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(71) Demandeurs/Applicants:
NEOVACS, FR;
INSERM (INSTITUT NATIONAL DE LA SANTE ET DE
LA RECHERCHE MEDICALE), FR;
INSTITUT PASTEUR, FR
(72) Inventeurs/Inventors:
GROUARD-VOGEL, GERALDINE, FR;
CONDE GARCIA, EVA, FR;
BERTRAND, ROMAIN, FR; ...

(54) Titre : PRODUIT IMMUNOGENE COMPRENANT IL-4 ET/OU IL-13 POUR LE TRAITEMENT DE TROUBLES ASSOCIES A L'EXPRESSION OU A L'ACTIVITE ABERRANTE DE L'IL-4 ET/OU DE L'IL-13
(54) Title: IMMUNOGENIC PRODUCT COMPRISING IL-4 AND/OR IL-13 FOR TREATING DISORDERS ASSOCIATED WITH ABERRANT IL-4 AND/OR IL-13 EXPRESSION OR ACTIVITY

(57) **Abrégé/Abstract:**

The present invention relates to an immunogenic product comprising a cytokine conjugated with a carrier protein, wherein the cytokine is selected from the group comprising IL-4, IL-13 and mixtures thereof, and wherein the carrier protein is CRM197. The present invention further relates to a method for manufacturing the immunogenic product of the invention. The present invention also relates to the therapeutic use of the immunogenic product of the invention for treating an inflammatory disorder associated with aberrant IL-4 and/or IL-13 expression or activity.

(72) **Inventeurs(suite)/Inventors(continued):** CAILLOT, NOEMIE, FR; REBER, LAURENT, FR; BRUHNS, PIERRE, FR;
SERRA, VINCENT, FR

(74) **Agent:** BORDEN LADNER GERVAIS LLP

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(71) Applicants: NEOVACS [FR/FR]; 3-5 impasse Reille, 75014 Paris (FR). INSERM (INSTITUT NATIONAL DE LA SANTÉ ET DE LA RECHERCHE MÉDICALE) [FR/FR]; 101 rue de Tolbiac, 75654 Paris Cedex 13 (FR). INSTITUT PASTEUR [FR/FR]; 28 rue du Docteur Roux, 75015 Paris (FR).

(72) Inventors: GROUARD-VOGEL, Géraldine; 15 rue Sarrette, 75014 Paris (FR). CONDE GARCIA, Eva; 192 rue Raymond Losserand, 75014 Paris (FR). BERTRAND, Romain; 19 rue du Moulin Vert, 75014 Paris (FR). CAILLOT, Noémie; 93 rue Barrault, 75013 Paris (FR). REBER, Laurent; 84 rue de la Cité Moderne, 92160 Antony (FR). BRUHNS, Pierre; 3 rue Chomel, 75007 Paris (FR). SERRA, Vincent; 8 place de l'Eglise, 91070 Bondoufle (FR).

(74) Agent: ICOSA; 83 avenue Denfert-Rochereau, 75014 Paris (FR).

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(54) Title: IMMUNOGENIC PRODUCT COMPRISING IL-4 AND/OR IL-13 FOR TREATING DISORDERS ASSOCIATED WITH ABERRANT IL-4 AND/OR IL 13 EXPRESSION OR ACTIVITY

(57) Abstract: The present invention relates to an immunogenic product comprising a cytokine conjugated with a carrier protein, wherein the cytokine is selected from the group comprising IL-4, IL-13 and mixtures thereof, and wherein the carrier protein is CRM197. The present invention further relates to a method for manufacturing the immunogenic product of the invention. The present invention also relates to the therapeutic use of the immunogenic product of the invention for treating an inflammatory disorder associated with aberrant IL-4 and/or IL-13 expression or activity.



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**IMMUNOGENIC PRODUCT COMPRISING IL-4 AND/OR IL-13 FOR
TREATING DISORDERS ASSOCIATED WITH ABERRANT IL-4 AND/OR
IL-13 EXPRESSION OR ACTIVITY**

5 FIELD OF INVENTION

The present invention relates to an immunogenic product and to the use thereof for treating disorders associated with aberrant IL-4 and/or IL-13 expression or activity, in particular asthma, atopic dermatitis and allergic disorders.

10 BACKGROUND OF INVENTION

Allergic disorders are complex diseases resulting from interactions between multiple genetic and environmental factors. The increase in allergies observed in the past decades is explained mostly by environmental changes occurring in the same period. Among all allergies, allergic asthma, allergic rhinitis and food allergies are major public health
15 problems, now each affecting at least 300 million peoples worldwide. Moreover, it is estimated that half of the global population will be affected by an allergic disease by 2050. In terms of annual mortality, globally, there are almost 300,000 avoidable allergy-related deaths caused by asthma, food allergy, or anaphylaxis. Thus, the increase in allergic diseases has become an important health issue throughout the globe resulting in
20 significant socioeconomic burden and for which there is still no efficient long-term therapy.

Pathogenesis of allergic disorders results from the exposure of the immune system to allergens. Such exposures are considered to be responsible of a breakdown of tolerance, resulting in type 2 immune responses characterized by the production of T helper cell
25 type 2 (Th2) cytokines such as interleukin 4 (IL-4) and interleukin 13 (IL-13), high levels of immunoglobulin E (IgE) antibodies, and infiltration and expansion of immune cells within the inflamed tissue. Mast cells, basophils, and eosinophils are especially involved in the release of cytoplasmic granules containing preformed inflammatory mediators such as histamine. Upon exposure to an allergen, such allergen is recognized by IgE and bound

to receptors on mast cell basophil and eosinophil surfaces, which promotes the degranulation of these cells and therefore the appearance of clinical symptoms. Of note, for these reasons, clinical diagnoses of allergies are largely based on measurements of allergen-specific IgE.

5 Interestingly, IL-4 and IL-13 cytokines play key roles in the pathogenesis of allergic disorders. Both cytokines have long been associated with the pathogenesis of allergic disorders and are therapeutically important cytokines based on their biological functions. These two cytokines present similar structure, and share one receptor subunit (IL-4R α). However, despite their many similarities, IL-4 and IL-13 are also thought to play some
10 non-redundant functions in allergy.

IL-4 is a pleiotropic cytokine that is involved in the development of allergy (Gour N. & Wills-Karp M., 2015), as increased IL-4 levels have been observed in serum and in bronchoalveolar lavage of asthmatic patients. IL-4 is considered to specifically act in the early phase of allergy development. The crucial role of IL-4 lies in its multiple effects
15 which drive to allergy such as induction of IgE production, up-regulation of IgE receptor expression and differentiation of naïve T helper cell type 0 (Th0) into Th2 lymphocytes.

Type 2 immune cells play a pivotal role in allergy process by controlling humoral immunity and B cell switch in antibody response to IgE class. Thus, Th2 cells are mediators of Ig production (*e.g.*, IgE, IgG) and produce various cytokine as well as IL-4
20 and IL-13.

In contrast, IL-13 is more involved in effector and late phases of allergic reactions (Gour N. & Wills-Karp M., 2015). It has been shown that IL-13 is sufficient to induce the main manifestations of allergic diseases including, without limitation, airways hyperresponsiveness, mucus production, airway smooth muscle alterations and sub-
25 epithelial fibrosis.

Given the range of cells involved in asthma on which IL-4 and IL-13 are known to act, and the pathogenic functions associated with these interleukins, neutralization of one or both cytokines is a credible approach to the treatment of allergic inflammatory disorders. Therefore, as IL-4 and IL-13 are promising therapeutic targets for the treatment of

allergies, there is a clear need to improve current strategies to block these molecules, in order to reach long-term therapeutic effects.

Recently, novel therapies have been developed to treat allergies. These treatments, based on passive immunization, specifically target pathogenic factors involved in allergy. For example, the use of recombinant antibodies directed to IL-4 and IL-13 or their receptors was described in the art. However, use of recombinant antibodies is limited by high cost, the need to perform repeated injections, and potential risks of appearance of anti-drug antibodies (ADAs) or other adverse reactions.

The Applicant herein provide a novel immunogenic product, based on the combination of a cytokine selected from IL-4 and IL-13 with CRM₁₉₇. This novel immunogenic product is of particular interest for treating inflammatory disorders, such as, in particular asthma, atopic dermatitis and allergic disorders.

SUMMARY

The present invention relates to an immunogenic product comprising at least one cytokine conjugated with a carrier protein, wherein the at least one cytokine is selected from the group comprising IL-4, IL-13 and mixtures thereof, and wherein the carrier protein is CRM₁₉₇.

In one embodiment, the at least one cytokine is IL-4.

In one embodiment, wherein the at least one cytokine is IL-13.

In one embodiment, the immunogenic product of the invention comprises CRM₁₉₇ coupled with both IL-4 and IL-13.

The present invention further relates to a composition comprising at least one immunogenic product as described hereinabove.

In one embodiment, the composition comprises a mixture of at least two immunogenic products as described hereinabove.

In one embodiment, the composition comprises a mixture of an immunogenic product comprising IL-4 and CRM₁₉₇ with an immunogenic product comprising IL-13 and CRM₁₉₇.

In one embodiment, the composition comprises a mixture of an immunogenic product
5 comprising IL-4 and CRM₁₉₇ with an immunogenic product comprising IL-13 and CRM₁₉₇ at a weight ratio ranging from about 10:1 to about 1:10.

In one embodiment, the composition further comprises at least one pharmaceutically acceptable excipient and/or at least one adjuvant.

In one embodiment, the composition is an emulsion.

10 The present invention further relates to a method for producing an immunogenic product as described herein, the method comprising steps of:

- a) contacting the at least one cytokine with a heterobifunctional crosslinker containing a NHS-ester, preferably N-[γ -maleimidobutyryloxy]-succinimide ester (sGMBS);
- 15 b) contacting the carrier protein with a heterobifunctional crosslinker containing a NHS-ester, preferably N-succinimidyl-S-acetylthioacetate (SATA) to generate a carrier-SATA complex;
- c) contacting the sGMBS-cytokine complex obtained at step (a) with the carrier SATA complex obtained at step (b).

20 The present invention further relates to an immunogenic product as described herein or a composition as described herein, for treating an inflammatory disorder.

In one embodiment, the inflammatory disorder is a disorder associated with aberrant IL-4 and/or IL-13 expression or activity.

