0.063 Bq/kg
01DO.P.02	3-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	31.7 ± 0.80 Bq/kg	35 ± 4.3 Bq/kg	1.46 ± 0.073 Bq/kg
01DO.P.03	3-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	40 ± 1.6 Bq/kg	45 ± 6.2 Bq/kg	1.83 ± 0.093 Bq/kg
01DO.P.04	3-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	42 ± 1.3 Bq/kg	47 ± 5.4 Bq/kg	1.90 ± 0.083 Bq/kg
01DO.P.05	3-Feb-02	N 29°21'40.5" E 47°48'56.4"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	21.9 ± 0.53 Bq/kg	20 ± 2.4 Bq/kg	0.90 ± 0.031 Bq/kg
01DO.P.06	3-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	23.6 ± 0.38 Bq/kg	22 ± 2.4 Bq/kg	0.98 ± 0.022 Bq/kg
01DO.P.07	3-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	45.0 ± 0.97 Bq/kg	23 ± 2.5 Bq/kg	1.23 ± 0.031 Bq/kg
01DO.P.08	3-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	121 ± 3.4 Bq/kg	33 ± 4.3 Bq/kg	2.24 ± 0.072 Bq/kg
01DO.S.01	3-Feb-02	N 29°21'40.1" E 47°48'57.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	30.5 ± 0.44 Bq/kg	30 ± 3.6 Bq/kg	1.30 ± 0.067 Bq/kg
01DO.S.02	3-Feb-02	N 29°21'40.0" E 47°48'57.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	87 ± 1.3 Bq/kg	37 ± 4.5 Bq/kg	2.04 ± 0.051 Bq/kg
01DO.S.03	3-Feb-02	N 29°21'40.5" E 47°48'57.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	22.2 ± 0.42 Bq/kg	15 ± 1.8 Bq/kg	0.83 ± 0.022 Bq/kg
01DO.S.04	3-Feb-02	N 29°21'40.5" E 47°48'56.7"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	14.9 ± 0.27 Bq/kg	13 ± 1.7 Bq/kg	0.69 ± 0.021 Bq/kg
01DO.S.05	3-Feb-02	N 29°21'40.5" E 47°48'56.4"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	14.6 ± 0.26 Bq/kg	13 ± 1.5 Bq/kg	0.68 ± 0.024 Bq/kg
01DO.S.06	3-Feb-02	N 29°21'40.2" E 47°48'56.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	17.6 ± 0.39 Bq/kg	14 ± 1.6 Bq/kg	0.73 ± 0.024 Bq/kg
01DO.S.07	3-Feb-02	N 29°21'39.9" E 47°48'56.4'	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	14.4 ± 0.24 Bq/kg	13 ± 1.5 Bq/kg	0.66 ± 0.025 Bq/kg
01DO.S.08	3-Feb-02	N 29°21'40.3" E 47°48'56.4"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	80 ± 1.2 Bq/kg	31 ± 3.2 Bq/kg	1.78 ± 0.037 Bq/kg

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
DOHA			Soil	—	RPD	IAEA	α-spec γ-spec	15000 ± 1000 Bq/kg 7000 ÷ 19400 Bq/kg		
01DO.W.01	3-Feb-02	N 29°21'40.2" E 47°48'56.6"	Water	PE bucket	IAEA team	IAEA	α-spec	1.4 ± 0.12 Bq/kg		
01DO.W.02	3-Feb-02	N 29°21'39.3" E 47°48'56.2"	Water	PE bucket	IAEA team	IAEA	α-spec	4.5 ± 0.25 Bq/kg		
01DO.W.03	3-Feb-02	N 29°21'39.4" E 47°48'55.0"	Water	PE bucket	IAEA team	IAEA	α-spec	3.5 ± 0.25 Bq/kg		
Al Jahra										
02JA.S.01	4-Feb-02	N 29°21'50.0" E 47°39'57.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	9.7 ± 0.21 Bq/kg	9 ± 1.1 Bq/kg	0.46 ± 0.016 Bq/kg
02JA.S.02	4-Feb-02	N 29°21'34.4" E 47°39'46.8"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.8 ± 0.41 Bq/kg	12 ± 1.4 Bq/kg	0.55 ± 0.023 Bq/kg
02JA.S.03	4-Feb-02	N 29°21'34.4" E 47°39'46.8"	Soil (0-2)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	10.8 ± 0.25 Bq/kg	11 ± 1.2 Bq/kg	0.50 ± 0.020 Bq/kg
