A pilot choice experiment among French nuclear specialists to measure the intangible value of territories

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A discrete choice experiment was conducted in France, among 400 persons working in the French nuclear safety authority (ASN) and the French Institute for radiation protection and nuclear safety (IRSN) to value the loss of welfare of the society after a nuclear accident. People were asked to choose repeatedly between three different alternatives describing life conditions in their supposed living territory after a nuclear accident. These alternatives were characterized by the proportion of people who stay in the territory after the accident, the proportion of services which stay in the territory, whether the access to nature places of the territory is prohibited or not and the duration of the deteriorated situation. A mixed-logit model shows that the access to areas of nature and the runaway of services are the main sources of disutility for the population. It is worth noting that people having children under 18 years old and the ones leaving outside the Paris region give even more importance to these aspects whereas younger people and people leaving in the Paris region value the proportion of persons and services around them more. The willingness to pay (WTP) of a household to avoid living in a contaminated territory for 30 years is about 15,000 euros.

The conclusion of the paper is that places considered as the more important by inhabitants are not necessarily the ones they attend more. Such a study could permit to advise policy makers on the best strategy to adopt to mitigate the loss of welfare after a deterioration of life conditions on a territory.

I. INTRODUCTION

With its 58 operating nuclear power plants, France is one of the main nuclearized countries in the world. The Chernobyl and the Fukushima accidents showed that even if the probability of such a catastrophe is extremely low, its dire economic and social consequences justify studying this risk to better prevent it. Moreover, in France like in other European countries, the society faces nowadays the question of the place of the nuclear technology in the future energy mix chosen. In this regard, it is really important to assess the different externalities of each mean of production of electricity to make informed decision making.

One of the nuclear externality is the risk of nuclear accident. The complete social cost of a major accident (e.g., Fukushima, Chernobyl) has been estimated around 450 billion euros (IRSN (Ref.10)). This estimation takes into account the whole costs (independently of the agent who bears it), considering direct costs (directly linked to the contamination which deposits on the ground), indirect costs (non-directly linked with contamination). The main limit of these evaluations is that they only account for tangible costs (the cost of market value losses such as the value of foodstuffs banned from consumption or the losses in the tourism sector induced by a lower attractiveness of the country). The intangible costs (the cost of losses of non-market values such as the loss of welfare of a population leaving in a contaminated territory, for instance) are, for the

moment, not valued. The present article aims at addressing the value of a good that has never been studied before: the non-market value of a territory contaminated by radioactivity.

After a nuclear accident with core melt and releases to the environment, such as the Fukushima accident, the way of life of inhabitants living in contaminated areas would change. In heavily contaminated territories, exclusion zones are expected to be created: it implies that people and firms have to leave from this zone. In less contaminated territories, even if evacuation measures are not taken, some people may leave for fear of contamination, some economic activities may cease, some areas would undergo restrictions. Some of the elements which give a value to a territory before a nuclear accident (the social link, the proximity of services, the proximity of recreation places) are expected to be altered after a nuclear accident. It induces that the value given to the territory, by the persons living there, would decrease after such an event. This value loss is the intangible cost of the contaminated territory. In March 2011, a 20 km radius restriction zone was created in Fukushima. One year after the accident, a reorganization plan was proposed by the government: it consisted in the creation of three zones depending on the radiation dose observed and defined a plan for decontamination. In areas where the radiation dose was lower than 20mSv/year, intensive decontamination and early return were planned by the decision makers. Nevertheless, surveys performed in 2012 (Ref.9) show that the majority of evacuees did not want to return in their former place of living and this proportion increases with time. This discrepancy between the government's decisions and the citizen's acceptance can probably be explained by the unwillingness to come back in a territory that will never be as valuable as before (because the social link, the services and recreational amenities will never be the same as before the accident). Nowadays in Japan, some people question the legitimacy of a costly decontamination of a territory where people do not want to return, because of intangible reasons. Hence, we understand the need to take into account people's preference and will into the decision making process. For that purpose, it is necessary to translate immaterial welfare issues into a monetary equivalent which permits to make the cost accident's estimates as more accurate as possible and to give these immaterial consequences the same importance than any other consequences.

To meet the two objectives presented (evaluation of the intangible value of a territory and determination of the appropriated management of contaminated territories), we decided to adopt a multi-attributes choice-based experiment. The respondents were asked to choose between different alternatives defined by a description of the territory after a nuclear accident in terms of 1) proportion of persons who stay, 2) proportion of services which stay, 3) the fact that the nature spaces access is, or not, forbidden and 4) the duration of this degraded situation. The mixed logit model shows that, after a nuclear accident, the population mainly suffers from a ban of access to nature spaces and, to a lesser extent, to the runaway of a part of the services. The survey also asked people to state the different places or services or social links they considered as most important: it permitted to observe that the places people value the most are not necessary the one they attend the most.

In the following part, we present a review of literature related to the present article. Then, in part III, we present the discrete choice experiment construction and the survey. Part IV will focus on the results in terms of intangible value of a contaminated territory and will give examples of application of these results.

II. LITTERATURE REVIEW

II. The stated preference methods in the nuclear domain

Stated preference methods are nowadays currently used. In the domain of energy in general, several studies implement these technics to determine the citizens' willingness to pay for different energy mix.
Morita et al (Ref.14) implemented the choice experiment method to determine how several attributes (source of power generation, stability (in terms of black-out frequency), carbon dioxide emission and price of electricity) impact consumers' utility and to determine which transition scenario they would prefer. The results show that people are willing to pay for shifting to renewables but in average their WTP is not enough to finance this transition. Mukarami et al (Ref. 15) propose three-attribute (electricity price, the carbon missions, and the energy mix) choice-cards to Americans and Japanese

respondents. Results show that Americans have a high willingness to pay for emission reduction (about $0.30 per month for a 1% decrease in emissions) whereas Japanese would rather pay to avoid the nuclear energy.