In one embodiment, the inflammatory disorder is selected from the group comprising
25 asthma (either allergic or non-allergic), allergic conditions (such as, for example, food allergies, venom allergy, allergy to animals, drug allergy, hyper IgE syndrome, allergic rhinitis, allergic conjunctivitis and allergic enterogastritis), atopic disorders (such as, for example, atopic dermatitis, urticaria (including chronic idiopathic urticaria and chronic

spontaneous urticaria), eczema), bullous pemphigoid, respiratory disorders (such as allergic and nonallergic asthma, chronic obstructive pulmonary disease (COPD)), nasal polyposis and other conditions involving airway inflammation (such as, for example, eosinophilia, fibrosis and excess mucus production including cystic fibrosis and pulmonary fibrosis, systemic sclerosis (SSc)); inflammatory and/or autoimmune disorders or conditions, gastrointestinal disorders or conditions (such as, for example, inflammatory bowel diseases (IBD) and eosinophilic esophagitis (EE), and eosinophilic-mediated gastrointestinal disease, ulcerative colitis and Crohn's disease); systemic lupus erythematosus, liver disorders or conditions (such as, for example, cirrhosis, and hepatocellular carcinoma), scleroderma; fibrotic diseases or disorders (such as, for example, fibrosis of the liver (such as, for example, fibrosis caused by a hepatitis B and/or C virus)), scleroderma; solid tumors or cancers such as leukemia (such as, for example, B cell chronic lymphocytic leukaemia), glioblastoma, lymphoma (such as, for example, Hodgkin's lymphoma) and mastocytosis.

15 In one embodiment, the inflammatory disorder is selected from the group comprising asthma (e.g., allergic asthma), atopic dermatitis, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, food allergy, nasal polyposis and eosinophilic esophagitis.

In one embodiment, the inflammatory disorder is selected from the group comprising asthma (e.g., allergic asthma), atopic dermatitis, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis and food allergy.

In one embodiment, the inflammatory disorder is allergy, asthma, or atopic dermatitis.

In one embodiment, the immunogenic product or composition as described herein induces desensitization of an allergic subject toward an allergen.

The present invention further relates to an immunogenic product or to a composition as described herein, for inducing desensitization of a subject allergic to a specific antigen, wherein said immunogenic product or composition and said specific antigen are to be administered to the allergic subject.

The present invention further relates to a method for inducing desensitization of a subject allergic to a specific antigen, wherein said method comprises administering to the subject an immunogenic product or composition as described herein and said specific antigen.

5 The present invention also further relates to a method for increasing the efficacy and/or for decreasing the duration of a desensitization of a subject allergic to a specific allergen, wherein said subject is administered with an immunogenic product or composition as described herein and is further treated by desensitization.

DEFINITIONS

10 In the present invention, the following terms have the following meanings:

- As used herein, the term “**about**” when referring to a measurable value such as an amount, a temporal duration, and the like, is meant to encompass variations of $\pm 20\%$ or in some instances $\pm 10\%$, or in some instances $\pm 5\%$, or in some instances $\pm 1\%$, or in some instances $\pm 0.1\%$ from the specified value, as such variations are appropriate to perform the disclosed methods.
15
- As used herein, an “**adjuvant**” is a substance that enhances the immunogenicity of an immunogenic product of this invention. Adjuvants are often given to boost the immune response and are well known to the skilled artisan.
- As used herein, the term “**carrier protein molecule**” refers to a protein or a peptide
20 of at least 15, 30 or 50 amino acids long which, when it is partially covalently associated to at least one cytokine selected from IL-4; IL-13 and mixtures thereof for forming heterocomplexes, allows for a large number of antigens of said at least one cytokine to be presented to the B lymphocytes.
- As used herein, the term “**immune response**” refers to the action, for example of
25 lymphocytes, antigen presenting cells, phagocytic cells and macromolecules produced by the above cells or the liver (including antibodies, cytokines and complement).

- As used herein, the term “**immunogenic product**” refers to at least one cytokine coupled to a carrier protein that induces an immune response in a subject, preferably a mammal, to whom said immunogenic product is administered, including a humoral immune response, *i.e.*, the production of antibodies that neutralize the properties, such as, for example, the biological activity of the endogenous cytokine.
5
- As used herein, an antibody that “**inhibits the biological activity**” or “**neutralizes the biological activity**” of at least one cytokine selected from IL-4, IL-13 or mixtures thereof is intended to refer to an antibody that inhibits the activity of that cytokine by at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, or 80% or more, as compared to the
10 level of activity of the cytokine in the absence of the antibody, for example by using a functional assay such as those described in the Examples.
- As used herein, the term “**pharmaceutically acceptable excipient**” refers to an excipient that does not produce an adverse, allergic or other untoward reaction when administered to a mammal, preferably a human. It includes any and all solvents,
15 dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents and the like. A pharmaceutically acceptable carrier or excipient refers to a non-toxic solid, semi-solid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type. For human administration, preparations should meet sterility, pyrogenicity, general safety and purity standards as required by
20 the regulatory offices such as the FDA or EMA.
- As used herein, the term “**recombinant protein**” refers to a protein (*e.g.*, a cytokine or a carrier protein CRM₁₉₇) which is generated using recombinant DNA technology, such as, for example, a protein (*e.g.*, a cytokine or a carrier protein CRM₁₉₇) expressed in prokaryote cells (using a bacteriophage or a plasmid expression system) or in
25 eukaryotic cells (such as for example yeast, insect or mammalian expression system). This term should also be construed to mean a protein (*e.g.*, a cytokine or a carrier protein CRM₁₉₇) which has been generated by the synthesis of a DNA molecule encoding the protein (*e.g.*, the cytokine or a carrier protein CRM₁₉₇) and which DNA molecule expresses a protein (*e.g.*, a cytokine or a carrier protein CRM₁₉₇), or an
30 amino acid sequence specifying the protein (*e.g.*, the cytokine or a carrier protein CRM₁₉₇), wherein the DNA or amino acid sequence has been obtained using

recombinant DNA or amino acid sequence technology which is available and well known in the art.

- As used herein, the term “**subject**” is intended to include living organisms in which an immune response can be elicited (*e.g.*, mammals, in particular human, primates, dogs, cats, horses, sheep and the like). Preferably, the subject is a human. In one embodiment, a subject may be a “patient”, *i.e.* a warm-blooded animal, preferably a human, who/which is awaiting the receipt of, or is receiving medical care or was/is/will be the object of a medical procedure or is monitored for the development of the targeted disease or condition, such as, for example, an inflammatory disorder. In one embodiment, the subject is an adult (for example a subject above the age of 18). In another embodiment, the subject is a child (for example a subject below the age of 18). In one embodiment, the subject is a male. In another embodiment, the subject is a female. In one embodiment, the subject is affected, preferably is diagnosed, with an inflammatory disorder. In one embodiment, the subject is at risk of developing an inflammatory disorder. Examples of risks factor include, but are not limited to, genetic predisposition, or familial history of inflammatory disorders.
- As used herein, the terms “**therapeutically effective amount**” refer to an amount of the immunogenic product as described herein, effective to achieve a particular biological result. Thus, the terms “therapeutically effective amount” mean a level or amount of immunogenic product that is aimed at, without causing significant negative or adverse side effects to the target, (1) delaying or preventing the onset of the targeted disease or condition; (2) slowing down or stopping the progression, aggravation, or deterioration of one or more symptoms of the targeted disease or condition; (3) bringing about ameliorations of the symptoms of the targeted disease or condition; (4) reducing the severity or incidence of the targeted disease or condition; or (5) curing the targeted disease or condition. A therapeutically effective amount may be administered prior to the onset of the targeted disease or condition, for a prophylactic or preventive action. Alternatively, or additionally, the therapeutically effective amount may be administered after initiation of the targeted disease or condition, for a therapeutic action.

- As used herein, the term “**treatment**” or “**treating**” refers to both therapeutic treatment and prophylactic or preventative measures; wherein the object is to prevent or slow down (lessen) the targeted disease or condition. Those in need of treatment include those already with the condition as well as those prone to have the condition or those in whom the condition is to be prevented. A subject is successfully “treated” for a disease or condition if, after receiving a therapeutic amount of an immunogenic product as described herein, the subject shows observable and/or measurable improvement in one or more of the following: reduction in the number of pathogenic cells; reduction in the percent of total cells that are pathogenic; relief to some extent of one or more of the symptoms associated with the specific condition; reduced morbidity and mortality, and/or improvement in quality of life issues. The above parameters for assessing successful treatment and improvement in the condition are readily measurable by routine procedures familiar to a physician.

15 DETAILED DESCRIPTION

The present invention relates to an immunogenic product comprising at least one cytokine conjugated with a carrier protein, wherein the at least one cytokine is selected from the group comprising IL-4, IL-13 and mixtures thereof, and wherein the carrier protein is CRM₁₉₇.

- 20 The Inventors herein demonstrated that an immunogenic product of the invention presents advantages as compared to the same immunogenic product comprising KLH instead of CRM₁₉₇, in particular in terms of immunogenicity.

CRM₁₉₇ is a non-toxic mutant of diphtheria toxin having the sequence SEQ ID NO: 1, without toxic activity due to a single base substitution (mutation from glycine to glutamate in position 52).

SEQ ID NO: 1

GADDVVDSSKSFVMENFSSYHGKPGYVDSIQKGIQKPKSGTQGNYYYYDDWKE
FYSTDNKKYDAAGYSVDNENPLSGKAGGVVKVTYPGLTKVLALKVDNAETIKK

ELGLSLTEPLMEQVGTEEFIKRFGDGASRVVLSLPFAEGSSSVEYINNWEQAKA
 LSVELEINFETRGRGQDAMYEYMAQACAGNRVRRSVGSSLSCINLDWDVIRD
 KTKTKIESLKEHGPIKNKMSESPNKTVSEEKAKQYLEEFHQTALEHPELSELKTV
 TGTNPVFAGANYAAWAVNVAQVIDSETADNLEKTTAALSILPGIGSVMGIADG
 5 AVHHNTEEIQAQSIALLSSLMVAQAIPLVGELVDIGFAAYNFVESIINLFQVVHNS
 YNRPAYSPGHKTQPFLHDGYAVSWNTVEDSIIRTGFQGESGHDIKITAENTPLPI
 AGVLLPTIPGKLDVNKSKTHISVNGRKRMRMCRAGDVTFCRPKSPVYVGNV
 HANLHVAFHRSSEKIHSNEISSDSIGVLGYQKTV DHTKVNSKLSLFFFEIKS

In one embodiment, CRM₁₉₇ may be obtained by conventional methods known in the art
 10 in autologous (*C. diphtheriae*) or heterologous systems (*E. coli* and *P. fluorescens*) as
 described by Hickey in 2018 (Hickey *et al.* 2018). For example, recombinant CRM₁₉₇
 may be obtained by culturing cells containing an expression vector comprising the gene
 of CRM₁₉₇, harvesting inclusion bodies and purifying CRM₁₉₇. CRM₁₉₇ could also be
 extracted from culture of *Corynebacterium diphtheriae* from bacteria strain purchased at
 15 ATCC (ATCC39255). In one embodiment, CRM₁₉₇ is commercially available, and may
 be purchased, for example, from Reagent Proteins (San Diego, CA, US).