02JA.S.04	4-Feb-02	N 29°21'16.5" E 47°40'11.6"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	10.9 ± 0.29 Bq/kg	11 ± 1.2 Bq/kg	0.50 ± 0.021 Bq/kg
02JA.S.05	4-Feb-02	N 29°20'37.2" E 47°40'38.9"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.0 ± 0.43 Bq/kg	11 ± 1.2 Bq/kg	0.51 ± 0.027 Bq/kg
02JA.S.06	4-Feb-02	N 29°20'08.0" E 47°40'54.7"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.2 ± 0.21 Bq/kg	10 ± 1.3 Bq/kg	0.52 ± 0.025 Bq/kg
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04WA.P.06	5-Feb-02	N 28°33'95.3" E 48°04'06.3"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	11.7 ± 0.23 Bq/kg	13 ± 1.8 Bq/kg	0.55 ± 0.014 Bq/kg
04WA.P.07	5-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	8.8 ± 0.22 Bq/kg	9 ± 1.4 Bq/kg	0.42 ± 0.013 Bq/kg
04WA.P.08	5-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	8.4 ± 0.17 Bq/kg	8 ± 1.9 Bq/kg	0.39 ± 0.012 Bq/kg
04WA.P.09	5-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	7.6 ± 0.20 Bq/kg	8 ± 1.5 Bq/kg	0.36 ± 0.014 Bq/kg
04WA.S.01	5-Feb-02	N 28°33'52.8" E 48°00'22.5"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.7 ± 0.35 Bq/kg	13 ± 2.9 Bq/kg	0.54 ± 0.019 Bq/kg
04WA.S.02	5-Feb-02	N 28°33'54.2" E 48°00'20.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.2 ± 0.24 Bq/kg	12 ± 1.6 Bq/kg	0.53 ± 0.014 Bq/kg
04WA.S.03	5-Feb-02	N 28°33'54.8" E 48°00'20.4"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	10.0 ± 0.20 Bq/kg	10 ± 1.9 Bq/kg	0.47 ± 0.012 Bq/kg
04WA.S.04	5-Feb-02	N 28°33'58.2" E 48°00'21.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	13.6 ± 0.27 Bq/kg	14 ± 2.2 Bq/kg	0.65 ± 0.017 Bq/kg
04WA.S.05	5-Feb-02	N 28°33'57.6" E 48°00'23.8"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.0 ± 0.29 Bq/kg	11 ± 1.5 Bq/kg	0.52 ± 0.015 Bq/kg
04WA.S.06	5-Feb-02	N 28°33'58.7" E 48°04'11.7"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	9.8 ± 0.29 Bq/kg	11 ± 2.2 Bq/kg	0.47 ± 0.016 Bq/kg

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
04WA.S.07	5-Feb-02	N 28°33'58.8" E 48°04'13.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	10.0 ± 0.29 Bq/kg	11 ± 2.2 Bq/kg	0.48 ± 0.016 Bq/kg
04WA.S.08	5-Feb-02	N 28°33'59.5" E 48°04'15.0"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	10.2 ± 0.23 Bq/kg	11 ± 1.7 Bq/kg	0.48 ± 0.013 Bq/kg
04WA.S.11	5-Feb-02	N 28°33'94.5" E 48°00'31.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	13.4 ± 0.29 Bq/kg	16 ± 2.1 Bq/kg	0.63 ± 0.016 Bq/kg
04WA.S.12	5-Feb-02	N 28°33'99.7" E 48°00'36.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.4 ± 0.28 Bq/kg	14 ± 2.1 Bq/kg	0.59 ± 0.016 Bq/kg
04WA.S.13	5-Feb-02	N 28°34'00.4" E 48°00'40.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.3 ± 0.30 Bq/kg	12 ± 1.7 Bq/kg	0.54 ± 0.017 Bq/kg
W1	—	—	Soil	—	RPD	IAEA	α-spec	8.6 ± 0.6 Bq/kg		
							γ-spec	<19 Bq/kg		
W2	—	—	Soil	—	RPD	IAEA	α-spec	71.3 ± 4.8 Bq/kg		
							γ-spec	50 Bq/kg		
W3	—	—	Soil	—	RPD	IAEA	α-spec	7.7 ± 0.7 Bq/kg		
							γ-spec	<23 Bq/kg		
04WA.W.01	5-Feb-02	N 28°33'58.8" E 48°00'15.6"	Water	Pump	IAEA team	Spiez	ICP-MS	103 ± 2.1 mBq/L	100 ± 13 mBq/L	4.8 ± 0.12 mBq/L