In the domain of measurement of nuclear externality and consequences of an accident, Schneider et al (Ref.16) use the experiment method to analyze the relationship between the distance to a nuclear power plant and the willingness to pay to avoid two externalities of the nuclear technology: the risk of accident and the waste problem. They measure the amount of utility induced by different characteristics of the electricity production system such as the price of electricity, the size of the area exposed to hazard, the security and sustainability of waste disposal, the reliability (in terms of black-out frequency) and the financial compensation in case of a nuclear accident. The random effect probit model they implement shows that the relationship between distance and willingness to pay for an increase in insurance coverage is U-shaped: due to sorting effect, people leaving close to the NPP accept more the risk than people living at greater distance. As a consequence, people leaving close to the NPP have a lower WTP to increase the coverage whereas WTP can reach about $5per year for a 1% increase in the insurance coverage for people living 100 km away from a NPP. Distance has no effect on the willingness to pay for solving the waste problem: it is about $212 per year.

After the Fukushima accident, several studies focused on the WTP of consumers for different foodstuffs. For instance, Tajima et al (Ref. 19) use the hedonic method to analyze the price fall of vegetables produced in Fukushima, after the nuclear accident. They estimate this fall to about 10 to 38% and show that people are averse to food produced in Fukushima, even if their radioactivity is measured and below the dose threshold. Another article focusing on the way consumers perceive and trust the foodstuff produced in the affected territories is the choice experiment by Sawada et al. (Ref 20). They ask the informants to choose between several pieces of beef defined by their price, origin and contamination measurement (defined precisely (by a three-level system: “under the limit”, “under one-tenth of the limit” and “undetectable”) or not (only one level: “under the limit”)). The results show a WTP higher for food produced in a non-at-risk zone if we present the precise labelling. Here again, for Fukushima, the label doesn’t change anything since people prefer avoiding the consumption of risk zone products.

II.B Valuations of the value of territories

Many studies focused on the value of territories or ecosystems to assess the impacts of a modification of these places. Colombo (Ref.3) evaluates the welfare associated with the fauna, flora and water quality, with landscape desertification to assess the benefit of reducing soil erosion measures. Dachary-Bernard (Ref.4)) measures the welfare associated to a typical landscape in Britany to know how much the local government should spend in preventing this landscape transformation. Han et al (Ref.6)) evaluate the welfare associated to the amount of fauna, flora, forest, historical remains protected in a territory to determine the willingness to pay of a community to mitigate the environmental impacts of a dam construction (i.e. the welfare loss associated to this construction).

In the domain of the nuclear accident, some study focus on the tangible value loss of territories: Managi and Tanaka (Ref. 21) use the hedonic price method to determine the effect of the Fukushima accident on land price, isolating other effects due to the Tsunami and Earthquake. According to this study, an increase of the dose rate by 1µSv/h leads to a decrease by 3.39% of the land prices in the Fukushima and Miyagi prefectures. As a conclusion, the land would have suffered a loss of about 64.1 billions Yen (about 5 billions euros).

To our knowledge, no study intended to measure the intangible loss of a population who has to live in a radiological or chemical contaminated territory.

III.THE DISCRETE CHOICE EXPERIMENT METHOD

III.A. The method

This paper applies the discrete choice experiment method to assess the value of a radiological contaminated territory. This well-known method finds its foundation in the Lancaster’s theory (Ref.11) which considers that “the good, per

se, does not give utility to the consumer; it possesses characteristics, and these characteristics give rise to utility". The principle of the choice experiment (CE) is to create several alternatives, describing different possible forms of the good to be evaluated, characterized by different levels of each attributes. These several alternatives are then proposed by couples (or more generally by n-tuples) to the respondents who have to select the alternative they prefer. The existence of a price attribute defining the amount that the respondent has to pay to obtain such an alternative, allows observing the trade-off he makes between the monetary loss induced by a payment and the immaterial welfare gain induced by the hypothetical "consumption" of the alternative.

Since the objective of this article is not only to evaluate the total cost of contaminated territories but also to determine the willingness to pay (that is the monetary value) for each of its components (in a decision making guidance perspective), the CE method was logically preferred over another contingent valuation method (CV). Moreover, according to Schneider et al. (Ref.17), this method is particularly accurate to measure a complex intangible good in order to determine the impacts of any measure on this good.

Estimating the willingness to pay (to avoid a deterioration of the good) or the willingness to accept (an improvement of the good) is theoretically equivalent to measure the value attributed to this good. Nevertheless, in practice, it is well-known that WTA exceeds WTP (NOAA panel (Ref17)) and this result also stands for CE (Ref.5). The main problem with WTP approach in our particular case could be the unacceptance of people to be twice a victim: that is paying to avoid a contamination they suffer. Moreover, imagining living in a territory contaminated by radioactivity is not easy. Hence, the main challenge was to imagine a credible and accepted (by the respondents) setting integrating economic constraints (the use of WTP): people were asked to imagine that a nuclear accident will happen, with certainty, in five years. The respondents then had the choice to contribute (or not, in the status quo case) to a monetary fund created to mitigate the consequences of the accident after its happening. To be sure that this setting was clear and that all the relevant information was well understood, it was presented through a seven minutes animated film.

This reflection and all the choices presented in the following parts are the results of several pilot groups organized to test the survey at different steps of the project.