In one embodiment, the immunogenic product of the invention comprises a variant of
 CRM₁₉₇, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more
 identity with SEQ ID NO: 1. In one embodiment, said variant of CRM₁₉₇ comprises the
 20 mutation from glycine to glutamate in position 52 and is thus non-toxic.

The term “identity” or “identical”, when used in a relationship between the sequences of
 two or more nucleic acid sequences or of two or more polypeptides, refers to the degree
 of sequence relatedness between nucleic acid sequences or polypeptides, as determined
 by the number of matches between strings of two or more nucleic or amino acid residues,
 25 respectively. “Identity” measures the percent of identical matches between the smaller of
 two or more sequences with gap alignments (if any) addressed by a particular
 mathematical model or computer program (i.e., “algorithms”). Identity of related nucleic
 acid sequences or polypeptides can be readily calculated by known methods. Such
 methods include, but are not limited to, those described in Computational Molecular
 30 Biology, Lesk, A. M., ed., Oxford University Press, New York, 1988; Biocomputing:

Informatics and Genome Projects, Smith, D. W., ed., Academic Press, New York, 1993; Computer Analysis of Sequence Data, Part 1, Griffin, A. M., and Griffin, H. G., eds., Humana Press, New Jersey, 1994; Sequence Analysis in Molecular Biology, von Heinje, G., Academic Press, 1987; Sequence Analysis Primer, Gribskov, M. and Devereux, J., eds., M. Stockton Press, New York, 1991; and Carillo et al., SIAM J. Applied Math. 48, 1073 (1988). Preferred methods for determining identity are designed to give the largest match between the sequences tested. Methods of determining identity are described in publicly available computer programs. Preferred computer program methods for determining identity between two sequences include ClustalO (Sievers F., et al 2011),
10 the GCG program package, including, GAP (Devereux et al., Nucl. Acid. Res. \2, 387 (1984); Genetics Computer Group, University of Wisconsin, Madison, Wis.), BLASTP, BLASTN, and FASTA (Altschul et al., J. Mol. Biol. 215, 403-410 (1990)). The BLASTX program is publicly available from the National Center for Biotechnology Information (NCBI) and other sources (BLAST Manual, Altschul et al. NCB/NLM/NIH
15 Bethesda, Md. 20894; Altschul et al., supra). The well-known Smith Waterman algorithm may also be used to determine identity.

In one embodiment, CRM₁₉₇ is full-length CRM₁₉₇.

In one embodiment, the immunogenic product of the invention comprises a fragment of CRM₁₉₇, such as, for example, a fragment comprising at least about 50, 100, 150, 200,
20 250, 300, 350, 400, 450, or 500 amino acids (preferably contiguous amino acids) from SEQ ID NO: 1.

In one embodiment, the at least one cytokine is IL-4.

In one embodiment, IL-4 is recombinant. Recombinant IL-4 may be obtained by conventional methods known in the art using the nucleic sequence encoding IL-4. For
25 example, recombinant IL-4 may be obtained by culturing cells containing an expression vector comprising the gene of IL-4, harvesting inclusion bodies and purifying the IL-4 cytokine. Recombinant IL-4 is commercially available and may be purchased, for example, from PeproTech (Rocky Hill, NJ, US).

In one embodiment of the present invention, IL-4 is derived from a mammal.

In one embodiment, IL-4 is a variant of a mammal IL-4, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with the mammal IL-4 from which it derives.

- 5 In one embodiment, IL-4 is full-length IL-4.

In another embodiment, the at least one cytokine is a fragment of IL-4, such as, for example, a fragment of IL-4 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120 or 125 amino acids (preferably contiguous amino acids) of the IL-4 from which it derives.

- 10 In one embodiment, said fragment comprises at least one specific epitope of IL-4.

In one embodiment of the present invention, IL-4 is human IL-4, preferably recombinant human IL-4. Human IL-4 has a sequence SEQ ID NO: 2 (UniProt ID: P05112-1).

SEQ ID NO: 2

- 15 HKCDITLQEIHKTLNSLTEQKTLCTELTVTDIFAASKNTTEKETFCRAATVLRQFY
SHHEKDTRCLGATAQQFHRHKQLIRFLKRLDRNLWGLAGLNSCPVKEANQSTL
ENFLERLKTIMREKYSKCSS

In one embodiment, IL-4 is a variant of SEQ ID NO: 2, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with SEQ ID NO: 2.

In one embodiment, IL-4 is full-length human IL-4.

- 20 In another embodiment, the at least one cytokine is a fragment of human IL-4, such as, for example, a fragment of human IL-4 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120 or 125 amino acids (preferably contiguous amino acids) of SEQ ID NO: 2.

In one embodiment, said fragment comprises at least one specific epitope of human IL-4.

In one embodiment, said fragment comprises or consists in the following sequence:
AQQFHRHKQLIRFLKRLDRNLW (SEQ ID NO: 3).

In one embodiment of the present invention, IL-4 is murine IL-4, preferably recombinant murine IL-4. Murine IL-4 has a sequence SEQ ID NO: 4 (UniProt ID: P07750-1).

5 SEQ ID NO: 4

HHGCDKNHLREIIGILNEVTGEGTPCTEMDVPNVLTATKNTTESELVCRASKVL
RIFYLKHGKTPCLKKNSSVLMELQRLFRAFRCLDSSISCTMNESKSTSLKDFLES
LKSIMQMDYS

In one embodiment, IL-4 is a variant of SEQ ID NO: 4, wherein said variant presents at
10 least about 70%, 75, 80, 85, 90, 95% or more identity with SEQ ID NO: 4.

In one embodiment, IL-4 is full-length murine IL-4.

In another embodiment, the at least one cytokine is a fragment of murine IL-4, such as,
for example, a fragment of murine IL-4 comprising at least about 50, 55, 60, 65, 70, 75,
80, 85, 90, 95, 100, 105, 110, or 115 amino acids (preferably contiguous amino acids) of
15 SEQ ID NO: 4.

In one embodiment, said fragment comprises at least one specific epitope of murine IL-4.

In one embodiment of the present invention, IL-4 is canine IL-4, preferably recombinant canine IL-4. Canine IL-4 has a sequence SEQ ID NO: 5 (UniProt ID: O77762-1).

SEQ ID NO: 5

20 HNFNITIKEIHKMLNILTARNDSCMELTVKDVFTAPKNTSDKEIFCRAATVLRQIY
THNCSNRYLRGLYRNLSMANKTCSMNEIKKSTLKDFLERLKVIMQKKYYRH

In one embodiment, IL-4 is a variant of SEQ ID NO: 5, wherein said variant present at
least about 70%, 75, 80, 85, 90, 95% or more identity with SEQ ID NO: 5.

In one embodiment, IL-4 is full-length canine IL-4.

In another embodiment, the at least one cytokine is a fragment of canine IL-4, such as, for example, a fragment of canine IL-4 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, or 105 amino acids (preferably contiguous amino acids) of SEQ ID NO: 5.

5 In one embodiment, said fragment comprises at least one specific epitope of canine IL-4.

In one embodiment, the immunogenic product of the invention comprises IL-4 coupled to CRM₁₉₇ at a molar ratio IL-4:CRM₁₉₇ ranging from about 16:1 to about 1:2, preferably from about 8:1 to about 2:1, more preferably of about 4:1.

10 In one embodiment, the immunogenic product of the invention comprises IL-4 coupled to CRM₁₉₇ and is recognized by anti-IL-4 antibodies.

The fact that the immunogenic product comprises IL-4 coupled to CRM₁₉₇ and is recognized by anti-IL-4 antibodies may be verified by conventional methods known in the art. An example of such methods is a sandwich ELISA anti-cytokine/carrier protein, using for example a detection antibody labelled with biotin, streptavidin HRP
15 amplification system and an o-phenylenediamine dihydrochloride (OPD) substrate solution.

In one embodiment, the **TEST A^{IL-4}** described herein may be used for verifying that the immunogenic product of the invention comprises IL-4 coupled to CRM₁₉₇ and is recognized by anti-IL-4 antibodies. **TEST A^{IL-4}** is an ELISA test anti-IL-4/CRM₁₉₇.

20 **TEST A^{IL-4}** is carried out as follows:

- Coating a plate with a capture antibody directed to CRM₁₉₇, such as, for example anti-diphtheriae toxin antibodies from Abcam (AB53828) or Bio-Rad (3710-0956, 3710-0150 or 3710-0100),
- Blocking the plate with a blocking buffer (such as, for example, casein 2% (w/v) in
25 PBS for example) during about 90 min at about 37°C,

- Incubating during about 90 min at about 37°C the plate with a two-fold-serial dilution of the immunogenic product starting at 250 ng/mL or with negative controls such as, for example, IL-4 and CRM₁₉₇,
- Incubating during about 90 min at about 37°C the plate with a biotinylated detection antibody directed to IL-4, such as, for example anti-IL-4 biotinylated antibodies from Abcam (AB84278), R&D systems (BAF204) or PeproTech (500-P24BT) or murine anti-IL-4 biotinylated antibodies from Southern Biotech (10204-08), R&D systems (BAF404) or PeproTech (500-P54BT),
- Incubating the plate with streptavidin-HRP during about 30 min at about 37°C and developing the complex with an OPD substrate solution during about 30 min,
- After stopping the enzymatic reaction, the intensity of the resulting color is determined by spectrophotometric methods at 490 nm.

In one embodiment, when the optical density of wells containing the immunogenic product of the invention at about 25 ng per well is at least about 3-fold, preferably at least about 5-fold, and more preferably at least about 10-fold the optical density of wells containing a negative control, the person skilled in the art may conclude that the immunogenic product of the invention (i) is recognized by anti-IL-4 antibodies and (ii) comprises IL-4 coupled to CRM₁₉₇.

In one embodiment, the immunogenic product of the invention comprises IL-4 coupled to CRM₁₉₇, and is strongly inactivated, which means that the immunogenic product shows less than about 10% of IL-4 initial activity, preferably less than about 5% and preferably less than about 1% of IL-4 initial activity in the condition of hereunder cited **TEST B^{IL-4}**. **TEST B^{IL-4}** is a colorimetric T cell proliferation assay or a reporter gene bioassay, using a cell line expressing an IL-4R α that may be functionally activated by the IL-4 comprised in the immunogenic product of the invention (*i.e.*, which may bind the IL-4 comprised in the immunogenic product of the invention, and be activated following this binding).

