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Epidemiological studies of Fukushima residents exposed to ionising radiation from the Fukushima Daiichi Nuclear Power Plant prefecture—a preliminary review of current plans

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Abstract

It is now more than six months since the beginning of the accident on 11 March 2011 at the Fukushima Daiichi Nuclear Power Plant in Japan. The Japanese government and local health authorities have started to collect the information necessary to estimate radiation doses received by those living in the area around the plant, drafted plans for the health care of residents, and started to implement some of them. This paper reviews and discusses the studies necessary for risk evaluation of cancer and non-cancer diseases, including those already planned, mainly from the view point of evaluating health risk using epidemiological approaches. In the long run, it is important to establish a cohort with a control group. Even if the cumulative doses are estimated to be so low that it is difficult to evaluate the risk of cancer and non-cancer diseases, it is necessary to conduct such a study to reassure residents. The health care programme of the Fukushima Prefecture government, including health check-ups of residents, will help to assess indirect effects of radiation exposure, including psychological problems.

The success of any studies of radiation epidemiology depends on the collection of accurate information on radiation doses received by the study subjects. However, some of the dosimetry surveys were not conducted in a timely manner. (It should be recognised, though, that such a problem might have been inevitable, considering the chaotic condition after the nuclear accident.) Accurate estimation of the radiation dose received by each resident is not only important for scientific risk evaluation but also to inform each resident about his or her potential risk. Otherwise, residents will bear an undue psychological burden from uncertainties regarding their radiation exposure and its health consequences. One of other important tasks in Fukushima is the improvement of the quality of the regional cancer registry in this prefecture. It is also important to start thyroid cancer screening in a year or two since the expected minimum latent period among those exposed in early childhood is about 4 years. Recently,
local health authorities decided to start a thyroid screening programme for those aged 18 years or younger.

Any scientific efforts in Fukushima, which need to gain the trust of study subjects about the objectivity of research, may suffer from the fact that residents in Fukushima Prefecture have begun to suspect that the Japanese government and local authorities are keeping important information from them. It seems necessary to make more effort to reflect the opinions of residents when planning health care programmes and to gain the understanding of the public for the programme. In summary, there are many problems that make the evaluation of cancer and non-cancer disease risk in Fukushima difficult. The help of international colleagues will be invaluable for overcoming those problems. In this paper, these efforts are briefly summarised and some comments are made.

1. Introduction

It is now more than 6 months since the beginning of the accident on 11 March 2011 at the Fukushima Daiichi Nuclear Power Plant (Fukushima I NPP) in Japan. The Japanese government and local authorities have started to collect the information necessary to estimate radiation doses received by those living in the area around the plant, drafted plans for the health care of residents, and have already implemented some of them. This paper reviews and discusses the studies necessary for risk evaluation of cancer and non-cancer diseases, including those already planned, mainly from the view point of evaluating health risk using epidemiological approaches.

2. Dosimetry

One of the most important tasks for risk evaluation is the collection of accurate information on the exposure level of each individual. Accurate estimation of the radiation dose received by each resident is not only important for scientific risk evaluation but also to inform each resident about his or her risk. Otherwise, residents will bear an undue psychological burden from uncertainties regarding radiation exposure and its health consequences.

The Science Council of Japan made the second emergency recommendation regarding the need for the investigation of radiation levels on 4 April 2011 (2011). It recommended measuring radiation levels in soil and air samples in the 30 km radius zone. Regarding the radiation exposure of residents, including evacuees, it recommended to measuring I-131 and Cs-137 in the thyroid and to conduct whole body counting (WBC) to detect them. It also recommended recording residents’ daily life activities before and after the accident.

The Japanese government and local authorities have already conducted or have plans to carry out these investigations. However, some of the dosimetry surveys were not conducted in a timely manner. It should be recognised though that such a problem might have been inevitable, considering the chaotic conditions after the nuclear accident. In the following sections, dosimetry work conducted so far will be reviewed, and the problems related to dosimetry will be discussed.