III.B. Selection of attributes

The second step consisted in selecting the attributes and their level, presented in table I. To select the attributes, we firstly referred to the French doctrine for the management of the post-Accidental Nuclear situation (Ref.2) which defines zoning in contaminating areas and provides the main measures to apply in these zones in case of an accident in France. These guidelines provide for the creation of a relocation perimeter from which people have to leave, a public protection area where actions are needed to reduce exposure (such as the consumption ban of foodstuffs locally produced and the limitation of the access to zones where contamination is high, like in the nature places) and a territorial surveillance zone. Based on these recommendations we selected the attributes "INTERDICTION", which is a 2 levels variable. The Fukushima experience allowed us to select the attribute "PROP_PERS" since we observe in japan that people who stay in the contaminated zones suffer the run-away of others (especially children). We also organized focus group meetings to discuss about the elements that give a value to a territory. People mentioned that the existence and proximity of urban commodities (school, public utilities, shops, cultural places, etc.) was very important. That is why the attribute "PROP_SERV" was created. Hasegawa (Ref. 7) gives support to this attribute integration, telling that the existence of social infrastructure such as clinics, shops, schools is an aspect evacuees seem to present as something essential for coming back in their former living territory. Finally, the attribute "DURATION" was introduced: it is not directly a component of the territory but the literature and the focus group discussion taught that the duration of the degraded situation plays a major role in the acceptability of the situation.

To determine the monetary attribute, a CV study was submitted to 25 persons. These persons were both experts and non-experts' population. The test panel included both experts and non-experts to choose levels that could be appropriate to any French respondent. It would permit to have appropriate levels if we would carry on this study in a French population panel in

the future. They were asked to state their WTP for different scenarios. The mean WTP for living after the nuclear accident without any change was about 220 euros per month during 5 years in the expert population. That is why the upper bound for the "PRICE" attribute was set at 200 Euros. The mean WTP for the worst improvement (with respect to the status quo) was about 53 Euros in the experts' population but only 12 euros in the non-experts' population. A lower bound of 10 seemed appropriated to reflect the preference of the general population.

TABLE I. attributes and levels description. "*" indicates that the level is the status quo one for the attribute considered.

Attribute	Description	Levels
PROP_PERS	Percentage of the population which stay after the accident	25%*/ 50%/ 75% / 100%
PROP_SERV	Percentage of services who stay after the accident	25%*/ 50% / 75% / 100%
INTERDICTION	Ban access to "green spaces"	YES* / NO
DURATION	Duration of the situation (in years)	5/ 10 / 15 / 30*
PRICE	Fund contribution to be paid per month for 5 years before the accident (in Euros), per household.	0*/ 10 / 50 / 100 / 200

III.C. Experimental design

Given the number of alternatives and level defined, there were 512 possible alternatives (4×4×2×4×4). An orthogonal main-effect array decreased this number to 128 (Louvière et al (Ref. 12)). We then created 64 choice sets, composed of two alternatives and a status quo option. They were divided into 8 different blocks of 8 choice sets so that each respondent answered to one block. To control for heterogeneity between the respondents from the different groups, a common design was also created. Thus, each respondent was randomly assigned to 16 choice sets in total.

III.D. Survey

Data were collected through 403 face-to-face interviews. The respondents were IRSN (Institute of Radioprotection and Nuclear safety) and ASN (Nuclear Safety Authority) employees and were interviewed on their working place, during their working time, between the 15th of September and the 10th of December 2015. The opinion and market research Institute (BVA) carried on the survey. IRSN provided them a list of professional telephone number of randomly selected employees (the panel was representative of the IRSN employees) they could contact to plan a meeting: this way of proceeding allowed IRSN to make sure that the personal information (such as age, position in the institute) were not given to BVA. ASN participants asked to be interviewed after an intern communication explained them the purpose of the study and asked for voluntary participants. IRSN and ASN have offices all around the French territory: it permitted to interview people living in the Paris Region but also in Provinces. Note nevertheless than the respondents living in provinces are mainly from the south east of France. The panel has been done to be representative of the institutes' population but it is necessary non-representative of the French population.

At the beginning of the interview, the respondent watched a short video presenting the objectives of the study, the attributes which define the territory and listing all the elements belonging to each of the attributes. For instance, they were told that, *a priori*, the existence of nature recreational areas gives a value to the place where they live. Then, the elements that compose this attribute category were listed (and presented with pictograms to visually help the respondent). After the viewing, informants were asked to state, for each element, whether they frequent this element in their territory and whether they expect to frequent it in 5 years. They finally had to classify all the elements composing an attribute by order of importance. This step has two main goals: 1) ensuring that people were aware of all the elements that we accounted for in the

attributes we developed, 2) analyzing more deeply the final results by knowing for which precise elements people are willing to pay a certain amount.
The second part was also introduced by a short video, presenting the setting and the choice cards principle. They were told that they had to imagine that an accident would occur in 5 years with certainty and that they had to make the hypothesis they would stay in the territory where they live. We explain them the hypothetical status quo way of life that they would achieve if they do not contribute to the "rehabilitation fund" proposed. Some examples of alternative situations which can be achieved by contributing were also given. Finally, a cheap talk warned them about the necessity to pay attention on the real amount they would accept to spend if they faced this situation in the real life.

The respondents who answered 16 times the status quo option (30 respondents, 7.4% of the panel) were then asked to state the reason for this choice. They could choose between several propositions: 1) "I'm not interested in the topic of this study", 2) "I did not understand the survey", 3) "I do not think that the described situations can happen", 4) "The amounts proposed are too high", 5) "My incomes are to low", 6)"Other (to be specified)". Respondents who selected answers 1, 2 or 3 was considered as protest respondents and was excluded from the panel (it represents 28 respondents). To the contrary, the ones who answered 4 or 5 were kept in the panel (2 respondents).
The third part was dedicated to the collection of socio-demographic questions whose results are available in table II. Note that one of the cards of the common design presented a strictly domination of the status quo alternative over one of the others. This allows to check whether people answered rationally or not. 61 persons have chosen the dominated alternative. Among them, 26 never answered the status quo: we can so suggest that these respondents wanted to show their strong aversion to this alternative. These 26 persons are not removed because their answer has maybe a sense.

Finally, after the removal of protest, incomplete (11 persons did not answer to the income related question) and inconsistent surveys, we end up with 332 complete questionnaires. Table II presents the mean values associated to each socio-demographic variable in the initial sample and in the final one. It shows that we keep the same profile of respondents.