In one embodiment, the immunogenic product of the invention comprises murine IL-4, and **TEST B^{IL-4}** is a colorimetric T cell proliferation assay carried out using CTLL-2 cells

(from ECACC cell lines, provided by Sigma-Aldrich, reference 93042610-1VL) in the following method:

- CTLL-2 cells are grown in presence of IL-2 at 10 ng/mL final with RPMI supplemented with 2 mM glutamine, 1 mM sodium pyruvate, 1 mM HEPES,
5 100 U/mL penicillin, 100 µg/mL streptomycin (completed RMPI or RPMIc), and 10 % (v/v) FBS,
- The immunogenic product of the invention (IL-4/CRM₁₉₇) and muIL-4 control are two-fold serially diluted in RPMIc + 10 % (v/v) FBS in 96-well plates beginning at 1000 ng/mL until 4 ng/mL final for the immunogenic product and 10 ng/mL until
10 0.04 ng/mL final for muIL-4,
- As a positive control, six wells with muIL-4 at 10 ng/mL were added and used as the maximum cell proliferation control,
- These samples are added to 20,000 CTLL-2 cells per well and plates are incubated for about 48 h at about 37°C, 5 % CO₂ in a humidified incubator,
- 15 - At the end of the culture, cell viability is assessed using methods well-known in the art. One example of such methods is the following: 40 µL/well of a solution of MTS/PMS (Promega, Madison, Wi, US) (wherein MTS stands form 3-(4,5-dimethylthiazol-2-yl)-5-(3-carboxymethoxyphenyl)-2-(4-sulfophenyl)-2H-tetrazolium, inner salt; and PMS stands for phenazine methosulfate) are added to the
20 wells and the plate is incubated for another 4h at 37°C 5% CO₂, according to the manufacturer instruction. The plate is then read at 490 nm on a spectrophotometer.

In another embodiment, the immunogenic product of the invention comprises human IL-4, and **TEST B^{IL-4}** is a reporter gene assay carried out using a HEK-Blue™ IL-4/IL-13 cell line purchased from InvivoGen (San Diego, CA, US). In these cells, stimulation with
25 IL-4 or IL-13 activates the JAK/STAT6 pathway with the subsequent production of SEAP. IL-4 biological activity comprised in the immunogenic product of the invention can then be evaluated by assessing SEAP levels in the supernatant.

According to this embodiment, **TEST B^{IL-4}** comprises the following steps:

- HEK-Blue™ IL-4/IL-13 cells are cultured in an assay medium composed of DMEM GlutaMAX™ supplemented with 10 % (v/v) FBS, 10 mM HEPES, 50 U/mL penicillin and 50 µg/mL streptomycin,
- Immunogenic product (IL-4/CRM₁₉₇) and IL-4 control are two-fold serially diluted in
5 assay medium at 8000 and 1 ng/mL final, respectively.
- These dilution samples are then transferred to pre-seeded plates containing 40,000 cells per well HEK-Blue™ IL-4/IL-13 cells. Plates are incubated for about 24 h about 37°C, in a 5% CO₂ humidified incubator.
- At the end of the culture, activation pathway is assessed using methods well-known
10 in the art. One example of such methods is the following: 90 µL/well of QUANTI-Blue™ solution (purchased from InvivoGen) are added to 10 µL/well of cell supernatant. Then, the plate is incubated for about 1 h at about 37°C, in a 5% CO₂ humidified incubator. The plate is then read at 625 nm on a spectrophotometer.

The effective dose 50 (ED₅₀) value corresponds to the amount of immunogenic product
15 or cytokine resulting in 50 % of maximum cell signal. This value is determined by interpolating the 50 % of maximum cell signal onto the abscissa axis using the $y = ax + b$ formula from the curve passing by the dilution points surrounding the 50 % inflexion point.

In **TEST B^{IL-4}**, the inactivation factor is calculated by dividing the ED₅₀ of the tested
20 immunogenic product by the mean ED₅₀ of the IL-4 control standard curves. A result with an inactivation factor > 100 means that for the same amount of protein, the IL-4 activity in the immunogenic product corresponds to less than 1% of native IL-4 activity. In one embodiment, an inactivation factor superior to about 2, 2.5, 3.33, 5 or 10, preferably to about 20, more preferably to about 100, indicates that the immunogenic product is
25 strongly inactivated. In one embodiment, a residual activity inferior to about 50%, 40%, 30%, 20% or 10%, preferably inferior to about 5%, and more preferably inferior to about 1% of native IL-4 activity indicates that the immunogenic product is strongly inactivated.

In one embodiment, the immunogenic product of the invention comprises IL-4 coupled to CRM₁₉₇, and is immunogenic, which means that the immunogenic product is capable

of inducing anti-IL-4 antibodies *in vivo* in the conditions of **TEST C^{IL-4}**. In one embodiment, the immunogenic product of the invention is capable of inducing polyclonal anti-IL-4 antibodies *in vivo*, such as, for example, in the conditions of **TEST C^{IL-4}**.

TEST C^{IL-4} is carried out according to the following method:

- 5 Specific amounts of total proteins (as determined, for example, by a Bradford protein assay) of the immunogenic product are injected in mice (older than 3 weeks of age), three to four times in 120 days. In one embodiment, **TEST C^{IL-4}** is a heterologous system for example an immunogenic product comprising a non-murine IL-4 is injected in a mouse, and the test comprises administering a dose of total proteins ranging from about 0.3 to
- 10 30 µg. In another embodiment, **TEST C^{IL-4}** is a homologous system, *i.e.*, an immunogenic product comprising a murine IL-4 is injected in a mouse, and the test comprises administering a dose of total proteins ranging from about 5 to about 30 µg. Serum samples are obtained before immunization (pre-immune serum sample) and between day 39 and day 120 (test serum sample). ELISA anti-IL-4 are carried out as
- 15 explained below.

Briefly, a 96 wells plate is coated with 1 µg/mL of IL-4 used for preparing the immunogenic product and incubated overnight at a temperature ranging from about 2°C to about 8°C. The plate is then blocked with a blocking buffer during about 90 min at about 37°C. 100 µL of pre-immune sample and serum samples (pre-immune and test) are

20 added to the wells at two-fold-serial dilution, such as, for example, starting at 500 dil⁻¹ until 256,000 dil⁻¹. An anti-mouse immunoglobulin labeled secondary antibody (such as, for example, an HRP conjugated antibody) is finally added to the wells and the ELISA is developed using any colorimetric means known in the art such as, for example, an OPD substrate solution.

- 25 In one embodiment, when the optical density of wells (490 nm) containing the test serum sample is at least about 1.5-fold, preferably at least about 2-fold superior to the optical density of wells containing the pre-immune serum sample, the immunogenic product is considered as immunogenic, which means that it has induced anti-IL-4 antibodies *in vivo*.

In this test, the titers were defined as the dilution of the serum where 50% of the OD_{max} minus OD of corresponding preimmune sample in the assay is reached. This mode of calculation is much more stringent than looking at the well-known seroconversion titers but provides more robust analysis and less false positive. Titers were expressed as serum dilution factors (dil⁻¹).

In another embodiment, in TEST C^{IL-4}, a titer value ≥ 250 dil⁻¹, preferably ≥ 500 dil⁻¹ indicates that the immunogenic product of the invention allows the production of binding antibodies against IL-4.

In one embodiment, the immunogenic product of the invention comprises IL-4 coupled to CRM₁₉₇ and is capable of neutralizing IL-4 activity in condition of hereunder cited TEST D^{IL-4}. According to the invention, TEST D^{IL-4} is performed to evaluate the neutralizing capacity of the serum obtained from mice immunized with the immunogenic product. Such evaluation may be assessed by a colorimetric T cell proliferation assay for the murine product or a reporter gene bioassay for the human product, using HEK-Blue™ IL-4/IL-13 cells. In these cells, stimulation with IL-4 or IL-13 activates the JAK/STAT6 pathway with the subsequent production of SEAP. Neutralizing antibodies anti-IL-4 induced by immunization with the immunogenic products can then be evaluated by assessing SEAP levels in the supernatant.

In one embodiment, the immunogenic product of the invention comprises murine IL-4, and TEST D^{IL-4} is a colorimetric T cell proliferation assay carried out using CTLL-2 cells in the following method:

- CTLL-2 cells are grown in presence of IL-2 at 10 ng/mL final with RPMIc and 10 % (v/v) FBS,
- Serum samples are added at 1/200 final and positive control polyclonal anti-IL-4 antibody at 1 µg/mL final and 2-fold serially diluted in 25 µL per well RPMIc + 10 % (v/v) FBS in culture plates.
- muIL-4 is then added at 2 ng/mL final to serum samples and control are then incubated for 1 hour at room temperature.

- Then, 20,000 CTLL-2 cells per well are added to pre-incubated samples. Plates are then incubated for about 48 h at about 37°C, 5 % CO₂ in a humidified incubator.
- At the end of the culture, cell viability is assessed using methods well- known in the art. One example of such methods is the following: 40 µL/well of a solution of MTS/PMS are added to the wells and the plate is incubated for another 4h at 37°C 5% CO₂. The plate is then read at 490 nm on a spectrophotometer.

In another embodiment, the immunogenic product of the invention comprises human IL-4, and **TEST D^{IL-4}** is a reporter gene bioassay carried out using HEK-Blue™ IL-4/IL-13 cells and comprises the following steps:

- HEK-Blue™ IL-4/IL-13 cells are plated in an assay medium composed of DMEM GlutaMAX™ supplemented with 10 % (v/v) FBS, 10 mM HEPES, 50 U/mL penicillin and 50 µg/mL streptomycin.
 - Serum samples, control antibody (polyclonal goat anti-IL-4 antibody) were diluted in assay medium at 1/200 and 1 µg/mL final, respectively. Serum samples or control antibody were two-fold serially diluted in a 96 round-bottomed well plates in the presence of 0.25 ng/mL final of IL-4 for one hour incubation at room temperature.
 - These mixes were then added to pre-seeded plates containing 40,000 HEK-Blue™ IL-4/IL-13 cells per well. Plates were incubated for about 24 h at about 37°C, in a 5% CO₂ humidified incubator.
 - At the end of the culture, activation pathway is assessed using methods well-known in the art. One example of such methods is the following: 90 µL/well of QUANTI-Blue™ solution are added to 10 µL/well of cell supernatant. Then, plates are incubated for 1 h at 37 °C, in a 5 % CO₂ humidified incubator. Plates are then read at 625 nm on a spectrophotometer.
- NC₅₀ results were expressed as the serum dilution factor (dil⁻¹) neutralizing 50 % of muIL-4 or IL-4 activity. The NC₅₀ is determined by interpolating the serum dilution resulting in a 50 % of IL-4 activity on the abscissa axis.