2.1. Doses and dose rates from external irradiation

The Japanese government and local authorities conducted extensive environmental dosimetry surveys with the help of various domestic and foreign institutions. The data available at the
website of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) show that areas located north-west of Fukushima I NPP tend to have relatively high external doses from deposited nuclides (now predominantly from radioisotopes of caesium). In one of these areas outside the 30 km radius zone, an external radiation dose rate as high as $10 \mu \text{Sv h}^{-1}$ was recorded even 3 months after the accident. An area in Namie town recorded a cumulative dose in the air of $73.9 \text{mSv}$ during the period between 12 March and 25 May according to a media release from MEXT in early June. Note, however, the radiation doses received by the residents in this area were unlikely to be that high because most of the residents tried to stay indoors in the early days after the accident, and were evacuated by early April.

Radionuclides with long half-lives will play a major role in long-term exposure. Those include Cs-137 and Cs-134, with half-lives of 30 years and 2 years, respectively. In Fukushima city, which is approximately 60 km away from the Fukushima I NPP, the gamma radiation dose rate exceeded $100 \mu \text{Sv h}^{-1}$ on 16–17 March, and decreased to $1–2 \mu \text{Sv h}^{-1}$ in the next 2–3 weeks (www.cms.pref.fukushima.jp). Hosoda et al reported that the dose rate in areas more than 200 km away from the power station had increased by a factor of about 1.5–2.5 on 25 April compared to the levels before 11 March (Hosoda et al 2011). In October 2011, some areas of Fukushima city still had radiation levels higher than $1.0 \mu \text{Sv h}^{-1}$.

IRSN, the French National Institute for Radiation Protection and Nuclear Safety, estimated projected doses due to external exposure from radioactive deposits for exposure durations of 3 months, 1 year and 4 years before evacuation on the basis of the dose assessment carried out by IRSN on the 66th day after the accident (www.irsn.fr/EN/Pages/home.aspx). IRSN estimates a deposition of 300–600 kBq m$^{-2}$ of Cs-137 and Cs-134, corresponding to external dose of 5–10 mSv projected for the first year of exposure. They estimate that 29 200 and 69 400 people could be exposed to 5 mSv and 10 mSv, respectively, in the first year of exposure. Those estimates do not include those in the exclusion zone. Note, however, that the estimation does not take into account voluntary evacuation or the lifestyles of residents.

2.2. Thyroid gland exposure in the early days after the accident

In the early days after the accident, a primary concern was the exposure of children to radioactive iodine, which is known to accumulate in the thyroid, giving the gland relatively high doses; this increases the risk of thyroid cancer, particularly among those exposed as young children. Since I-131 has the half-life of 8 days, it was necessary to conduct the measurements as early as possible.

From 28 to 30 March, local health authorities examined the thyroid glands of 1149 children aged from 0 to 15 years in Iitate town and Kawamata town and Iwaki city, areas with relatively high radiation dose rates (Nuclear Safety Commission of Japan 2011). In the measurements, a NaI scintillation survey meter was placed on the throat. The maximum dose rate was $0.07 \mu \text{Sv h}^{-1}$. More detailed information was presented at a forum of the Japan Pediatrics Society in 2011. Radiation from radionuclides accumulated in the thyroid was detected in more than half of the children examined. The maximum thyroid dose possibly received by those children was estimated to be 35 mSv (Tashiro 2011). Note that the starting date of internal exposure, which is necessary for estimating cumulative thyroid dose, is not entirely clear. In addition to this survey, which was led by local authorities, some researchers conducted thyroid dosimetry surveys using gamma spectrometers in various areas, according to the media and other sources.

Unfortunately, however, only a small proportion of children, even in areas that received relatively high radiation doses, underwent thyroid dosimetry. According to the report from the Associated Press, children from Karino Elementary School gathered in the grounds of the
school, which is just over 10 km away from the plant, and then fled to Tsushima District of Namie, which was later hit by radioactive plume (Associated Press 2011). Whether those children underwent thyroid dosimetry or WBC before radioactive iodine became undetectable through decay is as yet unclear.