TABLE II. Description and mean values of the socio-demographic variables for the complete and the final panel

		Final sample N=332	**Initial sample N = 403**
Variables	**Description**	**Mean**	**Mean**
Questions related to nuclear risk and consequences perception			
CONF	1 if the person are confident in the French authorities for civil protection in the contaminated territories	0,85	0,84
POSSIBLE	1 if the person think that the occurrence of a nuclear accident in the 5 next year is possible or rather possible	0,33	0,34
Questions related to the territory of living			
PREF1	1 if the person prefers living in a very urban area (up to 50,000 inhabitants)	0,23	0,23
POP1	1 if the population of the person's city is larger than 50,000 inhabitants	0,31	0,30
POP2	1 if the population of the person's city is larger than 20,000 inhabitants	0,66	0,66
PARIS	1 if the person lives in Paris	0,08	0,08
MARSEILLE	1 if the person lives in Marseille	0,02	0,01
REG_PAR	1 if the person lives in the Paris Region	0,70	0,71
DEP_DURATION	1 if the person has lived for more than 10 years in his department of residence	0,59	0,59
NB_DEP	1 is the person has lived in strictly less than 3 departments in his lifetime	0,24	0,25
FREQ_OTHER	1 if the respondent currently frequent another department (e.g. to work, make shopping of to make a sport activity)	0,64	0,65

Socio-demographic characteristics			
GENDER	1 if the person is a male	0,52	0,51
AGE	Age of the respondent	42,54	42,98
DIPLOMA	1 if the respondent has a diploma higher that Baccalaureate degree	0,96	0,95
CHILD	1 if the respondent has at least one child	0,53	0,54
INCOME4	1 if the respondent's household earns more than 2,000 euros per month	0,96	0,94
INCOME6	1 if the respondent's household earns more than 4,000 euros per month	0,68	0,67
INCOME10	1 if the respondent's household earns more than 8,000 euros per month	0,12	0,11
OWNER	1 if the person is the owner of his housing	0,70	0,72
HOUSING	1 if the person lives in a house	0,44	0,44

III.E. Econometric specification

Several econometric models can be used to estimate WTP measures: the standard multinomial logit, the mixed logit or the latent class model for instance. The first one permits to easily achieve the estimations taking into account observed heterogeneity between the respondents (thanks to the socio-demographic variables). Nevertheless, this model does not permit to take into account a potential unobserved heterogeneity in preferences. Depending on the good to be valuated, if we guess that there are no intra-personal preferences towards the different attributes, this model can be appropriate. If we guess that each individual can have a different perception on the different attributes, a mixed logit model is better. Finally, the latent class model is appropriate when we can distinguish different groups of persons having the same intra-group preferences but different inter-group preferences. In our case, as long as we estimate the value of the welfare associated to the elements of someone's territory, one can imagine that everyone has a own valuation of the good evaluated (the perception of the attractiveness of a territory is something which can be considered as really personal). We so use a Random parameter Logit (RPL) model to account for heterogeneity across respondents. We allow each attribute coefficient (except for the price attribute) to follow a normal distribution. The price parameter is considered non-random but we introduce interaction variables between the price attribute and the socio-demographic variables to take into account the observed heterogeneity associated to this variable. This model is presented in equation (1) and gives the results available in the second column of appendix 3.

$$U_{ij} = ASC_j + x_{1,ij} \times \beta_1 + x_{2,ij} \times \beta_2 + x_{3,ij} \times \beta_3 + x_{4,ij} \times \beta_4 + x_{5,ij} \times \beta_5 + x_{5,ij} \times z_{1j} \times \gamma_1 + x_{5,ij} \times z_{2i} \times \gamma_2 + \ldots + x_{5,ij} \times z_{18i} \times \gamma_{18} + \varepsilon_j + \lambda_i \quad (1)$$

With X_j, the vector of attributes levels of the alternative j and Z_i is the vector of sociodemographic characteristics of individual i. ε_j is the error term λ_i is the unobserved heterogeneity error term.

This model presents standard results: utility decreases with the price attribute, with the existence of an access ban to nature spaces of the territory and with an increase in the duration of a degraded situation. On the other hand, the higher the proportion of people and services which stay after the accident, the higher is the utility. Finally, the highly significant parameters of the variables sd.ASC, sd.INTERDICTION, sd.DURATION, sd.PROP_PERS and sd.PROP_SERV prove the existence of a significant unobserved heterogeneity and justify the use of a RPL model.
To improve this model, we introduce interaction effects between our different attributes, which is possible thanks to the experimental design chosen. The utility model can be expressed as in (2). Results are available in the first column of appendix 3.

$$U_{ij} = ASC_j + x_{1,ij} \times \beta_1 + x_{2,ij} \times \beta_2 + x_{3,ij} \times \beta_3 + x_{4,ij} \times \beta_4 + x_{5,ij} \times \beta_5 + x_{1,ij} \times x_{2,ij} \times \beta_6 + x_{1,ij} \times x_{3,ij} \times \beta_7 + x_{1,ij} \times x_{4,ij} \times \beta_8 + x_{2,ij} \times x_{3,ij} \times \beta_9 + x_{2,ij} \times x_{4,ij} \times \beta_{10} + x_{3,ij} \times x_{4,ij} \times \beta_{11} + \left[x_{5,ij} \times z_{1i} \times \gamma_1 + \ldots + x_{5,ij} \times z_{18i} \times \gamma_{18}\right] + \left[x_{1,ij} \times z_{1i} \times \sigma_1 + \ldots + x_{1,ij} \times z_{18i} \times \sigma_{18}\right] + \ldots + \left[x_{4,ij} \times z_{1i} \times \theta_1 + \ldots + x_{4,ij} \times z_{18ij} \times \theta_{18}\right] + \varepsilon_j + \lambda_i \quad (2)$$