In **TEST D^{IL-4}**, a NC₅₀ value ≥ 100 dil⁻¹, preferably ≥ 200 dil⁻¹ indicates that the immunogenic product of the invention allows the production of neutralizing antibodies

against IL-4. In one embodiment, the neutralizing antibodies against IL-4 induced by the administration of the immunogenic product of the invention are polyclonal.

In one embodiment, the at least one cytokine is IL-13.

In one embodiment, IL-13 is recombinant. Recombinant IL-13 may be obtained by
5 conventional methods known in the art using the nucleic sequence encoding IL-13. For example, recombinant IL-13 may be obtained by culturing cells containing an expression vector comprising the gene of IL-13, harvesting inclusion bodies and purifying the IL-13 cytokine. Recombinant IL-13 is commercially available and may be purchased, for example, from PeproTech (Rocky Hill, NJ, US).

10 In one embodiment of the present invention, IL-13 is derived from a mammal.

In one embodiment, IL-13 is a variant of a mammal IL-13, wherein said variant present at least about 70%, 75, 80, 85, 90, 95% or more identity with the mammal IL-13 from which it derives.

In one embodiment, IL-13 is full-length IL-13.

15 In another embodiment, the at least one cytokine is a fragment of IL-13, such as, for example, a fragment of IL-13 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, or 120 amino acids (preferably contiguous amino acids) of the IL-13 from which it derives.

In one embodiment, said fragment comprises at least one specific epitope of IL-13.

20 In one embodiment of the present invention, IL-13 is human IL-13, preferably recombinant human IL-13. Human IL-13 has a sequence SEQ ID NO: 6 (UniProt ID: P35225-1).

SEQ ID NO: 6

LTCLGGFASPGPVPPSTALRELIEELVNITQNQKAPLCNGSMVWSINLTAGMYC
25 AALES LINVSGCSAIEKTQRMLSGFCPHKVSAGQFSSLHVRDTKIEVAQFVKDL
LLHLKKLFRGRFN

In one embodiment, IL-13 is a variant of SEQ ID NO: 6, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with SEQ ID NO: 6.

In one embodiment, IL-13 is full-length human IL-13.

In another embodiment, the at least one cytokine is a fragment of human IL-13, such as,
5 for example, a fragment of human IL-13 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, or 120 amino acids (preferably contiguous amino acids) of SEQ ID NO: 6.

In one embodiment, said fragment comprises at least one specific epitope of human IL-13.

10 In one embodiment of the present invention, IL-13 is murine IL-13, preferably recombinant murine IL-13. Murine IL-13 has a sequence SEQ ID NO: 7 (UniProt ID: P20109-1).

SEQ ID NO: 7

PVPRSVSLPLTLKELIEELSNITQDQTPLCNGSMVWSVDLAAGGFCVALDSLNI
15 SNCNAIYRTQRILHGLCNRKAPTTVSSLPDTKIEVAHFITKLLSYTKQLFRHGPF

In one embodiment, IL-13 is a variant of SEQ ID NO: 7, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with SEQ ID NO: 7.

In one embodiment, IL-13 is full-length murine IL-13.

In another embodiment, the at least one cytokine is a fragment of murine IL-13, such as,
20 for example, a fragment of murine IL-13 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, or 105 amino acids (preferably contiguous amino acids) of SEQ ID NO: 7.

In one embodiment, said fragment comprises at least one specific epitope of murine IL-13.

In one embodiment of the present invention, IL-13 is canine IL-13, preferably recombinant canine IL-13. Canine IL-13 has a sequence SEQ ID NO: 8 (UniProt ID: Q9N0W9-1).

SEQ ID NO: 8

5 SPSPVTPSPTLKEELVNITQNQASLCNGSMVWSVNLTAGMYCAALES LINVS
DCSAIQRTQRMLKALCSQKPAAGQISSERSRDTKIEVIQLVKNLLTYVRGVYRH
GNFR

In one embodiment, IL-13 is a variant of SEQ ID NO: 8, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with SEQ ID NO: 8.

10 In one embodiment, IL-13 is full-length canine IL-13.

In another embodiment, the at least one cytokine is a fragment of canine IL-13, such as, for example, a fragment of canine IL-13 comprising at least about 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105 or 110 amino acids (preferably contiguous amino acids) of SEQ ID NO: 8.

15 In one embodiment, said fragment comprises at least one specific epitope of canine IL-13.

In one embodiment, the immunogenic product of the invention comprises IL-13 coupled to CRM₁₉₇ at a molar ratio IL13:CRM₁₉₇ ranging from about 16:1 to about 1:2, preferably from about 8:1 to about 2:1, more preferably of about 4:1.

20 In one embodiment of the invention, the immunogenic product comprises IL-13 coupled to CRM₁₉₇ and is recognized by anti-IL-13 antibodies.

The fact that the immunogenic product comprises IL-13 coupled to CRM₁₉₇ and is recognized by anti-IL-13 antibodies may be verified by conventional methods known in the art. An example of such methods is a sandwich ELISA anti-cytokine/carrier protein, using for example a detection antibody labelled with biotin, a streptavidin HRP
25 amplification system and/or an OPD substrate solution.

In one embodiment, the **TEST A^{IL-13}** described herein may be used for verifying that the immunogenic product of the invention comprises IL-13 coupled to CRM₁₉₇ and is recognized by anti-IL-13 antibodies. **TEST A^{IL-13}** is an ELISA test anti-IL-13/CRM₁₉₇.

TEST A^{IL-13} is carried out as follows:

- 5 - Coating a plate with a capture antibody directed to CRM₁₉₇, such as, for example anti-diphtheriae toxin antibodies from Abcam (AB53828) or Bio-Rad (3710-0956, 3710-0150 or 3710-0100),
- Blocking the plate with a blocking buffer (such as, for example, casein 2% (w/v) in PBS for example) during about 90 min at about 37°C,
- 10 - Incubating during about 90 min at about 37°C the plate with a two-fold-serial dilution of the immunogenic product starting at 250 ng/mL or with negative controls such as, for example, IL-13 and CRM₁₉₇,
- Incubating during about 90 min at about 37°C the plate with a biotinylated detection antibody directed to IL-13, such as, for example anti-IL-13 biotinylated antibodies
- 15 from SouthernBiotech (10126-08), PeproTech (500-P13BT) or R&D systems (BAF213), or murine anti-IL-13 biotinylated antibodies from Bio-Rad (AAM34B), PeproTech (500-P178BT) or R&D systems (BAF413),
- Incubating the plate with streptavidin-HRP during about 30 min at about 37°C and developing the complex with an OPD substrate solution during about 30 min,
- 20 - After stopping the enzymatic reaction, the intensity of the resulting color is determined by spectrophotometric methods at 490 nm.

In one embodiment, when the optical density of wells containing the immunogenic product of the invention at 25 ng per well is at least about 3-fold, preferably at least about 5-fold, and more preferably at least about 10-fold the optical density of wells containing

25 a negative control, the person skilled in the art may conclude that the immunogenic product of the invention (i) is recognized by anti-IL-13 antibodies and (ii) comprises IL-13 coupled to CRM₁₉₇.

In another embodiment, the immunogenic product of the invention comprises IL-13 coupled to CRM₁₉₇, and is strongly inactivated, which means that the immunogenic

product shows less than about 15% of residual activity in condition of hereunder cited **TEST B^{IL-13}**, preferably less than about 10% of residual activity, and more preferably less than about 5% of residual activity. **TEST B^{IL-13}** is a reporter gene bioassay using HEK-BlueTM IL-4/IL-13 cells. In these cells, stimulation with IL-4 or IL-13 activates the JAK/STAT6 pathway with the subsequent production of SEAP. IL-13 biological activity comprised in the immunogenic product of the invention can then be evaluated by assessing SEAP levels in the supernatant.

In one embodiment, **TEST B^{IL-13}** uses a HEK-BlueTM IL-4/IL-13 cell line purchased from InvivoGen. In presence of IL-13 murine or human, the STAT6 pathway of HEK-BlueTM IL-4/IL-13 cell line is activated and produces SEAP which can be quantified using methods well-known in the art.

TEST B^{IL-13} comprises the following steps:

- HEK-BlueTM IL-4/IL-13 cells are plated in an assay medium composed of DMEM GlutaMAXTM supplemented with 10 % (v/v) FBS, 10 mM HEPES, 50 U/mL penicillin and 50 µg/mL streptomycin,
- Human immunogenic product (IL-13/CRM₁₉₇) and IL-13 control are two-fold serially diluted in assay medium at 8000 and 10 ng/mL final, respectively.
- Murine immunogenic product (muIL-13/CRM₁₉₇) and muIL-13 control are two-fold serially diluted in assay medium at 250 and 10 ng/mL final, respectively.
- The samples are then transferred to pre-seeded plates containing 40,000 of HEK-BlueTM IL-4/IL-13 cells per well. Plates are incubated for about 24 h about 37°C, in a 5% CO₂ humidified incubator.
- At the end of the culture, activation pathway is assessed using methods well-known in the art. One example of such methods is the following: 90 µL/well of QUANTI-BlueTM solution (purchased from InvivoGen) are added to 10 µL/well of cell supernatant. Then, plates are incubated for about 1 h at about 37°C, in a 5% CO₂ humidified incubator. Plates are then read at 625 nm on a spectrophotometer.

The effective dose 50 (ED₅₀) value, corresponding to the amount of the immunogenic product (or IL-13) resulting in 50% of maximum signal recorded for the considered samples, is determined by interpolating the OD_{max}/2 values to the corresponding sample

concentrations using a four parameter logistic (4PL) nonlinear regression from the whole dilution points.

In **TEST B^{IL-13}**, the inactivation factor is calculated by dividing the ED₅₀ of the tested immunogenic product of the invention by the corresponding ED₅₀ of the IL-13 control standard curves. A result with an inactivation factor > 20 means that for the same amount of protein, the IL-13 activity in the immunogenic product correspond to less than 5% of native IL-13 activity. In one embodiment, an inactivation factor superior to about 2, 2.5, 3.33, 5 or 10, preferably to about 20, indicates that the immunogenic product is strongly inactivated. In one embodiment, a residual activity inferior to about 50%, 40%, 30%, 20% or 10%, preferably inferior to about 5% of native IL-13 activity indicates that the immunogenic product is strongly inactivated.

