The nuclear testing programme conducted by the United States between 1946 and 1958 on Bikini atoll and Eniwetak atoll resulted in radioactive contamination to various degrees of a number of atolls in the Marshall Islands1,2 (see Figure 1 for map). The most serious radiation exposures were caused by early fallout from the test Castle BRAVO, a hydrogen bomb detonated on Bikini atoll on 1 March 1954. The radioactive fallout was intense on the inhabited islands of Rongelap atoll resulting in thyroid exposures estimated between 50 and 200 Gy for a one-year-old child and one-tenth of that in Utrik atoll.3 The exposed communities were evacuated, treated for acute radiation illness, and provided with follow-up medical care over the decades since. The most frequent long-term health effect in the highly exposed population appeared to be an increased frequency of nodular thyroid disease including thyroid cancer.4,5

There is evidence to indicate that residents of other atolls may also have been exposed to radioactive fallout from the Bravo test as well as from some of the other 65 atmospheric explosions.6 However, little information exists about health consequences among residents of the many atolls other than Rongelap and Utrik except for that provided by the study by Hamilton7 who found that the population of other atolls in the Northern Marshall Islands may have a higher rate of palpable thyroid nodules than the populations living further away from Bikini. Therefore, in conjunction with a nationwide radiological monitoring programme of the environment of the Marshall Islands,2 a nationwide thyroid disease screening programme was
initiated to gather data. This would be useful for re-examining the relationship between distance and prevalence put forward by Hamilton and to provide assistance to the Government of the Republic of the Marshall Islands to understand better the relationship of thyroid disease with residence location, residual contamination, likely radiation exposure from fallout, age of individuals, and other variables. With co-operation and assistance from the Ministry of Health of the Marshall Islands Government, a programme was initiated to evaluate thyroid disease in all Marshallese old enough to have been alive during the years of the atomic weapons tests (1946–1958). In this programme, individuals could volunteer to be medically monitored; techniques used included physical examination, high resolution ultrasound, fine needle aspiration biopsy and various blood tests for thyroid function.

A high prevalence of thyroid nodules and a very high cumulative incidence rate of thyroid cancer in the Marshallese population outside Rongelap and Utrik was found yet, at present, there is no indication that benign thyroid nodules are related to past weapons-related radiation exposure. In contrast, there was a trend of increased cumulative thyroid cancer incidence with increasing potential radioiodine exposure as suggested by
the two proxy measures of exposure, i.e. distance and radio-
cesium deposition on the ground.9

A close relationship between thyroid adenomas and radiation
exposure has been established in the Japanese A-bomb
survivors (though not for adenomatous goitre),10 yet the major
risk factor for nodular thyroid disease remains dietary iodine
deficiency.11 The present study was performed in order to
understand the relationship between thyroid nodules, thyroid
function and dietary iodine in Marshallese. These factors are
important to the understanding of findings from ongoing and
future studies relating radiation exposure and prevalence of
thyroid disease.

Materials and Methods

Medical monitoring

Between 1993 and 1997, four of us (TT, KF, SLS, KRT) inves-
tigated 7221 Marshallese people for thyroid disease of any
type.9 The intention of the medical monitoring programme was
to examine all Marshallese residents in the Marshall Islands
during the examinations which took place in 1993, 1994, 1996
and 1997 and who were born before the last atmospheric bomb
test in the Marshall Islands (18 August 1958). However, we did
not refuse anybody who requested an examination even if they
were younger. Among the 7221 examined, 4766 were of an
age to be at risk from exposure to radioactive fallout; this cohort
represents over 60% of the potentially exposed population that
is alive today. Recruitment was by public announcement through
radio and by word of mouth. Since Marshallese people are very
concerned about long-term effects of the bomb testing and about
thyroid disease in particular, the attendance rate was high.
In Ebeye in 1993 and 1996, 1610 people were examined; an
additional 5263 people were examined in Majuro in 1994 and
348 were examined at three remote locations (Likiep atoll, Ailuk
atoll and Mejit island) in 1997. Response rates were similar in
either of the main population centres (Majuro and Ebeye).