IV.RESULTS

IV.A. Results of the statement questions

Appendix 1 presents the results of the first part of the questionnaire, asking the respondents to state about the places or persons they "frequent" now, they expect to "frequent" by five years and the elements that are the most important according to them. A first analysis brings two main insights: six elements are classified as the most important (among other elements from the same category) by more than 20% of the panel: family, nursery and schools, local shops, health facilities, parks and yards, woods and forests. The second insight, interesting in terms of management of contaminated territories, is the fact that places or social fabrics considered as the most important by the respondents are not necessary the ones which are the more "frequented". Indeed, nurseries and school are attended by less than half of the respondents; nevertheless, it is the second "most important" service according to them. Mass-merchandizers stores, bars and restaurants, culture places are frequented by more than 90% of respondents but these elements are ranked first in terms of importance by less than 10% of respondents. In terms of management of contaminated territories, these results suggest not to restore firstly the places or social fabrics that are the more currently frequented but to focus on the ones that account the most for people.

Appendix 2 presents these results for two distinct populations: the persons living in provinces and the ones living in the Paris region. As we could expect, the order of importance of the different places are different. Concerning the services, we observe that the attendance rates are rather similar in the two populations, except for the schools, nurseries and mass-merchandizing stores which are more attended by people living in provinces. These places are then logically considered as the most important by a larger proportion of persons in the province group. Concerning the nature spaces, we observe a clear preference of the Paris region inhabitants for the parks and yards and a clear preference of the persons living in province for the woods and forests whereas the rate of attendance of these places is similar in both populations.

IV.B. RPL model results

Appendix 3 presents the RPL model results. We observe that variables PROP_PERS and PROP_SERV are not significant any more themselves but their interaction effects with other variables are significant. When the duration of the degraded situation increases (DURATION), the proportion of services which stays increases utility. The utility of women, owners, people living in an apartment, people living in Paris or people who state that they trust the French authority in the field of civil protection in case of contamination is greater than others when the proportion of services increases. The estimate for the parameter INTERDICTION is negative as long as an access interdiction to nature spaces decreases people's utility and the interaction effect between INTERDICTION and DURATION is negative: it suggests that the longer the duration of the degraded situation is and the larger the disutility associated with interdiction of access to nature spaces is. Utility of males, of households who earn less than 2,000 euros a month, of people having children, of the ones who do not currently frequent another department, of people living in Marseille, of people not living in a very urbanized city (less than 50,000 inhabitants), and of people living outside the Paris region is more negatively affected by an interdiction of access than others. Females, people living in an apartment, owners, people living in Paris, suffer more than others of a decrease of services in the department.

Finally, it is worth noting that the Alternative Specific Constant (ASC) variable, which takes the value 0 when the alternative is the status quo and 1 otherwise, is significant and negative. It reflects the fact that people are reluctant to move from the status quo. It can mean that the territory under the status quo hypothesis has a nonnegative value.

IV.B.1.Marginal willingness to pay

Taking into account both the positive effect of avoiding to live a degraded situation and the negative effect of paying for avoiding that situation permits to deduce a mean marginal willingness to pay for each attribute of the territory:

$$MWT_a = -\left(\frac{\beta_{a\_adjusted}}{\beta_{price\_adjusted}} \right) \quad (3)$$

With $\beta a\_adjusted$, the marginal utility of attribute a (the first derivative of (2) with respect to the attribute a) and $\beta price\_adjusted$ the marginal utility of the price attribute.

Table III presents the marginal willingness to pay for each element of the territory: the average respondent is willing to pay 157.18 euros per month during five years to avoid a ban of access to his department territory during 5 years after the accident. This amount is equal 244.38 euros if the interdiction lasts for 30 years. Moreover, people are willing to pay 0.94 euros per month for 5 years to avoid the left of 1% of services during 5 years after the accident. This amount is equal to 2.88 euros when the situation is expected to last 30 years. The proportion of persons who stay after the accident is the attribute that people value the less since they are willing to pay only 0.87 euro per month during 5 years to avoid the left of 1% of the population of their territory. Finally, note that the value associated to the status quo is about 60 euros per month during 5 years.

TABLE III. Marginal willingness to pay for the different attributes of the territory. These values are computed from the RPL model result (Appendix 2) and from the mean values of the final panel socio-demographic variables (Table II).

Attribute		***β adjusted***	***Marginal willingness to pay***
PRICE		-0.010	
ASC		-0.632	-60.43
INTERDICTION if	DURATION= 5	-1.643	-157.18
	DURATION= 10	-1.826	-174.62
	DURATION = 15	-2.008	-192.06
	DURATION = 20	-2.191	-209.50
	DURATION = 25	-2.373	-226.94
	DURATION = 30	-2.555	-244.38
PROP_SERV if	DURATION = 5	0,010	0,94
	DURATION = 10	0,014	1,33
	DURATION = 15	0,018	1,71
	DURATION = 20	0,022	2,10
	DURATION = 25	0,026	2,49
	DURATION = 30	0,030	2,88
PROP_PERS		0,009	0,87

V. DISCUSSION AND PERSPECTIVES

It is worth noting that the results presented in this article are biased since, the sample is really different from the French population:

- The panel is richer than the French population and this could lead to overestimated willingness to pay,
- The panel is better informed in terms of nuclear issues, about countermeasures, about the consequences a nuclear accident than the French population.
- The panel is younger than the French population: it probably underestimates the value given to the social tissue attribute. Indeed, in Nahara (Fukushima) older people (over sixty) are more willing than younger people to return in zones for which evacuation order has been lifted (Takaki (ref.18)). Age seems to have a major influence on the value of the good we tend to estimate here. This is another limit to our non-representative panel which does not integrate any retired persons,
- People in the ASN and IRSN panel live essentially in the Paris region and the one living in Provinces are mainly from the Marseille region (South-east of France). It does not allow having an idea of preferences of the population across France.