In one embodiment, the immunogenic product of the invention comprises IL-13 coupled to CRM₁₉₇, and is immunogenic, which means that the immunogenic product is capable of inducing antibodies anti-IL-13 *in vivo* in the conditions of **TEST C^{IL-13}**. In one embodiment, the immunogenic product of the invention is capable of inducing polyclonal anti-IL-13 antibodies *in vivo*, such as, for example, in the conditions of **TEST C^{IL-13}**.

TEST C^{IL-13} is carried out according to the following method:

Specific amounts of total proteins (as determined, for example, by a Bradford protein assay) of the immunogenic product is injected in mice (older than 3 week of age), at least three times in 120 day. In one embodiment, **TEST C^{IL-13}** is a heterologous system for example an immunogenic product comprising a non-murine IL-13 is injected in a mouse, and the test comprises administering a dose of total proteins ranging from about 0.3 to 10 µg. In another embodiment, **TEST C^{IL-13}** is a homologous system for example an immunogenic product comprising a murine IL-13 is injected in a mouse, and the test comprises administering a dose of total proteins ranging from about 5 to about 30 µg. Serum samples are obtained before immunization (pre-immune serum sample) and between day 39 and day 120 (test serum sample). ELISA anti-IL-13 are carried out as explained below.

Briefly, a 96-well plate is coated with 1 $\mu\text{g/mL}$ of IL-13 used for preparing the immunogenic product and incubated overnight at a temperature ranging from about 2°C to about 8°C. The plate is then blocked with a blocking buffer during about 90 min at about 37°C. 100 μL of pre-immune sample and serum samples (pre-immune and test) are
5 added to the wells at two-fold-serial dilution, such as, for example, starting at 500 dil^{-1} until 256,000 dil^{-1} . An anti-mouse immunoglobulin labeled secondary antibody (such as an HRP conjugated antibody) is finally added to the wells and the ELISA is developed using any colorimetric means known in the art, such as, for example, OPD substrate solution.

10 In one embodiment, when optical density of wells containing the test serum sample is at least about 1.5-fold, preferably at least about 2-fold superior to the optical density of wells containing the pre-immune serum sample, the immunogenic product is considered as immunogenic, which means that it has induced anti-IL-13 antibodies *in vivo*.

In this test, the titers were defined as the dilution of the serum where 50% of the ODmax
15 minus OD of corresponding pre-immune sample in the assay is reached. This mode of calculation is much more stringent than looking at the well-known seroconversion titers but provides more robust analysis and less false positive. Titers were expressed as serum dilution factors (dil^{-1}).

In another embodiment, in TEST C^{IL-13}, a titer value $\geq 250 \text{ dil}^{-1}$, preferably $\geq 500 \text{ dil}^{-1}$
20 indicates that the immunogenic product of the invention allows the production of binding antibodies against IL-13.

In one embodiment, the immunogenic product of the invention comprises IL-13 coupled to CRM₁₉₇ and is capable of neutralizing IL-13 activity in condition of hereunder cited
25 **TEST D^{IL-13}**. According to the invention, **TEST D^{IL-13}** is performed to evaluate the neutralizing capacity of the serum obtained from mice immunized with the immunogenic product using the reporter cell line HEK-Blue™ IL-4/IL-13. In these cells, stimulation with IL-4 or IL-13 activates the JAK/STAT6 pathway with the subsequent production of SEAP. Neutralizing antibodies anti-IL-13 induced by immunization with the

immunogenic products can then be evaluated by assessing SEAP levels in the supernatant.

TEST D^{IL-13} is carried out using HEK-BlueTM IL-4/IL-13 cells in the following method:

In presence of bioactive IL-13, the STAT6 pathway of HEK-BlueTM IL-4/IL-13 cell line is activated and produces SEAP which can be quantified using methods well-known in the art. This assay is carried to the following method:

- HEK-BlueTM IL-4/IL-13 cells are cultured in an assay medium composed of DMEM GlutaMAXTM supplemented with 10 % (v/v) FBS, 10 mM HEPES, 50 U/mL penicillin and 50 µg/mL streptomycin.
- 10 - Serum samples obtained following human immunogenic product administration and control antibody (polyclonal goat anti-IL-13 antibody such as, for example, AF-213-NA) were diluted in assay medium at 1/100 and 4 µg/mL final respectively and added to 2 ng/mL of IL-13.
- Serum samples obtained following murine immunogenic product administration and control antibody (polyclonal goat anti-muIL-13 antibody such as AF-413-NA) were
15 diluted in assay medium at 1/100 and 1 µg/mL final respectively and added to 2 ng/mL of muIL-13.
- These mixes were then incubated 1 h at room temperature before being added to 40,000 HEK-BlueTM IL 4/IL-13 cells per well. Plates were incubated for about 24 h
20 at about 37°C, in a 5% CO₂ humidified incubator.
- At the end of the culture, activation pathway is assessed using methods well-known in the art. One example of such methods is the following: 90 µL/well of QUANTI-BlueTM solution are added to 10 µL/well of cell supernatant. Then, plates are incubated for 1 h at 37 °C, in a 5 % CO₂ humidified incubator. Plates are then read at
25 625 nm on a spectrophotometer.

NC₅₀ results were expressed as the serum dilution factor (dil⁻¹) neutralizing 50 % of muIL-13 or IL-13 activity. The NC₅₀ is determined by interpolating the serum dilution resulting in a 50 % of IL-13 activity on the abscissa axis.

In **TEST D^{IL-13}**, a NC_{50} value ≥ 50 , preferably a NC_{50} value ≥ 100 dil⁻¹ indicates that the immunogenic product of the invention allows the production of neutralizing antibodies against IL-13. In one embodiment, the neutralizing antibodies against IL-13 induced by the administration of the immunogenic product of the invention are polyclonal.

5 In one embodiment, the immunogenic product of the invention comprises IL-4 and IL-13.

In one embodiment, IL-4, IL-13 or both are recombinant.

In one embodiment, IL-4 and IL-13 both originate from the same mammal. In one embodiment, IL-4, IL-13 or both are human.

10 In one embodiment, IL-4 is a variant of human IL-4, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with human IL-4. In one embodiment, IL-13 is a variant of human IL-13, wherein said variant presents at least about 70%, 75, 80, 85, 90, 95% or more identity with human IL-13.

In one embodiment, IL-4, IL-13 or both are full-length.

15 In one embodiment, IL-4 is a fragment of full-length IL-4. In one embodiment, IL-13 is a fragment of full-length IL-13.

In one embodiment, the immunogenic product of the invention comprises IL-4 and IL-13, both coupled to CRM₁₉₇.

20 In one embodiment, the molar ratio cytokines (*i.e.*, IL-4 and IL-13):CRM₁₉₇ ranges from about 16:1 to about 1:2, preferably from about 8:1 to about 2:1, more preferably of about 4:1.

In one embodiment, the molar ratio IL-4:CRM₁₉₇ ranges from about 8:1 to about 1:2, preferably from about 4:1 to about 1:1, more preferably of about 2:1.

In one embodiment, the molar ratio IL-13:CRM₁₉₇ ranges from about 8:1 to about 1:2, preferably from about 4:1 to about 1:1, more preferably of about 2:1.

In one embodiment, the molar ratio IL-4:IL-13 ranges from about 5:1 to about 1:5, preferably from about 2:1 to about 1:2, more preferably of about 1:1.

In one embodiment, the immunogenic product of the invention comprises IL-4 and IL-13 coupled to CRM₁₉₇ and is recognized by anti-IL-4 and anti-IL-13 antibodies.

- 5 The fact that the immunogenic product comprises IL-4 and IL-13 coupled to CRM₁₉₇ and is recognized by anti-IL-4 and anti-IL-13 antibodies may be verified by conventional methods known in the art. An example of such methods is a sandwich ELISA anti-cytokine/carrier protein, using for example a detection antibody labelled with biotin, a streptavidin HRP amplification system and/or an OPD substrate solution.
- 10 In one embodiment, the recognition of the immunogenic product by anti-IL-4 and anti-IL-13 antibodies may be verified using the TESTS A (**TEST A^{IL-4}** and **TEST A^{IL-13}**) described herein.

- In one embodiment, the immunogenic product of the invention comprises IL-4 and IL-13 coupled to CRM₁₉₇ and is strongly inactivated, which means that the immunogenic
15 product shows less than about 10% of IL-4 initial activity, preferably less than about 5% and preferably less than about 1% of IL-4 initial activity and less than about 15% of IL-13 initial activity, preferably less than about 10% and preferably less than about 5% of IL-13 initial activity in condition of hereunder cited TESTS B (**TEST B^{IL-4}** and **TEST B^{IL-13}**).

- 20 In one embodiment, the immunogenic product comprises IL-4 and IL-13 coupled to CRM₁₉₇ and is immunogenic, which means that the immunogenic product is capable of (i) inducing anti-IL-4 antibodies *in vivo* in the conditions of **TEST C^{IL-4}** and (i) inducing anti-IL-13 antibodies *in vivo* in the conditions of **TEST C^{IL-13}**. In one embodiment, the immunogenic product of the invention is capable of inducing polyclonal anti-IL-4
25 antibodies *in vivo*, such as, for example, in the conditions of **TEST C^{IL-4}** and anti-IL-13 antibodies *in vivo*, such as, for example, in the conditions of **TEST C^{IL-13}**.

In one embodiment, the immunogenic product of the invention comprises IL-4 and IL-13 coupled to CRM₁₉₇ and is capable of (i) neutralizing IL-4 activity in condition of herein cited **TEST D^{IL-4}** and (ii) neutralizing IL-13 activity in condition of hereunder cited **TEST D^{IL-13}**. In one embodiment, the neutralizing antibodies against IL-4 and IL-13 induced by the administration of the immunogenic product of the invention are polyclonal.

The present invention further relates to a method for producing an immunogenic product comprising at least one cytokine selected from IL-4, IL-13 and mixtures thereof, coupled with a carrier protein, preferably CRM₁₉₇, wherein the method comprises the following steps:

- a) contacting the at least one cytokine with a heterobifunctional crosslinker containing a NHS-ester, preferably N-[γ -maleimidobutyryloxy]-succinimide ester (sGMBS);
- b) contacting the carrier protein with a heterobifunctional crosslinker containing a NHS-ester, preferably N-succinimidyl-S-acetylthioacetate (SATA) to generate a carrier-SATA complex;
- c) contacting the sGMBS-cytokine complex obtained at step (a) with the carrier SATA complex obtained at step (b).