			Water filter				ICP-MS	0.187 ± 0.0045 mBq/kg	0.18 ± 0.022 mBq/kg	8.4 ± 0.30 µBq/kg
04WA.W.02	5-Feb-02	N 28°34'02.0" E 48°00'46.0"	Water	Pump	IAEA team	Spiez	ICP-MS	2.7 ± 0.42 mBq/L	10 ± 1 mBq/L	0.12 ± 0.02 mBq/L
			Water filter				ICP-MS	0.080 ± 0.0014 mBq/kg	0.08 ± 0.011 mBq/kg	3.7 ± 0.13 µBq/kg
04WA.W.03	5-Feb-02	N 28°33'55.8" E 48°04'11.4"	Water	Pump	IAEA team	Spiez	ICP-MS	149 ± 4.7 mBq/L	200 ± 23 mBq/L	6.8 ± 0.27 mBq/L
			Water filter				ICP-MS	0.533 ± 0.014 mBq/kg	0.62 ± 0.070 mBq/kg	24 ± 0.84 µBq/kg
04WA.W.04	5-Feb-02	N 28°34'01.3" E 48°04'04.7"	Water	Pump	IAEA team	Spiez	ICP-MS	24.8 ± 0.75 mBq/L	40 ± 5 mBq/L	1.1 ± 0.06 mBq/L
			Water filter				ICP-MS	0.017 ± 0.0005 mBq/kg	0.02 ± 0.004 mBq/kg	0.78 ± 0.03 µBq/kg
04WA.V.01	5-Feb-02	N 28°33'51.8" E 48°00'23.3"	Lettuce	From uncovered greenhouse	IAEA team	Spiez	ICP-MS	2.6 ± 0.28 mBq/kg	2.5 ± 0.40 mBq/kg	0.10 ± 0.012 mBq/kg
04WA.V.02	5-Feb-02	N 28°33'51.1" E 48°00'20.8"	Cucumbers	From covered greenhouse	IAEA team	Spiez	ICP-MS	0.97 ± 0.08 mBq/kg	0.5 ± 0.14 mBq/kg	0.024 ± 0.004 mBq/kg
04WA.V.03	5-Feb-02	N 28°33'54.9" E 48°00'20.5"	Cabbages	From uncovered area	IAEA team	Spiez	ICP-MS	3.3 ± 0.21 mBq/kg	3.1 ± 0.45 mBq/kg	0.14 ± 0.008 mBq/kg
04WA.V.04	5-Feb-02	N 28°33'58.3" E 48°00'21.4"	Tomatoes	From uncovered area	IAEA team	Spiez	ICP-MS	0.88 ± 0.05 mBq/kg	0.9 ± 0.18 mBq/kg	0.039 ± 0.003 mBq/kg
04WA.V.05	5-Feb-02	N 28°33'54.7" E 48°04'14.0"	Carrots	From uncovered area	IAEA team	Spiez	ICP-MS	13.6 ± 0.59 mBq/kg	18 ± 2.1 mBq/kg	0.62 ± 0.030 mBq/kg
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06MU.S.01	4-Feb-02	N 29°27'13.3" E 47°39'05.4"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	10.4 ± 0.25 Bq/kg	11 ± 1.2 Bq/kg	0.49 ± 0.022 Bq/kg

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
06MU.S.02	4-Feb-02	N 29°27'16.4" E 47°38'36.8"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.6 ± 0.24 Bq/kg	13 ± 1.6 Bq/kg	0.59 ± 0.018 Bq/kg
06MU.S.03	4-Feb-02	N 29°26'29.2" E 47°38'20.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	7.9 ± 0.27 Bq/kg	8 ± 0.9 Bq/kg	0.37 ± 0.014 Bq/kg
06MU.S.04	4-Feb-02	N 29°26'18.8" E 47°38'29.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	8.6 ± 0.21 Bq/kg	9 ± 1.0 Bq/kg	0.40 ± 0.019 Bq/kg
06MU.S.05	4-Feb-02	N 29°23'00.0" E 47°39'05.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.0 ± 0.30 Bq/kg	12 ± 1.4 Bq/kg	0.56 ± 0.027 Bq/kg
06MU.S.06	4-Feb-02	N 29°22'54.9" E 47°39'04.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	14.6 ± 0.25 Bq/kg	16 ± 2.0 Bq/kg	0.67 ± 0.023 Bq/kg
06MU.S.07	4-Feb-02	N 29°23'07.7" E 47°39'09.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	8.8 ± 0.17 Bq/kg	8 ± 1.1 Bq/kg	0.41 ± 0.015 Bq/kg
06MU.S.08	4-Feb-02	N 29°23'07.7" E 47°39'39.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.3 ± 0.20 Bq/kg	11 ± 1.3 Bq/kg	0.52 ± 0.023 Bq/kg
06MU.V.01	4-Feb-02	N 29°26'28.3" E 47°38'20.6"	Stems	Cut at base with hand cutter	IAEA team	Spiez	ICP-MS	1.76 ± 0.029 Bq/kg	1.7 ± 0.18 Bq/kg	0.081 ± 0.0018 Bq/kg
06MU.V.02	4-Feb-02	N 29°26'18.9" E 47°38'29.3"	Vegetation	Cut with hand cutter	IAEA team	Spiez	ICP-MS	0.360 ± 0.0077 Bq/kg	0.35 ± 0.037 Bq/kg	0.017 ± 0.00040 Bq/kg