One of the main perspectives of this article is to develop the same questionnaire in the French population, to get more reliable values and compare the different perceptions between experts and the civil society.

Nevertheless, it is interesting to present the potential developments and applications which could be possible thanks to such a study, carried on in a French population panel.
First of all, it could be interesting to define scenarios based on the Fukushima and/or Chernobl accidents in order to compute ex-ante potential consequences of a nuclear accident in France. Two types of applications are then possible:

- Estimating the cost of the contamination of the territory and refining the externality measure of the nuclear technology,
- Evaluating the population's willingness to pay for different intervention strategies in order to help decision makers to optimally allocate resources.

The following parts develop these steps and give some outputs based on the data of this survey, which are necessary biased.

IV.B.2.Definition of scenarios

The computation of the cost of a nuclear accident can be an ex-post evaluation (measuring the consequences of the accident to account for the total damages to people) or an ex-ante evaluation (determining the latent risk born by the society to estimate the appropriate level of prevention). In that case, and due to the uncertainty about the consequence level that such a catastrophe could have, it is useful to develop a series of scenarios that represent different possible consequences.
IRSN economic studies define and characterize for the moment two types of contaminated territories:

- The moderately contaminated territories, defined by a contamination in Cesium 137 comprised between 37 and 555 KBq/m2,
- The heavily contaminated territories, defined by a contamination in Cesium 137 larger than 555 Kbq/m2.

Using the Fukushima experience, we can look at what happened in these territories to define the scenarios to be evaluated.
In the moderately contaminated territories, it appears that about 5% of the population has left. In these zones, the access to green spaces is also restricted (people limit the time they spent in nature to limit their dose exposure).
In heavily contaminated, people have been evacuated but some zones have been then decontaminated to permit the return of populations. This is the case of Nahara (orders of evacuation lifted in 2015), a village where only 6% of the population had

returned in mars 2016 and where a survey shown that less than 10% of the population wants to return. The slopes and forests, representing more than 70% of the village surface, are not decontaminated, so that the population cannot visit these nature places. In villages were the evacuation orders were lifted in 2014 (Tamura and Kawauchi), it appears that 50% of the population had returned at the end of the year.
Based on the Fukushima experience, we present two different scenarios that could apply to the contaminated territories (moderately contaminated (2) and heavily contaminated which have been decontaminated (1)):

1. During 30 years, 50% of the population and of the services stay in the department and access to green spaces is banned. The value loss for a household in, in that case, its willingness to pay to avoid the flight of 50% of the services (144 euros), 50% of the population (43.5 euros) and the access ban to green spaces (244.38 euros) during 30 years. The total department value loss is equal to 25,913 euros per household who lives in the territory,

2. During 30 years, 95% of the population and 100% of the services stay in the department and access to green spaces is banned. The value loss for a household in, in that case, its willingness to pay to avoid the flight of 5% of the population (4.35 euros) and the access ban to green spaces (244.38 euros) during 30 years. The total department value loss is equal to 14,924 euros per household who lives in the territory.

It is worth noting that a series of other scenarios could be created, depending on the situation observed, or expected to occur after an accident.

IV.B.3.Application to the case of a nuclear accident in France

In France, IRSN estimates a DCH accident (median accident in the range of serious accidents) would imply the following median[1] consequences (in terms of the population affected):

- The heavily contaminated territories would represent 1,330 Km^2 and 56,909 people would be evacuated: they would live during 5 years in another place. After 5 years, we can make an hypothetical scenario inspired from Fukushima saying that evacuation orders could be lifted (it results in scenario 1 for the ones who want to return)
- The moderately contaminated would represent 20,130 km^2 and 1,783,242 people would live in moderately contaminated territories (scenario 2 in Fukushima for the ones who decide to stay living there)

The non-discounted total loss per square kilometer, for a scenario s, can be defined as follows:

$$TIL_s = \sum_{i=1}^{n} \frac{House_i \times V_i}{Surface_s} \qquad (4)$$

With

TIL_s, the total intangible lost value of the territory for the scenario s,
$House_i$, the number of households concerned by scenario i[2],
V_i, the value per household i associated to scenario s in the whole department,
Surface s, the surface contaminated in the scenario s.

With the present data set, which is not representative of the population, under the hypothesis that 40% of evacuation orders would be lifted and that only 50% of people would come back in a territory where only 50% of services still exist, characterized by a ban of nature spaces, the total intangible value loss per square kilometer could be estimated to about **130 million euros in heavily contaminated territories decontaminated for allowing the return.**
Under the hypothesis that, like in Fukushima, about 5% of people living in the moderately contaminated territories would

[1] Median consequences in terms of the number of persons who are affected, based on simulations considering about 400 different historical weather forecasting.
[2] Housei = population i ×mean number of persons per households (2.26 according to INSEE in 2012. Source (consulted on the 25th of March 2016) : http://www.insee.fr/fr/themes/tableau.asp?reg_id=0&ref_id=amfd1.)

leave and that people who stay suffer from ban access to nature spaces, the total intangible value loss per square kilometer could be estimated to about **11 billion euros** in moderately contaminated territories (note that this result is biased due to the biased panel).

IV.B4. Application for decision making purpose

The main interest of this type of CE could be to determine the value of each element of the territory (and not only the value of the whole territory). This gives a precious help to determine which element of the territory people value the most: it allows determining which remediation action should be the decision makers' priority.
We saw that the mean respondent values more the possibility to have access to all the nature places of its department than the proportion of services and persons who stay after the catastrophe. Nevertheless, the results (Appendix 3) have shown that depending on the respondent's profile, the utility (or disutility) given by the attributes could vary. Typically, people living in the Paris region or in Paris tend to be more attached than others to the amount of services and less attached to the nature spaces access. The analysis of the RPL model can give the exact value people concerned by the accident are willing to pay for the restoration of different aspects of the territory. This permits to determine the best strategy depending on the place where the accident occurred.