In one embodiment, in step a), the reaction buffer is in a liquid, preferably aqueous, solution.

In one embodiment, in step a), the reaction buffer is at a pH ranging from about 6 to about 8, preferably ranging from about 6.5 to about 7.5, more preferably at about pH 7.2.

In one embodiment, in step a), the cytokine is present in solution at a concentration ranging from about 0.1 to about 10 mg/mL, preferably from about 0.5 to about 5 mg/mL, more preferably of about 1 mg/mL.

In one embodiment, in step a), the heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, is prepared in reaction buffer at a concentration ranging from 1 mM to 100 mM, preferably from 5 mM to 50 mM and more preferably at 10 mM.

In one embodiment, in step a), IL-4 and the heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, are mixed at a IL-4:heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, molar ratio ranging from about 1:120 to about 1:1, preferably from about 1:50 to about 1:10.

- 5 In one embodiment, in step a), IL-13 and the heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, are mixed at a IL-13:heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, molar ratio ranging from about 1:120 to about 1:1, preferably from about 1:50 to about 1:10,

- 10 In one embodiment, in step a), the at least one cytokine is incubated with the heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, for a period ranging from about 30 min to about 120 min, preferably from about 45 to about 90 minutes and more preferably during at least 60 minutes.

- 15 In one embodiment, in step a), the contacting step of the at least one cytokine with the heterobifunctional crosslinker containing a NHS-ester, preferably sGMBS, is performed at a temperature ranging from about 15°C to about 35°C, preferably from about 18°C to about 27°C.

- 20 In one embodiment, following step a), small compounds having a molecular weight of less than about 10 kDa, less than about 5 kDa or less than about 3 kDa that are present in the reaction mixture are removed. These small compounds encompass mainly the excess of the heterobifunctional crosslinker containing a NHS-ester (and NHS-ester hydrolysis-related side-products), preferably sGMBS, and the excess molecules that have not reacted. Such removing may be performed by methods well known in the art.

In one embodiment, at the end of step a), the protein content is determined by Bradford assay or by any method well known in the art.

- 25 In one embodiment, in step b), the reaction buffer is in a liquid, preferably aqueous, solution.

In one embodiment, in step b), the reaction buffer is at a pH ranging from about 6 to about 8, preferably ranging from about 6.5 to about 7.5, more preferably at about pH 7.2.

In one embodiment, in step b), CRM₁₉₇ is present in solution at a concentration ranging from about 0.2 to about 20 mg/mL, preferably from about 1 to about 10 mg/ml, more
5 preferably of about 2 mg/mL.

In one embodiment, in step b), the heterobifunctional crosslinker containing a NHS-ester, preferably SATA, is present in solution, preferably in DMSO, at a concentration ranging from 20 mM to about 500 mM, preferably from about 50 mM to about 200 mM and more preferably at a concentration of about 100 mM.

10 In one embodiment, in step b), CRM₁₉₇ and the heterobifunctional crosslinker containing a NHS-ester, preferably SATA, are mixed at a carrier:heterobifunctional crosslinker containing a NHS-ester, preferably SATA, molar ratio ranging from about 1:320 to about 1:10.

In one embodiment, in step b), CRM₁₉₇ is incubated with the heterobifunctional
15 crosslinker containing a NHS-ester, preferably SATA, for a period of time ranging from about 10 min to about 60 min, preferably from about 15 minutes to about 45 minutes and more preferably during 30 minutes.

In one embodiment, the contacting step b) is performed at a temperature ranging from about 15°C to about 35°C, preferably from about 18°C to about 27°C.

20 In one embodiment, following step b), small compounds having a molecular weight of less than about 10 kDa, less than about 5 kDa or less than about 3 kDa that are present in the reaction mixture are removed. These small compounds encompass mainly the excess of the heterobifunctional crosslinker containing a NHS-ester (and NHS-ester hydrolysis-related side-products), preferably SATA, DMSO, and the excess molecules that have not
25 reacted. Such removing may be performed by methods well known in the art.

In one embodiment, after step b), the complexes between CRM₁₉₇ and the heterobifunctional crosslinker containing a NHS-ester, preferably SATA, are deprotected to convert the protecting group (the heterobifunctional crosslinker containing a NHS-

ester, preferably SATA) into a functional group. In one embodiment, said deprotecting step is carried out after a step of removing small compounds having a molecular weight of less than about 10 kDa, less than about 5 kDa or less than about 3 kDa that are present in the reaction mixture

- 5 Examples of method for deprotecting a molecule are well known in the art and include, without limitation, the use of hydroxylamine, the use of methoxylamine, or the use of a base (such as, for example, NaOH, KOH, K₂CO₃, MeONa, NH₃ in methanol).

In one embodiment, the deprotecting step comprises the addition to the reaction mixture of a hydroxylamine solution, preferably at a final concentration ranging from about
10 10 mM to about 500 mM, preferably from about 20 mM to about 100 mM, more preferably at about 50 mM.

In one embodiment, the hydroxylamine solution is incubated with the reaction mixture for a period of time ranging from about 60 min to about 180 min, preferably from about 90 minutes to about 150 minutes, and more preferably during 120 minutes.

- 15 In one embodiment, the hydroxylamine solution is added at 50 mM during 120 minutes.

In one embodiment, the incubation of the hydroxylamine solution with the reaction mixture is performed at a temperature ranging from about 15°C to about 35°C, preferably from about 18°C to about 27°C.

In one embodiment, following the deprotection step, small compounds having a
20 molecular weight of less than about 10 kDa, 5 kDa or 3 kDa that are present in the reaction mixture are removed. These small compounds encompass mainly the excess of hydroxylamine and potential residual SATA from the previous step. Such removing may be performed by methods well known in the art.

In one embodiment, at the end of step b), the protein content is determined by Bradford
25 assay or by any method well known in the art.

Then, in step c) of the method of the invention, the final product of step a) is contacted with the final product of step b), thereby producing the immunogenic product of the invention.

In one embodiment, in step c), the final product of step a) comprising IL-4 and the final
5 product of step b) comprising CRM₁₉₇ are contacted at a molar ratio IL-4:CRM₁₉₇ ranging from about 16:1 to about 1:2, preferably from about 8:1 to about 2:1, more preferably of about 4:1.

In one embodiment, in step c), the final product of step a) comprising IL-13 and the final
10 product of step b) comprising CRM₁₉₇ are contacted at a ratio IL-13:CRM₁₉₇ ranging from about 16:1 to about 1:2, preferably from about 8:1 to about 2:1, more preferably of about 4:1.

In another embodiment of step c), a final product of step a) comprising IL-4, a final
product of step a) comprising IL-13 and a final product of step b) are contacted. In one
embodiment, said contacting step is carried out at a molar ratio cytokines (*i.e.*, IL-4 and
15 IL-13):CRM₁₉₇ ranging from about 16:1 to about 1:2, preferably from about 8:1 to about 2:1, more preferably of about 4:1. In one embodiment, said contacting step is carried out at a molar ratio IL-4:CRM₁₉₇ ranging from about 8:1 to about 1:2, preferably from about 4:1 to about 1:1, more preferably of about 2:1. In one embodiment, said contacting step is carried out at a molar ratio IL-13:CRM₁₉₇ ranging from about 8:1 to about 1:2,
20 preferably from about 4:1 to about 1:1, more preferably of about 2:1. In one embodiment, said contacting step is carried out at a molar ratio IL-4:IL-13 ranging from about 5:1 to about 1:5, preferably from about 2:1 to about 1:2, more preferably of about 1:1.

In one embodiment, in step c), the reaction buffer is in a liquid, preferably aqueous, solution.

25 In one embodiment, in step c), the reaction buffer is at a pH ranging from about 6 to about 8, preferably ranging from about 6.5 to about 7.5, more preferably at about pH 7.2.

In one embodiment of step c), the contacting step is carried out for a period of time ranging from about 2 hours to about 26 hours, preferably from about 10 to 18 hours, more preferably from about 12 to about 18 hours.

5 In one embodiment, the incubation step c) is carried out at a temperature ranging from about 2°C to 10°C, preferably from about 3°C to about 7°C, and more preferably at about 4°C.

In one embodiment, following step c), small compounds having a molecular weight of less than about 100 kDa, less than about 50 kDa, less than about 25 kDa, less than about 10 kDa, less than about 5 kDa or less than about 3 kDa that are present in the reaction
10 mixture are removed. These small compounds encompass mainly the excess molecules that have not reacted. Such removing may be performed by methods well known in the art.

In one embodiment, the immunogenic product obtained at step c) is concentrated. The concentration of the immunogenic product may be performed by the skilled artisan by
15 any technique known in the art, such as, for example, by a centrifugal ultrafiltration method that may optionally be combined with sterile filtration.

In one embodiment, the immunogenic product obtained at step c) and optionally concentrated is lyophilized.

The present invention further relates to an immunogenic product susceptible to be
20 obtained by the method of the present invention.

The present invention further relates to a composition comprising, consisting essentially of or consisting of at least one immunogenic product as described hereinabove. In one embodiment, said composition may be referred to as an immunogenic composition.

The present invention further relates to a pharmaceutical composition comprising,
25 consisting essentially of or consisting of at least one immunogenic product as described hereinabove, and at least one pharmaceutically acceptable excipient.

Pharmaceutically acceptable excipients that may be used in the pharmaceutical composition of the invention include, but are not limited to, ion exchangers, alumina, aluminum stearate, lecithin, serum proteins, such as, for example, human serum albumin, buffer substances such as, for example, phosphates, glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts or electrolytes, such as, for example, protamine sulfate, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances (for example sodium carboxymethylcellulose), polyethylene glycol, polyacrylates, waxes, polyethylene-polyoxypropylene- block polymers, polyethylene glycol and wool fat.

The present invention further relates to a medicament comprising, consisting essentially of or consisting of at least one immunogenic product as described hereinabove.

As used herein, the term “consisting essentially of”, with reference to a composition, pharmaceutical composition or medicament, means that the at least one immunogenic product of the invention is the only one therapeutic agent or agent with a biologic activity within said composition, pharmaceutical composition or medicament.

In one embodiment, the composition, pharmaceutical composition or medicament of the invention comprises or consists essentially of an immunogenic product comprising IL-4 coupled with CRM₁₉₇.

In one embodiment, the composition, pharmaceutical composition or medicament of the invention comprises or consists essentially of an immunogenic product comprising IL-13 coupled with CRM₁₉₇.