During the examination phases of the study, detailed
information about the background and the purpose of the study
was provided to each participant by a Marshallese assistant in
the Marshallese language and afterwards, informed consent
to participate in the study was acquired. Following that, each
participant was interviewed, also in their native language.
Questions were asked relating to date of birth and age, history
of residence, fertility, diet and general health. The interview
was followed by a brief medical examination by a surgeon including
palpation of the neck. A second surgeon performed the ultra-
sound examination of the thyroid using an ALOKA echo camera
SSD-121™ with a 7.5 MHz mechanical sector probe. Our
definition of a nodule as imaged by ultrasound included all focal
abnormalities of the echo pattern that were larger than 4 mm.
All participants identified with a palpable nodule were further
examined by fine needle aspiration biopsy of the dominant
nodule. Medical findings from biopsies were reported to indivi-
duals and the Ministry of Health by letter. The medical moni-
toring has been described in detail elsewhere.12

Study of thyroid function

Large subgroups of the study population were also examined for
thyroid function. In Ebeye in 1993, 1050 consecutive study
participants were examined for the presence of hypothyroidism
using a blood spot technique for thyroid stimulating hormone
(TSH). In Majuro 1994, a venous blood sample was taken from
3000 consecutive study participants and examined for TSH, free
T₃, free T₄, and anti-thyroid antibodies.

For the blood test spot of TSH, one drop of capillary blood
taken from the tip of the ring finger by a small incision was col-
lected on a special filter paper (Schüll and Schleicher, Germany)
which had been labelled with the name, sex, age and study
number of the person, air-dried, individually packed and stored
in the freezer until it was shipped to London. For the analysis,
a 6 mm diameter blood spot was punched out from each filter
paper and eluted overnight in 300 μl special buffer solution.
TSH was determined using a new non-radioactive two-site
immuno-enzymometric assay using a sheep polyclonal anti-h-TSH
(whole molecule) solid phase antibody which is passively
coated onto the surface of microtitre wells and a horse radish
peroxidase-conjugated murine monoclonal anti-h-TSH
(b-subunit) tracer antibody. This method was specifically
designed for this study and is a modification of the method
described in Little et al.13

In Majuro, 5 ml of venous blood were taken by a physician or
a registered nurse. After centrifugation, serum was stored at
4°C until TSH, free T₃, free T₄ and anti-thyroid antibody levels
were determined in the serum, usually within 48 hours after
phlebotomy. TSH, free T₄ and free T₃ were measured using
Amerlite MAB-FT3, or Amerlite MAB FT4 or Amerlite TSH
60 M fluorescence antibodies in the dedicated Amerlite™
enhanced luminescence assay system.14,15 Anti-thyroid micro-
somal antibodies and anti-thyroglobulin antibodies were meas-
ured using the Serodia-ATG and Serodia-AMC agglutination
test (Fuji Rebio Inc., Tokyo, Japan).

Study of iodine status

Analysis of urinary excretion of iodine was used to evaluate
typical dietary intakes of individuals. Because it was not
practical to obtain 24-hour urine samples from the Marshallese
population, spot samples—sometimes called casual samples—
were acquired and the iodine to creatinine ratio was determined
and used as an index of the daily iodine excretion, presumably
reflecting mainly dietary intake. This sampling method, though
generally not used for metabolic studies, has been found useful
for field studies such as the one which we conducted.16

Urine was collected from 309 study participants (184 female,
median age of 50 years; 125 male, median age of 43 years) in
Majuro who were recalled several weeks after the primary
examination. One hundred and fifty-five people were randomly
selected from those who had palpable nodules and matched
by sex and age with 154 people who had no palpable nodule.
Urine was stored in the freezer until it was divided into two
aliquots and sent to Japan and Germany for the determination
of iodine and creatinine concentrations. Two different methods
of measuring iodine were used: total iodine (including organic
iodine) was determined in München by a modification of the
ceric-arsenite method.17 This method is well established and
used for routine analysis of urine samples of hospital patients.
The method has been validated in national and international
quality control exercises organized by the International Council
for Control of Iodine Deficiency Disorders (ICCIDD). Analyses
were performed in duplicates. To detect possible interfering
substances, each sample was analysed undiluted and after 1:10
dilution. In addition, the recovery of a defined KI103 standard and the suppression of the specific iodide signal by addition of a defined amount of HgCl2 were checked.