If radiation exposure of the thyroid was mainly through inhalation, the thyroid dose of those children without direct thyroid dosimetry data may be estimated on the basis of residential history, information on house occupancy and outdoor activities. It is also necessary for such dose estimation to take into account the administration of stable iodine, which was given to a small number of evacuees/residents. Fortunately, however, parents carefully avoided giving their children locally grown foods, tap water and river water, according to media reports. Therefore, foodstuffs and water are unlikely to be the major sources of internal exposure to radioactive iodine. In that case, estimating thyroid dose may be easier than in Chernobyl, where a major source of radioactive iodine was milk intake (Cardis and Hatch 2011). A study conducted in the areas of Russia affected by the Chernobyl accident showed that I-131 concentrations in milk were strongly correlated with the soil concentrations of Cs-137. However, the correlation was small in low dose ranges (Balonov et al 2000). In Fukushima, it is as yet unclear how useful the ratio between Cs-137 and I-131 will be for estimating thyroid dose from radioactive iodine for children with Cs-137 doses in the body but without directly measured I-131 doses.

2.3. Individual dose estimation other than thyroid exposure

As pointed out by many researchers, it is important for individual dose estimation to collect information on the residential history and the hours spent indoors and outdoors (and whereabouts), means of transportation, the consumption of local water, and the amounts and kinds of locally grown foods consumed. Since the chaotic conditions caused by the earthquake/tsunami and the nuclear accident made it difficult to conduct such a survey immediately, local authorities should have asked the residents to record such information.

The indoor dosimetry measurements would seem to be necessary in the houses in relatively high dose areas. Note that dose distribution is not homogeneous even inside houses—let alone the ratio between outdoor and indoor doses in various houses. However, only in a small number of houses were indoor doses directly measured during the early days after the accident, when external doses were high. It should also be noted that some houses had radioactive dust on the roof (Mainichi Daily News 2011), making indoor dose distributions even more heterogeneous.

Even if directly measured indoor and outdoor doses are available, individual dose estimation is a difficult task. The heterogeneous dose distributions and possible long-term exposure caused by radionuclides with a long half-life will make it even more difficult. For example, the dose rates on unsealed surfaces were from 1.0 to 2.1 times (average: 1.3 times, \(n = 20\)) higher than those on pavements (Hosoda et al 2011). In addition, radiation doses in drainage ditches are reported to be much higher than those on roads (Mainichi Daily News 2011).

In June 2011, local authorities decided to distribute glass badges to all children aged 15 years or younger and pregnant women in Fukushima Prefecture in order to measure the cumulative radiation doses. The length of measurement is differed between municipalities. In Kawamata, which is an area where high environmental radiation levels were recorded, badges were retrieved every 3 months and year-long measurement will be conducted (Kawamata Bulletin Magazine 2011). Even if the programme to decontaminate the environment is as successful as expected, longer measurements may be necessary.
The lack of detailed information on the source of internal radiation exposure is another problem. Needless to say, the glass dosimeters distributed to children cannot measure internal exposure. As part of the prefectural health care programme, the local authorities decided to examine 120 residents in Iitate, Namie and Kawamata for their internal exposure. In total 109 people underwent such dosimetry. The first 10 people underwent WBC at the National Institute of Radiological Sciences on 27 June. In early July, it was announced that an additional 2800 residents would be examined at a facility of the Japan Atomic Energy Agency. Priority would be given to pregnant women and children. The change of plan in such a short time reflects residents’ concern about internal exposure. Anyway, the data to be obtained will also be invaluable for evaluating internal radiation exposure from long-lived radionuclides such as Cs-137.

Some researchers collected urine specimens from Fukushima residents and measured radioactive nuclides. One such investigation is that conducted by Dr Nanao Kamada, professor emeritus of radiation biology at Hiroshima University, and his colleagues (Japan Times 2011). Measuring radionuclides in urine specimens collected from residents is also useful for the validation of estimated dose. Local health authorities also measured radioactive iodine and caesium in urine specimens collected from 109 residents who underwent internal exposure dosimetry, which was described above (Minutes of the Fourth Investigative Committee Meeting on Fukushima Prefecture Health Management Survey). However, it was impossible, in practice, to collect urine from thousands of children and then to determine the concentrations of radionuclides. Therefore, it practical utility is limited.

In summary, even though data for the early days after the accident are not available, the data to be obtained will be invaluable for evaluating external exposure.