Um Al Kwaty										
07KW.S.01	9-Feb-02	N 29°25'01.2" E 47°30'44.8"	Soil (0-10)	Shovel	IAEA team	IAEA	γ-spec	54 ± 4 Bq/kg		
07KW.S.02	9-Feb-02	N 29°25'01.7" E 47°30'44.1"	Soil (0-10)	Shovel	IAEA team	IAEA	γ-spec	84 ± 6 Bq/kg		
07KW.S.03	9-Feb-02	N 29°25'02.4" E 47°30'43.4"	Soil (0-10)	Shovel	IAEA team	IAEA	α-spec γ-spec	253 ± 12 Bq/kg 195 ± 9 Bq/kg		
07KW.S.04	9-Feb-02	N 29°25'03.4" E 47°30'43.2"	Soil (0-10)	Shovel	IAEA team	IAEA	γ-spec	14970 ± 300 Bq/kg		
07KW.S.05	9-Feb-02	N 29°25'04.0" E 47°30'43.4"	Soil (0-10)	Shovel	IAEA team	IAEA	α-spec γ-spec	14000 ± 1500 Bq/kg 15000 Bq/kg		
07KW.S.06	9-Feb-02	N 29°25'05.4" E 47°30'42.9"	Soil (0-10)	Shovel	IAEA team	IAEA	γ-spec	117 ± 7 Bq/kg		
07KW.S.07	9-Feb-02	N 29°25'07.9" E 47°30'42.6"	Soil (0-10)	Shovel	IAEA team	IAEA	γ-spec	15800 ± 300 Bq/kg		
07KW.S.08	9-Feb-02	N 29°25'07.1" E 47°30'43.9"	Soil (0-10)	Shovel	IAEA team	IAEA	α-spec γ-spec	63 ± 4 Bq/kg 61 ± 6 Bq/kg		
07KW.S.09	9-Feb-02	N 29°25'06.7" E 47°30'44.9"	Soil (0-10)	Shovel	IAEA team	IAEA	α-spec γ-spec	1155 ± 56 Bq/kg 1090 ± 300 Bq/kg		
07KW.S.10	9-Feb-02	N 29°25'05.9" E 47°30'45.7"	Soil (0-10)	Shovel	IAEA team	IAEA	α-spec γ-spec	2822 ± 131 Bq/kg 1800 Bq/kg		

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
07KW.S.11	9-Feb-02	N 29°25'05.5" E 47°30'44.3"	Soil (0-10)	Shovel	IAEA team	IAEA	α-spec	275 ± 14 Bq/kg		
							γ-spec	597 ± 14 Bq/kg		
Military Hospital storage ground										
08HO.P.01	4-Feb-02	N 29°14'36.7" E 48°01'03.6"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	10.8 ± 0.38 Bq/kg	10 ± 1.2 Bq/kg	0.49 ± 0.025 Bq/kg
08HO.P.02	4-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	12.3 ± 0.24 Bq/kg	12 ± 1.5 Bq/kg	0.56 ± 0.031 Bq/kg
08HO.P.03	4-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	11.2 ± 0.40 Bq/kg	10 ± 1.2 Bq/kg	0.51 ± 0.033 Bq/kg
08HO.P.04	4-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	10.3 ± 0.17 Bq/kg	9 ± 1.2 Bq/kg	0.47 ± 0.022 Bq/kg
08HO.S.01	4-Feb-02	N 29°14'36.7" E 48°01'03.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.0 ± 0.26 Bq/kg	12 ± 1.3 Bq/kg	0.56 ± 0.015 Bq/kg
08HO.S.02	4-Feb-02	N 29°14'37.3" E 48°01'02.5"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	16.5 ± 0.43 Bq/kg	17 ± 2.0 Bq/kg	0.77 ± 0.029 Bq/kg
08HO.S.03	4-Feb-02	N 29°14'37.9" E 48°01'02.8"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	16.9 ± 0.24 Bq/kg	15 ± 1.7 Bq/kg	0.72 ± 0.027 Bq/kg
08HO.S.04	4-Feb-02	N 29°14'38.9" E 48°01'03.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	41 ± 1.0 Bq/kg	18 ± 1.9 Bq/kg	1.02 ± 0.030 Bq/kg
Umm Gudayar GC 18										
09GU.P.01	6-Feb-02	N 28°55'03.1" E 47°40'02.0"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	10.5 ± 0.18 Bq/kg	9 ± 2.0 Bq/kg	0.47 ± 0.023 Bq/kg
09GU.P.02	6-Feb-02		Soil (5-10)		IAEA team	Spiez	ICP-MS	10.7 ± 0.17 Bq/kg	10 ± 1.3 Bq/kg	0.50 ± 0.019 Bq/kg
09GU.P.03	6-Feb-02		Soil (10-15)		IAEA team	Spiez	ICP-MS	9.5 ± 0.44 Bq/kg	9 ± 1.1 Bq/kg	0.45 ± 0.024 Bq/kg
09GU.P.04	6-Feb-02		Soil (15-20)		IAEA team	Spiez	ICP-MS	10.8 ± 0.26 Bq/kg	9 ± 1.2 Bq/kg	0.50 ± 0.019 Bq/kg