At this stage, it may be interesting to take into account the result of the first part of the survey, on the perception of the important elements of the territory since it can permit to adapt the decision to the population affected by the accident. For instance, we see in appendix 2 that in the Paris region, the services which are the most important are the local shops (28% of the respondents quoted it first by order of preference), health facilities (20.9%) and the schools and nurseries (quoted by 18% of people as the most important) whereas, outside the Paris area, the most important services is the schools and nurseries (quoted by 25% of the respondents as the most important service). Outside the Paris region, 53.4% of the respondents stated the item "Woods and forests" as the most important element of the general attribute "access to nature spaces", whereas Paris region inhabitants classify the parks and yards as the most important element in this category.

These types of results could lead to the conclusion that, if the accident occurs in the Paris region for instance, the decision maker should give priority to the services (nurseries, schools, health facilities) and decontamination of parks and yards whereas woods and forests would be the priority if the accident would occur in provinces. As long as this element is the most important, if all the living areas are decontaminated but the woods are not, the disutility of living will be such that people will want to leave these places or won't accept to return (just like in Fukushima). The main limit of such a complete decontamination is its cost. We thus understand the necessity to compare the cost of such a decontamination measure with the benefit (tangible and intangible one) it induces. Giving a monetary equivalent to intangible benefits of decontamination, this study could contribute to a cost-benefit assessment of decontamination measures.

V.CONCLUSIONS

The aims of this article were to measure the intangible value of a contaminated territory and to give advice in terms of post-accidental management of these territories and of the population living there. The choice experiment method has the main advantage of fulfilling these two objectives. Based on a hypothetical scenario inspired from Fukushima (concerning the condition of living in contaminated territories) and on the predicted number of population who would live in these conditions in France after a similar accident, our biased data estimate the lost intangible value to be about 11 billion euros in a moderately contaminated territory and about 130 million euros in heavily contaminated territories which would be decontaminated to permit the populations' return.

Most important are the learnings this kind of study offers in terms of post-accidental management. The analysis of willingness to pay for each attribute permits to show that the detriment which induces the highest loss of welfare is the access ban to green spaces, followed by the runaway of services. Nevertheless, this hierarchy depends on the socio-demographic characteristics of the respondents: typically, people living in the Paris region are less attached than others to nature places and much more attached to the existence of services. Thanks to a series of questions asking people the places they consider as important, we are able to precise the nature places or the services that really matter for the population. For instance, in this sample, people living in the Paris region give more importance to schools, local shops and health services among other services. Among the nature places, they classify parks and yards as the most important elements. In Provinces, among the nature places, forests and woods are the most important elements for the population. Due to the cost associated to the decontamination of such a territory, the systematic decontamination measures are not necessary justified. A cost-benefit assessment based on the cost and the whole benefit of such a measure could help decision maker to take decisions about the future of the contaminated territories and of the population. For that purpose, it could be interesting to develop models integrating the cost of decontamination, the intangible benefit computed in this article and the tangible benefit of decontamination.

Due to the biased sample we interviewed, our results are not reliable enough and not fully usable: the results of the same study on a panel of the French population could allow obtaining more accurate estimates of the cost of the intangible cost of contamination but also to give more precise advice for decision making purposes.

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Appendix 1: Synthesis of responses to the first part of the questionnaire

	Attendance		***Attendance in 5 years***		***Importance***	
	Number (N=332)	***%***	***Number (N=332)***	***%***	***Number (N=332)***	***%***
Social fabric						
1. Family	177	0,53	198	0,60	267	0,80
2. Friends	314	0,95	319	0,10	61	0,18
3. Colleagues	245	0,74	253	0,76	4	0,01
Services						
1. Nurseries and schools	136	0,41	149	0,45	66	0,20
2. High school and colleges	111	0,33	126	0,38	42	0,13
3. Mass-merchandizers and supermarkets	304	0,92	301	0,91	25	0,08
4. Local shops (drugstores, markets, slaughter, grocery store, bakery)	303	0,91	302	0,91	87	0,26
5. Places of worship	73	0,22	83	0,25	3	0,01
6. Bars and restaurants	282	0,85	293	0,88	7	0,02
7. Culture places (cinema, library, theatre, museums…)	275	0,83	296	0,89	18	0,05
8. Sport facilities	231	0,70	259	0,78	10	0,03
9. Health facilities(public and private hospital, general practitionners)	294	0,89	299	0,90	69	0,21
10. Sport or cultural associations	220	0,66	266	0,80	5	0,02
Outdoor / Nature spaces						
1. Parks and yards	312	0,94	321	0,97	137	0,41
2. Sport fields (football, athetism…)	194	0,58	236	0,71	29	0,09
3. Outdoor swiming-pools	148	0,45	193	0,58	7	0,02
4. Lakes	140	0,42	175	0,53	9	0,03
5. Woods and forests	263	0,79	283	0,85	138	0,42
6. Beaches	56	0,17	77	0,23	12	0,04

Appendix 2 : Synthesis of responses to the first part of the questionnaire for two populations