Inorganic iodine was measured in all 309 samples by ion-pair reversed phase liquid chromatography with electrochemical detection18 by Roussel Morishita Laboratories in Ohtsu, Japan. Creatinine was measured in a clinical autoanalyzer (7150 Automatic Analyzer, HITACHI Ltd, Japan) using the established methods. Three additional smaller groups of urine samples were later collected from 50 children in Ebeye, 69 children in Likiep and 53 adults in Likiep. These samples were analysed by the electrochemical method in Japan to examine the variation of iodine in the diet at other atolls of residence. Likiep, located about 300 km NNW of the capital city Majuro is a typical outer atoll with a total population of approximately 500 living a traditional lifestyle whereas in the urban regions of Ebeye and Majuro, diet and lifestyle are much influenced by the American presence in the Marshall Islands.

Preliminary analysis of the urinary excretion data unexpectedly indicated that iodine deficiency may be a problem among some Marshallese. Consequently, we collected various food samples in Majuro which are typical of the local diet, in particular several types of fish (only the edible parts), drinking water, taro, coconut and other staple foods. Iodine content was measured in these foods in Germany after homogenization and alkaline hydrolysation using a similar method as used for urinary iodine.

Results

Thyroid nodules

The enlarged study9 of nodule prevalence, which also included the Majuro and Likiep populations, confirmed the findings of the investigation in the population of Ebeye island.1 The age-specific prevalence rate of palpable nodules for males and females are displayed in Figure 2. For women born before 1959, i.e. before the date of the last atomic bomb tests (22 August 1958), the prevalence of palpable thyroid nodules is 13% (407/3151), the prevalence of all thyroid nodules including those detected by ultrasound only is 28% (883/3151).

Thyroid function

Hypothyroidism is very rare in the investigated Marshallese population. In the blood spot test performed in Ebeye, preclinical hypothyroidism was defined as a TSH value of twice the modal value, and this was found in 30 cases, i.e. approximately 3%. In five subjects (0.5%) a ratio of five was exceeded, two of them had previous thyroid surgery. In the venous blood sample in Majuro, clinical hypothyroidism was defined as a TSH value of >3.1 mIU/ml and free T3 of <2.8 pg/ml and free T4 of <0.85 ng/ml. A high TSH was observed in 33 study participants, i.e. 1.5%, yet only in 10 cases was this accompanied by significantly low free T3 or/and T4 values (0.5%). This shows reasonable agreement between the logistically much more convenient filter paper method and the logistically more difficult serum method of determining TSH in a population screening programme. Methodological convenience is an important consideration for screening programmes in developing countries, particularly those in the tropics. In these examinations, we also diagnosed four cases of Grave’s disease.

Autoimmune thyroiditis is also very rare in the Marshall Islands. Ultrasonographic evidence of chronic thyroiditis was found in only one case, anti-thyroid antibody titres of >400 were found in 33 out of 3000 sera examined from consecutive study participants (1.1%).

We found evidence that a significant proportion of the Marshallese population suffers from moderate iodine deficiency. Figure 3 gives the distribution of the urinary iodine:creatinine ratio in the 309 adults from Majuro as determined with the electrochemical method. Since the mean creatinine concentration in the 309 samples was close to 1000 mg/l and thus similar to that in most Western industrialized countries, we can rule out any severe distortions of the iodine:creatinine ratio by dietary factors. Such problems had been encountered in some studies which reported mainly data from underdeveloped countries.19 Therefore the iodine:creatinine ratio as used in our study may be regarded as a reliable indicator of dietary iodine.

Urine samples were also taken from 45 of the 309 subjects in Majuro one year after the original sampling. The 45 individuals resampled in 1996 each contributed three urine samples over several days. We computed the coefficient of variation of the three new samples from each person. The median and mean coefficients of variation for the group of 45 people were 13.2% and 21%, respectively. These data indicate that the average variation over a few days was not large, suggesting a consistency of diet. In general, the values were correlated from one year to the next but differences were also noted.

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**Figure 2** The prevalence rate of palpable thyroid nodules in male (closed columns) and female (open columns) Marshallese according to different birth cohorts.