09GU.P.05	6-Feb-02	N 28°55'03.2" E 47°40'02.7"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	15.0 ± 0.23 Bq/kg	14 ± 1.7 Bq/kg	0.69 ± 0.035 Bq/kg
09GU.P.06	6-Feb-02		Soil (5-10)		IAEA team	Spiez	ICP-MS	14.4 ± 0.27 Bq/kg	13 ± 2.1 Bq/kg	0.66 ± 0.044 Bq/kg
09GU.P.07	6-Feb-02		Soil (10-15)		IAEA team	Spiez	ICP-MS	14.6 ± 0.22 Bq/kg	14 ± 1.5 Bq/kg	0.67 ± 0.016 Bq/kg
09GU.P.08	6-Feb-02		Soil (15-20)		IAEA team	Spiez	ICP-MS	18.7 ± 0.49 Bq/kg	19 ± 2.2 Bq/kg	0.88 ± 0.037 Bq/kg
09GU.S.01	6-Feb-02	N 28°55'04.1" E 47°40'02.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	9.7 ± 0.23 Bq/kg	9 ± 1.3 Bq/kg	0.44 ± 0.032 Bq/kg
09GU.S.02	6-Feb-02	N 28°55'04.0" E 47°40'01.6"	Soil (0-5)	Template(20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	20.2 ± 0.32 Bq/kg	21 ± 2.4 Bq/kg	0.94 ± 0.048 Bq/kg
09GU.S.03	6-Feb-02	N 28°55'04.0" E 47°40'01.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	8.1 ± 0.19 Bq/kg	7 ± 0.9 Bq/kg	0.34 ± 0.018 Bq/kg
09GU.S.04	6-Feb-02	N 28°55'05.0" E 47°40'00.8"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	8.1 ± 0.19 Bq/kg	7 ± 1.0 Bq/kg	0.37 ± 0.032 Bq/kg
09GU.S.05	6-Feb-02	N 28°55'05.0" E 47°40'04.5"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	5.8 ± 0.11 Bq/kg	5 ± 0.8 Bq/kg	0.26 ± 0.014 Bq/kg
Manageesh GC 28										
09MA.S.01	6-Feb-02	N 29°01'19.9" E 47°36'01.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	15.8 ± 0.9 Bq/kg		
							γ-spec	29 ± 4 Bq/kg		

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
09MA.S.02	6-Feb-02	N 29°01'20.2" E 47°36'00.9"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	25.0 ± 1.5 Bq/kg		
							γ-spec	28.3 ± 4.9 Bq/kg		
09MA.S.06	6-Feb-02	N 29°01'19.8" E 47°36'01.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	8.7 ± 0.7 Bq/kg		
							γ-spec	<26 Bq/kg		
09MA.S.07	6-Feb-02	N 29°01'16.8" E 47°36'04.0"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	10.9 ± 0.8 Bq/kg		
							γ-spec	<25 Bq/kg		
09MA.S.08	6-Feb-02	N 29°01'16.8" E 47°35'58.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	6.6 ± 0.5 Bq/kg		
							γ-spec	<27 Bq/kg		
09MA.S.09	6-Feb-02	N 29°01'22.8" E 47°36'04.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	8.2 ± 0.5 Bq/kg		
							γ-spec	<20 Bq/kg		
09MA.S.10	6-Feb-02	N 29°01'22.8" E 47°35'58.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	IAEA	α-spec	8.0 ± 0.6 Bq/kg		
09MA.RE.01	6-Feb-02	N 29°01'20.5" E 47°36'00.5"	Soil	Shovel	IAEA team	IAEA	α-spec	9.7 ± 0.5 Bq/kg		
09MA.P.01	6-Feb-02	N 29°01'19.8" E 47°36'00.7"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	IAEA	α-spec	52000 ± 3000 Bq/kg		
							γ-spec	89100 ± 1700 Bq/kg		
09MA.P.02	6-Feb-02		Soil (5-10)		IAEA team	IAEA	α-spec	115 ± 6 Bq/kg		
							γ-spec	90 ± 11 Bq/kg		
09MA.P.03	6-Feb-02		Soil (10-15)		IAEA team	IAEA	α-spec	44.7 ± 2.3 Bq/kg		
							γ-spec	<62 Bq/kg		
09MA.P.04	6-Feb-02		Soil (15-20)		IAEA team	IAEA	α-spec	29.8 ± 1.6 Bq/kg		
							γ-spec	<52 Bq/kg		
09MA.P.05	6-Feb-02		Soil (20-25)		IAEA team	IAEA	α-spec	30.9 ± 1.5 Bq/kg		