	Provinces						**Paris Region**					
	Attendance		***Attendance in 5 years***		***Importance***		***Attendance***		***Attendance in 5 years***		***Importance***	
	Effectif (N=100)	***%***	***Effectif (N=100)***	***%***	***Effectif (N=100)***	***%***	***Effectif (N=232)***	***%***	***Effectif (N=232)***	***%***	***Effectif (N=232)***	***%***
Social fabric												
1. Family	51	0,51	55	0,55	83	0,83	126	0,54	143	0,62	184	0,79
2. Friends	99	0,99	99	0,99	17	0,17	215	0,93	220	0,95	44	0,19
3. Colleagues	83	0,83	81	0,81	0	0	162	0,7	172	0,74	4	0,02
Services												
1. Nurseries and schools	48	0,48	38	0,38	25	0,25	88	0,38	111	0,48	41	0,18
2. High school and colleges	37	0,37	37	0,37	13	0,13	74	0,32	89	0,38	29	0,13
3. Mass-merchandizers and supermarkets	98	0,98	98	0,98	8	0,08	206	0,89	203	0,88	17	0,07
4. Local shops (drugstores, markets, slaughter, grocery store, bakery)	99	0,99	99	0,99	21	0,21	230	0,99	229	0,99	66	0,28
5. Places of worship	24	0,24	27	0,27	0	0	61	0,26	66	0,28	3	0,01
6. Bars and restaurants	98	0,98	98	0,98	1	0,01	209	0,9	220	0,95	6	0,03
7. Culture places (cinema, library, theatre, museums…)	90	0,9	99	0,99	5	0,05	209	0,9	223	0,96	13	0,06
8. Sport facilities	74	0,74	82	0,82	3	0,03	176	0,76	199	0,86	7	0,03
9. Health facilities(public and private hospital, general practitionners)	93	0,93	97	0,97	21	0,21	224	0,97	228	0,98	48	0,21
10. Sport or cultural associations	75	0,75	87	0,87	3	0,03	166	0,72	204	0,88	2	0,01
Outdoor / Nature spaces												
1. Parks and yards	85	0,85	94	0,94	16	0,16	227	0,98	227	0,98	121	0,52
2. Sport fields (football, athetism…)	61	0,61	69	0,69	14	0,14	133	0,57	167	0,72	15	0,06
3. Outdoor swiming-pools	50	0,5	62	0,62	3	0,03	98	0,42	131	0,56	4	0,02
4. Lakes	72	0,72	77	0,77	6	0,06	81	0,35	113	0,49	3	0,01
5. Woods and forests	90	0,9	91	0,91	53	0,53	198	0,85	217	0,94	85	0,37
6. Beaches	56	0,56	62	0,62	8	0,08	4	0,02	23	0,1	4	0,02

Appendix 3 : RPL model results. For simplification purposes, only the 5% level significant estimators are presented. "" stands for a 0.1% level significance, "**" stands for a 1% level significance and "*" stands for a 5% level significance.***

	RPL model with attribute interaction effects			*Simple RPL model*		
Variable	***Estimate***	***Pr(>|t|)***	***Signif***	***Estimate***	***Pr(>|t|)***	***Signif***
ASC	-0,632	0.0001312	***	0,011	0.8918606	
INTERDICTION	-3,917	8.449e-08	***	-1,585	< 2.2e-16	***
DUREE	-0,094	0.0007886	***	-0,071	< 2.2e-16	***
DUREE: INTERDICTION	-0,036	2.313e-05	***			
DUREE:PROP_SERV	0,001	1.256e-08	***			
PROP_PERS	0,004	0.6514972		0,014	< 2.2e-16	***
PROP_SERV	-0,014	0.1487669		0,005	6.731e-07	***
PRIX	-0,008	0.0240592	*	-0,005	0.0686020	.
INTERDICTION:SEXE	-0,327	0.0249028	*			
INTERDICTION:REVENUS4	2,172	1.081e-06	***			
INTERDICTION:ENF	-0,740	6.543e-07	***			
INTERDICTION:FREQ_AUTRE	0,265	0.0849269	.			
INTERDICTION:MARSEILLE	-1,559	0.0720213	.			
INTERDICTION:POP1	0,550	0.0013812	**			
INTERDICTION:POSSIBLE	0,278	0.0543776	.			
INTERDICTION:REG_PAR	0,739	0.0001074	***			
DUREE:REVENUS5	0,018	0.0366629	*			
DUREE:ENF	-0,017	0.0080269	**			
DUREE:PARIS	0,039	0.0031340	**			
DUREE:POP1	-0,023	0.0022698	**			
PROP_SERV:SEXE	-0,005	0.0183805	*			
PROP_SERV:TYPE_LOGEMENT	-0,005	0.0775671	.			
PROP_SERV:PROPRIO	0,007	0.0066943	**			
PROP_SERV:PARIS	0,011	0.0066374	**			
PROP_SERV:CONF	0,005	0.0466574	*			
PROP_PERS:REVENUS6	0,004	0.0932575	.			
PROP_PERS:MARSEILLE	0,018	0.0713378	.			
PROP_PERS:POP2	0,006	0.0182683	*			
PROP_PERS:POSSIBLE	0,007	0.0016423	**			

PRIX:AGE	0,000	0.0001007	***	0,000	1.379e-05	***
PRIX:REVENUS10	0,002	0.0828478	.	0,003	0.0173806	*
PRIX:DIPLOME	-0,008	3.559e-05	***	-0,009	5.435e-08	***
PRIX:PARIS	0,006	0.0011086	**	0,005	0.0001913	***
PRIX:POP1	-0,003	0.0027733	**	-0,002	0.0037822	**
PRIX:POSSIBLE	-0,002	0.0437195	*	-0,001	0.1735880	
PRIX:CONF	-0,003	0.0137955	*	-0,002	0.0220850	*
PRIX:ENF				0,003	6.607e-06	***
PRIX:TYPE_LOGEMENT				-0,002	0.0639305	.
PRIX:FREQ_AUTRE				-0,002	0.0024243	**
PRIX:REG_PAR				-0,004	6.322e-05	***
sd.ASC	0,049	0.8468704		-0,019	0.9379973	
sd.INTERDICTION	1,617	1.250e-12	***	1,828	< 2.2e-16	***
sd.DUREE	0,074	1.843e-14	***	0,064	5.065e-13	***
sd.PROP_PERS	0,023	5.536e-11	***	-0,009	0.0029245	**
sd.PROP_SERV	0,006	0.1127397		0,016	6.250e-08	***

Log-Likelihood	-4098.2	-4244,1
Mc fadden R^2	0,226	0,199