**Figure 3** The distribution of the iodine:creatinine ratio (nM/mM) among 309 adult Marshallese from Majuro.
Table 1  Urinary iodine excretion in 309 urban adults (Majuro atoll) and 55 adults and 68 children from an ‘outer-island’ (Likiep atoll) and iodine status based on WHO guidelines

<table>
<thead>
<tr>
<th>Iodine excretion category</th>
<th>Iodine:creatinine (nM/mM)</th>
<th>% study subjects (sample size)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Majuro adults (n = 310)</td>
</tr>
<tr>
<td>Normal</td>
<td>&gt;89</td>
<td>25</td>
</tr>
<tr>
<td>Mild deficiency</td>
<td>45–89</td>
<td>53</td>
</tr>
<tr>
<td>Moderate deficiency</td>
<td>22–45</td>
<td>21</td>
</tr>
<tr>
<td>Severe deficiency</td>
<td>&lt;22</td>
<td>1</td>
</tr>
</tbody>
</table>

The 1996 data were compared with the 1995 data to look for variations over a year period and to evaluate the suitability of the original spot samples collected from the population of 309 people. We computed a statistic defined as the ratio of median of the samples taken in 1996 to the 1995 sample (96/n/95). With the data from both sexes pooled, the median of the statistic from the 45 people was 1.28 indicating that, on average, the differences could be the result of variations in seasonal variations of iodine excretion. We believe that statistical sampling error and the inherent limitations of spot sampling are mainly responsible for the differences.

The urinary iodine excretion was more consistent for males from 1995 to 1996; only a 15% difference was noted. The statistic for females was unstable, however, the 1996 iodine:creatinine values were nearly 50% higher among the 19 women resampled.

As shown in Table 1, 22% of the 309 adults studied meet the WHO criteria of moderate iodine deficiency. Iodine deficiency was significantly (P < 0.001) more frequent in males who had a palpable nodule (17/44 = 39) than in those who did not have any palpable nodules (14/81 = 17%) (P < 0.001). Yet there was no difference in the frequency of iodine deficiency of females with or without nodules. However, the mean urinary iodine concentration in females with nodules was significantly lower than in females with no nodules (P < 0.01).

In those examined on Likiep atoll, iodine deficiency was even more pronounced than in Majuro. Of the adult participants, 7/53 (13%) showed severe iodine deficiency and 24/53 (48%) showed moderate iodine deficiency. There was, however, no relationship between the degree of iodine deficiency and the frequency of thyroid nodules in this small group from Likiep.

In children, the frequency of moderate iodine deficiency was 10%, much less than in adults. However, the children in the outer atoll of Likiep are of particular concern with 5 of 69 (7%) having severe iodine deficiency as indicated by the spot test and 39 of 69 (57%) having moderate iodine deficiency. This finding contradicts our expectation that the more traditional lifestyle on the outer atolls, far from the main population centre and where lifestyles are based on fishing and traditional food-gathering practices, would provide children with more iodine than the diets in the semi-industrialized urban areas of Majuro and Ebeye. This observation may suggest that the traditional lifestyle may cause iodine deficiency by itself and that the Marshallese may have suffered from iodine deficiency for a long time.

It is important to note that the two analytical methods measured different chemical forms of iodine compounds. Whereas the electrochemical method measures inorganic iodine only, the chemical method measures total iodine. For purposes of cross-comparison of the methods, 60 samples which spanned the entire range of values were measured in both laboratories. Values about 10% higher were expected with the second (total iodine) method, however, results were about 33% higher. There was, however, a high correlation (r = 0.95) of the measurements between the two methods.

Thyroid volume

Since iodine deficiency tends to be associated with an enlargement of the thyroid gland, we calculated the thyroid volume from data obtained during the ultrasound examinations. The calculations were limited to those subjects from Majuro who participated in the iodine excretion study. The volume of a lobe was taken as half the product of its three diameters. The distribution of thyroid lobe volumes is shown in Figure 4. The median volume is 10 ml. However, there were differences in the size distribution which were related both to nodularity and to iodine excretion. Figure 4 compares the thyroid volume distributions of low-iodine people with palpable nodules with that of normal iodine people without thyroid nodules. Taking twice the modal volume of 10 ml as a criterion for a large thyroid, the frequency of an enlarged gland varied in the different groups.
frequency of a large thyroid occurred in those who had nodules and iodine deficiency (8/37 = 22%) whereas large thyroids occurred only in 4/39 (10%) of those who had nodules but no iodine deficiency.