							γ-spec	15 ± 9 Bq/kg		
09MA.P.06	6-Feb-02	N 29°01'19.7" E 47°36'01.1"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	IAEA	α-spec	6.6 ± 0.4 Bq/kg		
							γ-spec	<51 Bq/kg		
09MA.P.07	6-Feb-02		Soil (5-10)		IAEA team	IAEA	α-spec	8.0 ± 0.5 Bq/kg		
							γ-spec	<43 Bq/kg		
09MA.P.08	6-Feb-02		Soil (10-15)		IAEA team	IAEA	α-spec	8.8 ± 0.6 Bq/kg		
							γ-spec	<51 Bq/kg		
09MA.P.09	6-Feb-02		Soil (15-20)		IAEA team	IAEA	α-spec	8.5 ± 0.5 Bq/kg		
							γ-spec	<49 Bq/kg		
							γ-spec	10 ± 4 Bq/kg		
							γ-spec	<22 Bq/kg		
09MA.U.01	6-Feb-02	N 29°01'19.8" E 47°36'00.7"	Soil	—	IAEA team	IAEA	—	—		

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
GC28#1	—	—	Soil	—	RPD	IAEA	α-spec	1283 ± 72 Bq/kg		
							γ-spec	1970 Bq/kg		
GC28#2	—	—	Soil	—	RPD	IAEA	α-spec	92 ± 10 Bq/kg		
							γ-spec	74 Bq/kg		
GC28#3	—	—	Soil	—	RPD	IAEA	α-spec	1054 ± 61 Bq/kg		
							γ-spec	1160 Bq/kg		
GC28#4	—	—	Soil	—	RPD	IAEA	α-spec	168 ± 8 Bq/kg		
							γ-spec	64 Bq/kg		
GC28#5	—	—	Soil	—	RPD	IAEA	α-spec	6.7 ± 0.5 Bq/kg		
							γ-spec	<18 Bq/kg		
Soil/GC 28 1D	—	—	Soil (0-5)	Corer	RPD	IAEA	α-spec	19000 ± 5000 Bq/kg		
							γ-spec	57000 Bq/kg		
			Soil (5-15)	Corer	RPD	IAEA	α-spec	842 ± 46 Bq/kg		
							γ-spec	570 Bq/kg		
			Soil (15-25)	Corer	RPD	IAEA	α-spec	33 ± 2 Bq/kg		
							γ-spec	<31 Bq/kg		
			Soil (25-35)	Corer	RPD	IAEA	α-spec	25.8 ± 1.5 Bq/kg		
							γ-spec	<21 Bq/kg		
GC 28 1D	—	—	Soil (0-5)	Corer	RPD	IAEA	α-spec	106000 ± 6000 Bq/kg		
							γ-spec	58300 ± 600 Bq/kg		
GC 28 2D	—	—	Soil (5-15)	Corer	RPD	IAEA	α-spec	96 ± 6 Bq/kg		
							γ-spec	469 ± 22 Bq/kg		
GC 28 3D	—	—	Soil (15-25)	Corer	RPD	IAEA	γ-spec	<63 Bq/kg		
GC 28 4D	—	—	Soil (25-35)	Corer	RPD	IAEA	α-spec	32.4 ± 1.8 Bq/kg		
							γ-spec	<59 Bq/kg		
Al Sabhan										
09SA.S.01	4-Feb-02	N 29°14'43.1" E 48°01'50.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.5 ± 0.25 Bq/kg	12 ± 1.4 Bq/kg	0.58 ± 0.021 Bq/kg
09SA.S.02	4-Feb-02	N 29°14'41.5" E 48°01'50.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.2 ± 0.27 Bq/kg	12 ± 1.4 Bq/kg	0.57 ± 0.021 Bq/kg
09SA.S.03	4-Feb-02	N 29°14'45.0" E 48°01'50.4"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	11.2 ± 0.23 Bq/kg	11 ± 1.3 Bq/kg	0.52 ± 0.016 Bq/kg
09SA.S.04	4-Feb-02	N 29°14'43.2" E 48°01'48.1"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	12.9 ± 0.19 Bq/kg	13 ± 1.4 Bq/kg	0.60 ± 0.016 Bq/kg

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
Al Abdali										
10AB.FE.01	7-Feb-02	N 30°01'42.4" E 47°44'35.7"	Soil	—	IAEA team	Spiez	ICP-MS	<0.062 Bq/kg		
10AB.P.01	7-Feb-02	N 30°01'29.4" E 47°44'29.4"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	12.8 ± 0.50 Bq/kg	13 ± 1.5 Bq/kg	0.60 ± 0.027 Bq/kg
10AB.P.02	7-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	14.3 ± 0.27 Bq/kg	14 ± 1.6 Bq/kg	0.67 ± 0.023 Bq/kg
10AB.P.03	7-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	13.4 ± 0.52 Bq/kg	14 ± 1.6 Bq/kg	0.62 ± 0.031 Bq/kg
10AB.P.04	7-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	14.1 ± 0.26 Bq/kg	15 ± 1.8 Bq/kg	0.66 ± 0.027 Bq/kg