2.4. ‘The Basic Survey’ conducted by the prefectural government

The Fukushima Prefecture government initiated the Basic Survey, part of the prefectural health care programme, in late June. It collects information necessary to evaluate external radiation exposure levels from all the people living in Fukushima Prefecture as of 11 March 2011. The number of people to be surveyed is expected to be approximately 2 million. A self-administered questionnaire will be used. The information to be collected includes the following: name; date of birth; Honseki (see section ‘Mortality survey’ below); registered address; telephone number; household members; history of radiation work; structure of residence; structure of school or office building; administration of stable iodine; indoor and outdoor activities, including means of transportation, and the consumption of locally grown foods and the source of drinking water during the periods of 11–25 March and 26 March–11 July 2011.

In late June, the survey was started in Iitate village, Namie town and the Yamakiya district of Kawamata town, where radiation levels are known to be high. The number of subjects in this antecedent survey is about 27 000. The study of the rest of Fukushima Prefecture residents was started in late August. Since the survey was being conducted several months after the accident, fading memory is a concern. By early October, fewer than half of residents responded to the survey (Fukushima Prefecture Health Check-up Program Exploratory Committee (2011)).

3. Risk evaluation

In the case of ionising radiation exposure, the most serious late health effect is the development of cancer, particularly among children. External radiation exposure increases the risk of thyroid cancer only when the exposure takes place in childhood (Ron et al 1995). Information on internal exposure is limited. Before the Chernobyl accident, there was no convincing evidence
to indicate thyroid cancer risk associated with internal radiation exposure. Children and adolescents exposed to radiiodine from Chernobyl fallout have a sizeable dose-related increase in thyroid cancer (Cardis and Hatch 2011).

It is unclear how many infants and children were not evacuated in the first 10 days after the accident, during which the majority of nuclide deposition took place. In addition, we cannot deny the possibility that some families with infants and or small children came back to their houses from evacuation shelters in late March and early April. Therefore, the distribution of radiation doses to children is difficult to predict, although the median dose is likely to be low. However, unless the radiation doses received are much higher than currently predicted, the risk of leukaemia and thyroid cancer is unlikely to be detected.

Regarding childhood cancer risk, the population migration theory of Kinlen should be noted. He argues that marked rural population mixing increases childhood leukaemia risk due to exposure to as yet unknown infectious agents (Kinlen 2011). If his theory is correct, evacuated children evacuated from rural areas in Fukushima, Miyagi and Iwate may experience a higher risk of leukaemia. However, the effect of population mixing may be largest in Fukushima children since their evacuation is more extensive and longer than in other prefectures.

Needless to say, it is important to make efforts to reduce further radiation exposure as much as possible. Even if such efforts are successful and cumulative doses remain low, making the risk evaluation lack a sufficient statistical power, it is still necessary to conduct a risk evaluation in order to reassure residents and avoid possible stress and anxiety caused by harmful rumours. People in Fukushima, particularly children, are reported to have suffered from mental and psychological effects caused by the earthquake, tsunami, nuclear accidents, subsequent evacuation, harmful rumours and other things. It is necessary to conduct scientific and quantitative evaluations of these problems, and establish a system to deal with them.

3.1. Thyroid cancer survey

Any regional cancer registry is unlikely to provide sufficiently accurate information on thyroid cancer incidence in the region since there are many asymptomatic cases. Therefore, it is necessary to start thyroid tumour screening in Fukushima Prefecture. Since we cannot distinguish thyroid cancer cases caused by ionising radiation from others, it is necessary to know the background risk of thyroid cancer in Fukushima Prefecture at least a few years before the expected minimum latent period—as is well known, in the case of Chernobyl, thyroid cancer risk among children started to increase 4 years after the accident (Baverstock et al. 1992, Kazakov et al. 1992). The age range of the screening should be carefully determined, since exposure in early adulthood is suspected to increase thyroid cancer risk.