**Dietary iodine**

The iodine concentration in the different food samples is listed in Table 2. The variations among the different fish samples are particularly interesting (Table 3) and greater than those reported for fish caught commercially. Considering the typical diet of Marshallese only fish contributes significantly to dietary iodine uptake in the Marshallese population. In Western inland continental locations which are typically of the order of 10 ng I/g (Table 2). The low concentrations in fruits indicate minimal uptake of iodine from the soil. Iodine in surface soil samples taken from Kwajalein atoll and measured by inductively coupled plasma mass spectrometry (ICPMS) had a median value of 3.5 mg/g soil. That concentration is significantly greater than most inland continental locations which are typically of the order of 0.5 ng/g. Presumably, the higher soil concentrations are a result of deposition of sea spray, however, the uptake into fruit is still too small to significantly contribute to the required daily intake. Even moderate levels of inadvertent ingestion of soil (e.g. 100 mg/d) would contribute little iodine (~350 ng) to the total intake.

**Table 2** Iodine concentration in the Marshallese diet

<table>
<thead>
<tr>
<th>Dietary sample</th>
<th>No. samples</th>
<th>Amount consumed per day (g)</th>
<th>Mean concentration (ng/g)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconut</td>
<td>6</td>
<td>380</td>
<td>&lt;10</td>
<td>&lt;10–29</td>
</tr>
<tr>
<td>Jekaru</td>
<td>2</td>
<td>220</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Pandanus</td>
<td>1</td>
<td>100</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Papaya</td>
<td>1</td>
<td>50</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Breadfruit</td>
<td>1</td>
<td>90</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>2</td>
<td>350</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Drinking water</td>
<td>1</td>
<td>200</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>10</td>
<td>200</td>
<td>100–6800</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3** Iodine concentration in the flesh of fish commonly caught in the Marshall Islands

<table>
<thead>
<tr>
<th>Type of fish</th>
<th>Concentration (ng/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myristis</td>
<td>707</td>
</tr>
<tr>
<td>Myristis bernti</td>
<td>614</td>
</tr>
<tr>
<td>Naso lituratus</td>
<td>2260</td>
</tr>
<tr>
<td>Neothunus macropterus</td>
<td>104</td>
</tr>
<tr>
<td>Naso brevirostris</td>
<td>416</td>
</tr>
<tr>
<td>Lethrinus variegatus</td>
<td>322</td>
</tr>
<tr>
<td>Serranus fuscoguttatus</td>
<td>725</td>
</tr>
<tr>
<td>Naso unicronis</td>
<td>189</td>
</tr>
<tr>
<td>Tridacnidae (giant clam)</td>
<td>5002</td>
</tr>
<tr>
<td>Mixed salted fish</td>
<td>6798</td>
</tr>
</tbody>
</table>

**Discussion**

The data reported here suggest that there is a moderate degree of iodine deficiency among Marshallese which might explain at least some of the high prevalence of nodular thyroid disease, namely adenomatous goitre. The correlation between severe iodine deficiency and thyroid nodularity has been well documented before in many countries, among others Tanzania, Ecuador and Fiji. Yet also moderate degrees of iodine deficiency such as what has been found in the Marshall Islands are also associated with an increase in the prevalence of thyroid nodules. The study performed by Gutekunst is in many respects similar to ours and thus particularly informative. In 1174 German adults, the prevalence of nodular thyroid disease was determined by palpation and ultrasound and the urinary iodine concentration was measured. A prevalence of 13.4% nodules was diagnosed by ultrasound and a 25% prevalence of moderate iodine deficiency was found. For comparison, in an adult Swedish population which was well provided with iodine (0/292 had moderate iodine deficiency) the prevalence of thyroid nodules was only 2.6% using the same ultrasound criteria and measured by the same examiners. The distribution of thyroid sizes was also very different between Swedish and German adults. Gutekunst concluded that moderate dietary iodine deficiency could be the cause not only of goitre but also of thyroid nodules. It is interesting to note that the distribution of thyroid sizes was very similar between the German and the Marshallese adults.

The large discrepancy between the results of urinary iodine concentrations performed with the two methods casts some doubt on the frequency of iodine deficiency in our study. We based the definition of iodine deficiency according to the WHO criteria on inorganic iodine only. If, however, the classification had been based on total iodine excretion, 11% rather than 22% would meet the criteria of moderate or severe iodine deficiency. Since both methods of urinary iodine measurements were performed in laboratories which had successfully taken part in quality control programmes, this discrepancy has to be regarded as being genuine. It strongly suggests that other forms of organic iodine might be present in Marshallese people. This is supported by the unexpected findings of an increased iodo-protein concentration in sera of Marshallese people. Analyses for protein-bound iodine in sera of Marshallese people revealed a level significantly higher than seen in North America. This could be attributed to an increase in the iodo-protein fraction which subsequently was also found in other indigenous Pacific populations. In the population of Rongelap, the iodo-protein fraction remained high even in two athyreotic boys, after subtotal
thyroidectomy and during thyroid suppression by thyroxin administration. This strongly implies an extrathyroidal or dietary source. The chemical nature of this iodoprotein has not yet been determined but it is not related to thyroglobulin. The relationship of the high concentration of this iodoprotein in the serum to the high level of organic iodine in the urine remains to be clarified.