10AB.P.05	7-Feb-02	N 30°01'36.0" E 47°44'28.6"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	13.6 ± 0.25 Bq/kg	14 ± 1.6 Bq/kg	0.64 ± 0.027 Bq/kg
10AB.P.06	7-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	13.4 ± 0.35 Bq/kg	14 ± 1.8 Bq/kg	0.62 ± 0.032 Bq/kg
10AB.P.07	7-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	13.6 ± 0.24 Bq/kg	14 ± 1.8 Bq/kg	0.65 ± 0.024 Bq/kg
10AB.P.08	7-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	12.5 ± 0.41 Bq/kg	13 ± 1.6 Bq/kg	0.59 ± 0.027 Bq/kg
10AB.P.09	7-Feb-02	N 30°01'35.0" E 47°42'46.9"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	13.0 ± 0.42 Bq/kg	13 ± 1.5 Bq/kg	0.61 ± 0.028 Bq/kg
10AB.P.10	7-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	12.6 ± 0.25 Bq/kg	14 ± 1.6 Bq/kg	0.59 ± 0.023 Bq/kg
10AB.P.11	7-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	14.6 ± 0.26 Bq/kg	15 ± 1.8 Bq/kg	0.70 ± 0.018 Bq/kg
10AB.P.12	7-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	13.1 ± 0.28 Bq/kg	13 ± 1.5 Bq/kg	0.62 ± 0.017 Bq/kg
10AB.P.13	7-Feb-02	N 30°01'27.7" E 47°42'56.6"	Soil (0-5)	Corer (10 cm × 10 cm)	IAEA team	Spiez	ICP-MS	18.6 ± 0.38 Bq/kg	21 ± 2.2 Bq/kg	0.89 ± 0.023 Bq/kg
10AB.P.14	7-Feb-02		Soil (5-15)		IAEA team	Spiez	ICP-MS	20.2 ± 0.40 Bq/kg	23 ± 2.6 Bq/kg	0.96 ± 0.029 Bq/kg
10AB.P.15	7-Feb-02		Soil (15-25)		IAEA team	Spiez	ICP-MS	16.6 ± 0.32 Bq/kg	18 ± 2.2 Bq/kg	0.78 ± 0.029 Bq/kg
10AB.P.16	7-Feb-02		Soil (25-35)		IAEA team	Spiez	ICP-MS	16.9 ± 0.42 Bq/kg	19 ± 2.2 Bq/kg	0.79 ± 0.033 Bq/kg
10AB.S.10	7-Feb-02	N 30°01'42.4" E 47°44'35.7"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	21.3 ± 0.39 Bq/kg	23 ± 2.6 Bq/kg	1.01 ± 0.029 Bq/kg
10AB.S.11	7-Feb-02	N 30°01'41.9" E 47°44'36.0"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	16.6 ± 0.32 Bq/kg	17 ± 1.9 Bq/kg	0.78 ± 0.024 Bq/kg
10AB.S.12	7-Feb-02	N 30°01'45.7" E 47°44'40.2"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	14.1 ± 0.42 Bq/kg	14 ± 1.7 Bq/kg	0.66 ± 0.031 Bq/kg
10AB.S.13	7-Feb-02	N 30°01'29.7" E 47°42'53.3"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	20.6 ± 0.39 Bq/kg	23 ± 2.5 Bq/kg	0.96 ± 0.045 Bq/kg
10AB.S.14	7-Feb-02	N 30°01'30.3" E 47°42'54.5"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	18.4 ± 0.42 Bq/kg	20 ± 2.3 Bq/kg	0.87 ± 0.027 Bq/kg
10AB.S.15	7-Feb-02	N 30°01'32.9" E 47°42'57.0"	Soil (0-5)	Template (20 cm × 25 cm)	IAEA team	Spiez	ICP-MS	15.6 ± 0.33 Bq/kg	16 ± 1.8 Bq/kg	0.74 ± 0.019 Bq/kg
10AB.W.03	7-Feb-02	N 30°01'41.8" E 47°44'31.4"	Water	Pump	IAEA team	Spiez	ICP-MS	670 ± 32 mBq/L	810 ± 95 mBq/L	31 ± 1.4 mBq/L
			Water filter					0.155 ± 0.0032 mBq/kg	0.18 ± 0.021 mBq/kg	7.0 ± 0.17 µBq/kg
10AB.W.04	7-Feb-02	N 30°01'35.7" E 47°44'43.2"	Water	Pump	IAEA team	Spiez	ICP-MS	1430 ± 29 mBq/L	1700 ± 180 mBq/L	67 ± 1.3 mBq/L
			Water filter					0.388 ± 0.0096 mBq/kg	0.44 ± 0.050 mBq/kg	18 ± 0.61 µBq/kg
10AB.W.05	7-Feb-02	N 30°01'36.7" E 47°42'50.3"	Water	Pump	IAEA team	Spiez	ICP-MS	95 ± 2.0 mBq/L	150 ± 15 mBq/L	4 ± 0.1 mBq/L
			Water filter					0.024 ± 0.0004 mBq/kg	0.04 ± 0.006 mBq/kg	1.1 ± 0.03 µBq/kg

TABLE XXXIX. (cont.)