The Fukushima Prefecture government started to conduct thyroid screening of all the Fukushima residents aged 18 years or younger as of 11 March 2011. In October and November, residents in Iitate village, Namie town and the Yamakiya district of Kawamata town were examined. The surveys in other areas started in November 2011. Those subjects will undergo a thyroid examination using ultrasonography every other year until they reach the age of 20. In April 2014, the fully fledged survey will be started, and residents will undergo thyroid examinations every 2 years up to age 20, and, after that, the examination will be conducted every 5 years. Those who are found to have nodules and so on will be asked to undergo needle biopsies of the thyroid, and blood and urine tests. Those specimens are to be stored (Fukushima Prefecture Health Check-up Program Exploratory Committee (2011)).
3.2. Health check-ups

The prefectural government plans to conduct a health check-up of approximately 200,000 subjects, including evacuees and those considered necessary on the basis of the Basic Survey. The items to be examined are different in different age groups. For those aged under 6 years, the examination includes height and weight and blood counts, including red blood cell count, haematocrit, haemoglobin, platelet count, white blood cell count and white blood cell differential count. For those aged 6–18, if wished, the following items of blood biochemistry will be added: alanine aminotransferase (AST), aspartate aminotransferase (ALT), gamma-glutamyltransferase, triglycerides, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, haemoglobin A1c, fasting blood sugar, creatinine, estimated glomerular filtration rate (eGFR) and uric acid. Those aged 19 years or more will be examined for height/weight, abdominal circumference, blood pressure, blood counts, blood biochemistry and urine tests (proteins, sugar and occult blood). The information obtained from serial health check-ups may be useful for determining the incidence rates of various diseases.

3.3. Cancer incidence survey

The regional cancer registry in Fukushima Prefecture was established in April 2010. Unfortunately, however, the completeness and other aspects of the quality of the present regional cancer registry in Fukushima Prefecture are far from ideal. It is necessary to step up the efforts to improve the quality of Fukushima Prefecture cancer registry. In the case of a regional cancer registry, it is difficult to identify cancer cases once the cohort members leave Fukushima Prefecture. A possible solution is to collate the list of cohort members or those who move out of Fukushima Prefecture against cancer case list in regional cancer registries in areas other than Fukushima. However, it should be noted that the quality of regional cancer registries in many prefectures is far from ideal. Indeed, the IARC publication ‘Cancer Incidence in Five Continents’ included fewer than 10 prefectural regional cancer registries, although there are nearly 50 prefectures in Japan. The lack of a regional cancer registry in the Tokyo metropolitan area will also be a problem. Taken together, it is unlikely that cancer cases who move out of Fukushima will be identified with sufficient completeness.

It is desirable to establish a childhood cancer registry in Fukushima Prefecture as was the case in Aomori Prefecture, where a plutonium reprocessing plant was constructed. In the case of Aomori Prefecture, the national project to support the treatment of the selected chronic diseases of children will be helpful for identifying childhood cancer cases.

3.4. Mortality survey

It is possible to conduct a mortality follow-up of a cohort of the Fukushima population to examine their mortality experiences. In Japan, deaths among a cohort can be identified regardless of the place of residence. Examples are the mortality follow-up of atomic bomb survivors (Preston et al 2003) and the nuclear workers (Iwasaki et al 2003). Note that the mortality follow-up study of atomic bomb survivors conducted by the Radiation Effect Research Foundation used Honseki, which is the registered permanent address and is useful for the follow-up of the residents, since even if the registered address of a resident changes, the registered permanent address remains unchanged. Note, however, the nuclear worker study reported by Iwasaki et al did not use information on Honseki in the mortality follow-up. Even so, the follow-up was almost complete.
A potentially serious problem involved in any evaluation of health risk is the need for information on lifestyle. When considering the importance of the effects of smoking on cancer risk evaluation, it was desirable to include information on smoking in the questionnaire to be used in the Basic Survey. Local authorities decided to collect information on lifestyle from 200,000 residents, including evacuees, using a questionnaire. The content of the questionnaire has not yet been made public.

 Needless to say, it is desirable to collect information on factors other than tobacco smoking, such as alcohol intake, dietary habits, occupation and so on. The exposure to medical radiation for diagnostic purposes, including multiple CT scans, is also important, particularly for children. Note that Japan has one of the highest rates of CT scans, second only to the United States (Tsushima et al. 2010), and these medical exposures may be substantial and much greater than the Fukushima nuclear power plant exposure estimates; this could be a particular problem if medical radiography forms a part of the health check-up procedures.

Tondel et al. examined cancer incidence 1988–96 in relation to Cs-137 in northern Sweden, affected by the Chernobyl accident in 1986. In this study, individual dosimetry was not conducted. Instead, 450 parishes were categorised by Cs-137 deposition, and cancer incidence among those parishes was examined. The incidence of all cancers was significantly related to Cs-137 levels. No clear excess occurred for leukaemia or thyroid cancer (Tondel et al. 2004).