The high prevalence of iodine deficiency in the adult population of the Marshall Islands is very surprising, particularly, in light of studies of other island populations. Mason determined urinary iodine excretion in 30 pooled urine samples from four different Pacific Islands and observed significant differences with low values in Fiji and New Caledonia where the main source of staple food is from agriculture and high values in Cook Islands and Tahiti where fish is the staple food. According to the interview data we gathered from the study participants, fish appears to be a staple food in the Marshall Islands, too.

The analysis of the various components of the Marshallese diet (Table 2) confirmed that, indeed, fish is the only significant source of dietary iodine. Most salt sold in Marshallese shops appears to be not iodized. Large differences between different types of fish were found. Tuna (Thunnus loweryi) which has the lowest iodine content, is less frequently caught by local fishermen and would be less available in local shops whereas different types of reef fish which are commonly caught and consumed contain sufficient iodine to prevent any signs of iodine deficiency. Taking the results of the dietary review in the Marshall Islands as a basis, the average Marshallese should take in more than 130 mg of iodine from fish alone which would amply cover the needs of the body. Obviously this is not the case for all Marshallese.

During a recent (1996) interview session in Ebeye, we asked questions related to diet as was done earlier (1993) and, as before, received the same answer that fish would be eaten daily. However, after questioning more deeply, most study participants qualified their answer by affirming that they liked to eat fish every day but they could only get it if a member of the family caught enough for the typical large family. Over the past four decades, major changes in lifestyle have taken place in the Marshall Islands which affected particularly the population centres, Majuro and Ebeye: less food is caught from the sea, more is bought in shops, and includes imported canned meats and rice. It is very likely that without fish, the diet of a Marshallese from local products and rice and some other imported food could be iodine deficient. This is more likely to happen in the population centres than in outer atolls where lifestyle is more traditional. This may explain the observation that people who lived in Majuro in the 1950s and later have about the highest prevalence of thyroid nodules.

Although moderate iodine deficiency and a high prevalence of nodular thyroid disease—which may be causally related—have been found in the populations living in Ebeye and Majuro, this may not equally apply to people living in the more remote atolls where a much more traditional lifestyle based on fishing and food gathering is still common. Yet the results of the spot test in the Likiep population apparently contradict such a simple classification.

The variable correlation between iodine deficiency and thyroid nodularity may also be due, at least partly, to the fact that we were only able to determine iodine excretion for 1994 and 1996/1997. Yet, if iodine deficiency had played a role in the development of some of the thyroid nodules, the deficiency would have had to occur over a period of several years, although possibly not as far back as the bomb test period. Therefore, the poor overall correlation between iodine deficiency and thyroid nodularity is not unexpected.

The moderate degree of iodine deficiency reported in this study is certainly not severe enough to cause any clinical or biochemical signs of thyroid hormone disorder. All parameters which could indicate decreased thyroid function were normal. Moreover, the prevalence of autoimmune thyroiditis which is quite high in some Pacific countries is remarkably low in the population of the Marshall Islands.

The data which we present here are relevant to past and ongoing studies on the long-term consequences of the radioactive fallout from the bomb tests performed in the Marshall Islands between 1946 and 1958. Nodular thyroid disease and thyroid cancer has been linked to the exposure to short-lived radiiodines. Whereas there is little reason to attribute the high prevalence of thyroid cancer found in the Marshall Islands to the observed iodine deficiency, it may well be a confounding factor in the development of thyroid nodules, and in particular, its most common form, adenomatous goitre. This relationship is particularly important to consider as the rate of iodine deficiency may not have been the same in all atolls of the Marshall Islands. Future studies on the relationship between exposure to radiiodines and unspecified thyroid nodules would need to take this confounder into account in the interpretation of their findings.

Acknowledgements

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References

THYROID FUNCTION AND IODINE DEFICIENCY IN THE MARSHALL ISLANDS 749