Sample field code	Sampling date	Co-ordinates	Sample type (depth, cm)	Sampling equipment	Collected by	Analysed by	Method	^{238}U	^{234}U	^{235}U
#1	—	N 30°01'45.6" E 47°46'18.1"	Water	—	RPD	IAEA	α-spec	0.584 ± 0.013 Bq/kg		
							γ-spec	<3.9 Bq/kg		
#2	—	N 29°59'35.6" E 47°47'08.1"	Water	—	RPD	IAEA	α-spec	0.109 ± 0.004 Bq/kg		
#3	—	N 30°04'19.1" E 47°43'53.41"	Water	—	RPD	IAEA	α-spec	0.729 ± 0.016 Bq/kg		
10AB.V.01	7-Feb-02	N 30°01'42.4" E 47°44'35.7"	Tomatoes	From greenhouse	IAEA team	Spiez	ICP-MS	1.13 ± 0.06 mBq/kg	0.9 ± 0.34 mBq/kg	0.038 ± 0.010 mBq/kg
10AB.V.02	7-Feb-02	N 30°01'41.9" E 47°44'36.0"	Cucumbers	From greenhouse	IAEA team	Spiez	ICP-MS	1.82 ± 0.08 mBq/kg	2.1 ± 0.32 mBq/kg	0.082 ± 0.0045 mBq/kg
10AB.V.03	7-Feb-02	N 30°01'45.7" E 47°44'40.2"	Potatoes	From uncovered area	IAEA team	Spiez	ICP-MS	2.6 ± 0.13 mBq/kg	2.9 ± 0.46 mBq/kg	0.12 ± 0.0063 mBq/kg
10AB.V.04	7-Feb-02	N 30°01'29.7" E 47°42'53.3"	Onions	From uncovered area	IAEA team	Spiez	ICP-MS	20 ± 1.4 mBq/kg	26 ± 0.003.3 mBq/kg	0.92 ± 0.068 mBq/kg
10AB.V.05	7-Feb-02	N 30°01'30.3" E 47°42'54.5"	Radishes	From uncovered area	IAEA team	Spiez	ICP-MS	31 ± 1.5 mBq/kg	44 ± 0.005.1 mBq/kg	1.4 ± 0.074 mBq/kg
10AB.V.06	7-Feb-02	N 30°01'32.9" E 47°42'57.0"	Beets	From uncovered area	IAEA team	Spiez	ICP-MS	100 ± 12 mBq/kg	140 ± 22 mBq/kg	4.6 ± 0.54 mBq/kg
Al Rawdhatine										
10AB.W.01	7-Feb-02	N 29°55'01.8" E 47°39'44.9"	Water	Pump	IAEA team	Spiez	ICP-MS	22.3 ± 0.80 mBq/L	30 ± 4 mBq/L	1.0 ± 0.04 mBq/L
			Water filter				ICP-MS	0.004 ± 0.0002 mBq/kg	<0.0085 mBq/kg	0.18 ± 0.01 μBq/kg
10AB.W.02	7-Feb-02	N 29°55'01.8" E 47°39'44.9"	Water	Bottled for sale	IAEA team	Spiez	ICP-MS	19.8 ± 0.83 mBq/L	30 ± 3 mBq/L	0.88 ± 0.04 mBq/L
			Water filter				ICP-MS	<0.0040 mBq/kg		

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