In Fukushima, by using mortality follow-up data or regional cancer registry data, this kind of study can be conducted even by scientists not directly involved in the local studies. However, such a study is not sufficiently informative due to the lack of information on individual doses and on the lifestyle of each individual.

3.5. Transgenerational effects

No excess genetic abnormalities or congenital anomalies were observed among the children of atomic bomb survivors (Otaka et al. 1990, Satoh et al. 1996) or residents in high natural background areas (Cheriyan et al. 1999, Jaikrishan et al. 1999). Even before the Fukushima accident, the effects of environmental exposure on children were an important public concern. In 2010, the Japanese Ministry of Environment launched a nationwide birth cohort study to clarify the effects of exposure to chemical and physical environmental factors on children in a dozen areas of Japan, including Fukushima Prefecture (Kawamoto et al. 2011). This study, called the Japan Environment and Children’s Study (JECS), is expected to recruit around 100,000 pregnant women during the 3-year period between 2010 and 2012. Their children are observed from foetus to age 12 years. Fukushima city, Minami Souma city, and Hutaba county, which consists of Namie town and other municipalities near the Fukushima I NPP, were included in this study. In June 2011, Kawamata town, Koori town, Date city and Kunimi town were newly added to the study area. Some of those are areas with relatively high radiation exposure. In mid August, the media reported that the JECS decided on a follow-up survey of 6900 women pregnant at the time of the nuclear accident and their children. It is not clear how the JECS will evaluate the effects of ionising radiation, including medical exposure, on children.

In addition, local authorities in Fukushima decided to conduct a questionnaire survey of approximately 20,000 women who became pregnant and requested their Mother’s Books during the period between 1 August 2010 and 31 July 2011. Note that virtually all pregnant Japanese women request this booklet when they get pregnant. The content of the questionnaire to be used for the survey has not yet been made public.
3.6. Effects on psychological health

Fukushima Prefecture plans to evaluate the mental fitness of 200,000 Fukushima people, including evacuees, using a questionnaire (Minutes of the Fourth Investigative Committee meeting on Fukushima Prefecture Health Management Survey). Those studies in Fukushima will provide invaluable information on psychological disturbances caused by disasters, including serious nuclear accidents. In addition, the Ministry of Health, Labour and Welfare started a 10-year follow-up survey to examine the impact of the 11 March earthquake and tsunami on the physical and mental health of 30,000 residents in Iwate, Miyagi and Fukushima prefectures (Yomiuri Online 2011). Academic societies also plan to evaluate the mental health of residents in order to provide them with the necessary care.

4. Concluding remarks

Japanese scientists are expected to perform high-quality studies that will allow them to find a small radiation risk if any in Fukushima. At this moment, however, it is unclear whether local authorities plans to conduct a follow-up study using vital statistics data (a mortality survey), cancer registry data (a cancer incidence study) and/or health check-up data. Local authorities may concerned about the possibility that some of the residents included in the survey may complain about any scientific projects, arguing that they do not want to be ‘guinea pigs’. The help of international bodies, which understand the importance of these kinds of epidemiological studies, will be useful for minimizing those complaints.

Needless to say, obtaining individual doses, measured or estimated, is a most important task in a good radiation epidemiological study. It is also important to evaluate the background risk of cancer and non-cancer diseases. In the case of Fukushima, we cannot be too optimistic about those efforts. Unfortunately, Japanese people, particularly the residents of Fukushima Prefecture, have begun to suspect that the Japanese government and local authorities are keeping important information from them due to a series of belated revelations of important information on the nuclear accident and the related problems. Any scientific efforts which need to gain the trust of the study subjects may suffer from this problem. It seems necessary to make more effort to reflect the opinions of residents when planning health care programmes and to gain the understanding of the public for the programme.

There are many other problems that make the evaluation of health risks in Fukushima difficult. The help of international colleagues will be invaluable for overcoming those problems. For that purpose, the Japanese government should consider establishing an international institution to conduct epidemiological studies to evaluate the various health effects of the Fukushima I NPP accident.

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