In one embodiment, the composition, pharmaceutical composition or medicament of the invention comprises or consists essentially of an immunogenic product comprising CRM₁₉₇ coupled with both IL-4 and IL-13.

In one embodiment, the composition, pharmaceutical composition or medicament of the invention comprises or consists essentially of a mixture of an immunogenic product comprising IL-4 coupled with CRM₁₉₇ and of an immunogenic product comprising IL-13

coupled with CRM₁₉₇, at a weight ratio ranging from about 10:1 to about 1:10, preferably at a weight ratio ranging from about 4:1 to 1:4.

In one embodiment, the composition, pharmaceutical composition or medicament of the invention is a vaccine composition. In one embodiment of the invention, the vaccine
5 composition of the invention comprises at least one adjuvant.

This invention further relates to a formulation of the composition, pharmaceutical composition, medicament or vaccine of the invention, wherein the composition, pharmaceutical composition, medicament or vaccine is adjuvanted.

In one embodiment, the composition, pharmaceutical composition, medicament or
10 vaccine of the invention thus comprise one or more adjuvants.

Suitable adjuvants that may be used in the present invention include, but are not limited to:

- (1) aluminum salts (alum), such as, for example, aluminum hydroxide, aluminum phosphate, aluminum sulfate, etc.;
- 15 (2) oil-in-water emulsion formulations (with or without other specific immunostimulating agents such as, for example, muramyl peptides (defined below) or bacterial cell wall components), such as, for example, squalene-based emulsions (*e.g.*, squalene-based oil-in-water emulsions) or squalane-based emulsions, such as, for example,
 - (a) MF59 (a squalene-based oil-in-water adjuvant described in PCT Publ. No. WO 90/
20 14837), containing 5% squalene, 0.5% Tween 80, and 0.5% span 85 (optionally containing various amounts of MTP-PE (see below, although not required)) formulated into submicron particles using a microfluidizer such as Model 110Y microfluidizer (Microfluidics, Newton, Mass.),
 - (b) SAF, containing 10% Squalene, 0.4% Tween 80, 5% pluronic-blocked polymer L121,
25 and thr-MDP (see below) either microfluidized into a submicron emulsion or vortexed to generate a larger particle size emulsion, and

(c) RibiTM adjuvant system (RAS), (Corixa, Hamilton, Mont.) containing 2% squalene, 0.2% Tween 80, and one or more bacterial cell wall components from the group consisting of 3-O-deacylated monophosphorylipid A (MPLTM) described in US. Pat. No. 4,912,094 (Corixa), trehalose dimycolate (TDM), and cell wall skeleton (CWS),
 5 preferably MPL+CWS (DetoxTM);

(d) squalane based adjuvant comprising but not limited to the following composition: squalane 3.9%, w/v, sorbitan trioleate (0.47%, w/v), and polyoxyethylene (80) sorbitan monooleate (0.47%, w/v) dispersed in citrate buffer;

(3) water-in-oil emulsion formulations, such as, for example, ISA-51 or squalene-based
 10 water-in-oil adjuvant (*e.g.*, ISA-720); Oil adjuvants suitable for use in water-in-oil emulsions may include mineral oils and/or metabolizable oils. Mineral oils may be selected from Bayol®, Marcol®, and Drakeol, including Drakeol® 6VR (SEPPIC, France). ®. Metabolisable oils may be selected from SP oil (hereinafter described), Emulsigen (MPV Laboratories, Ralston, NZ), Montanide 264,266,26 (Seppic SA, Paris,
 15 France), as well as vegetable oils, animal oils such as the fish oils squalane and squalene, and tocopherol and its derivatives.

(4) saponin adjuvants, such as Quil A or STIMULONTM QS-21 (Antigenics, Framingham, Mass.) (U.S. Pat. No. 5,057,540) may be used or particles generated therefrom such as ISCOMs (immunostimulating complexes);

(5) bacterial lipopolysaccharides, synthetic lipidA analogs such as aminoalkyl glucosamine phosphate compounds (AGP), or derivatives or analogs thereof, which are available from Corixa, and which are described in US. Pat. No. 6,113,918; one such AGP is 2-[(R)-3-Tetradecanoyloxytetradecanoylamino]ethyl 2-Deoxy-4-O- phosphono-3-Oi[(R)-3tetradecanoyloxytetradecanoyl] -2 - [(R) -3 -tetradecanoyloxytetradecanoyl
 25 amino] -b-Dglucopyranoside, which is also known as 529 (formerly known as RC529), which is formulated as an aqueous form or as a stable emulsion, synthetic polynucleotides such as oligonucleotides containing CpG motif(s) (U .S. Pat. No. 6,207, 646);

(6) cytokines, such as interleukins (*e.g.*, IL-1, IL-2, IL-4, IL-5, IL-6, IL-7, IL-12, IL-15, IL-18, etc.), interferons (*e.g.*, gamma interferon), granulocyte macrophage colony

stimulating factor (GM-CSF), macrophage colony stimulating factor (M-CSF), tumor necrosis factor (TNF), costimulatory molecules B7-1 and B7-2, etc.;

(7) detoxified mutants of a bacterial ADP-ribosylating toxin such as a cholera toxin (CT) either in a wild-type or mutant form, for example, where the glutamic acid at amino acid
5 position 29 is replaced by another amino acid, preferably a histidine, in accordance with published international patent application number WO 00/ 18434 (see also WO 02/098368 and WO 02/098369), a pertussis toxin (PT), or an *E. coli* heat-labile toxin (LT), particularly LT-K63, LT-R72, CT-S109, PT-K9/G129 (see, e.g., WO 93/13302 and WO92/19265); and

10 (8) other substances that act as immunostimulating agents to enhance the effectiveness of the composition. Muramyl peptides include, but are not limited to, N-acetylmuramyl-L-threonyl-D-isoglutamine (thr-MDP), N-acetylnormuramyl-L-alanine-2-(1'-2'dipalmitoyl-sn-glycero-3hydroxyphosphoryloxy)-ethylamine (MTP-PE), etc.

The adjuvant used may depend, in part, on the recipient organism. Moreover, the amount
15 of adjuvant to administer will depend on the type and size of animal.

In one embodiment, the composition, pharmaceutical composition, medicament or vaccine composition of the invention is (or comprises) an emulsion further comprising one or more surfactant agents, and optionally at least one adjuvant as described hereinabove. In one embodiment, the emulsion is a water-in-oil emulsion or an oil-in-
20 water emulsion.

Examples of surfactants that may be used in the present invention are well known in the art and include, but are not limited to, mannide monooleate such as Montanide® 80 marketed by Arlacel (SEPPIC, France), Tween 20, Tween 80, span 85, Triton X-100.

In one embodiment, the composition, pharmaceutical composition, medicament, vaccine
25 composition of the invention comprises a therapeutically effective amount of at least one immunogenic product of the invention.

In one embodiment and for storage purposes, the immunogenic product or the composition, pharmaceutical composition, medicament, vaccine composition or emulsion of the invention is lyophilized.

5 In one embodiment, the composition, pharmaceutical composition, medicament, vaccine composition or emulsion of the invention may thus be presented in a freeze-dried (lyophilized) form. According to this embodiment, the immunogenic product of the invention is combined with one or more lyophilization auxiliary substances. Various lyophilization auxiliary substances are well known by the one skilled in the art and include, without limitation, sugars like lactose and mannitol.

10 In one embodiment, the composition, pharmaceutical composition, medicament, vaccine composition or emulsion of the invention may be mixed with stabilizers, *e.g.*, to protect degradation-prone proteins from being degraded, to enhance the shelf-life of the immunogenic product, or to improve freeze-drying efficiency. Useful stabilizers include, but are not limited to, SPGA, carbohydrates (*e.g.*, sorbitol, mannitol, trehalose, starch,
15 sucrose, dextran or glucose), proteins (such as, for example, albumin or casein or degradation products thereof), mixtures of amino acids such as, for example, lysine or glycine, and buffers, such as, for example, alkali metal phosphates.

In one embodiment, the immunogenic product, composition, pharmaceutical composition, vaccine composition or emulsion of the invention may be administered by
20 injection, topically (such as, for example, by transdermal delivery), rectally, nasally or vaginally.

In one embodiment, the immunogenic product, composition, pharmaceutical composition, medicament, vaccine composition or emulsion of the invention is in an adapted form for an injection. Thus, in one embodiment, the immunogenic product,
25 composition, pharmaceutical composition, medicament, or vaccine composition of the invention is to be injected to the subject by intramuscular, intraperitoneal, or subcutaneous injection.

Examples of forms suitable for injectable use include, but are not limited to, sterile solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersions. The prevention against contamination by microorganisms can be brought about by adding in the composition preservatives such as, for example, various antibacterial and antifungal agents (for example, parabens, chlorobutanol, phenol, sorbic acid, thimerosal and the like). In an embodiment, it may be preferable to include isotonic agents, for example, sugars or sodium chloride, to reduce pain during injection. In one embodiment, prolonged absorption of the injectable compositions can be brought about by the use in the compositions of agents delaying absorption, for example, aluminum monostearate and gelatin.

In one embodiment, a lyophilized vaccine composition of the invention is solubilized in water for injection and gently mixed; then an immunoadjuvant as described hereinabove, is added; the mixture is gently mixed and charged into a suitable syringe. This invention thus also relates to a medical device, including a syringe filled or prefilled with a vaccine composition of the invention.

In one embodiment, the immunogenic product, composition, pharmaceutical composition, medicament, or vaccine composition of the invention is in an adapted form for topical administration. Examples of forms adapted for topical administration include, without being limited to, polymeric patch, or controlled-release patch, and the like.

In another embodiment, the immunogenic product, composition, pharmaceutical composition, medicament, vaccine composition or emulsion of the invention is in an adapted form for rectal administration. Examples of forms adapted for rectal administration include, without being limited to, suppository, micro enemas, enemas, gel, rectal foam, cream, ointment, and the like.

This invention also relates to the medical device which is the syringe filled or prefilled with the composition, pharmaceutical composition, medicament, or vaccine composition of the invention.

In one embodiment, said syringe is a dual chamber syringe, wherein one chamber comprises a solution with the immunogenic product of the invention and the other chamber comprises the adjuvant.

The invention also relates to a medical device comprising a vial prefilled with the
5 immunogenic product of the invention or with the composition, pharmaceutical composition, medicament, or vaccine composition of the invention.

The present invention further relates to the immunogenic product, composition, pharmaceutical composition, medicament, or vaccine composition of the invention, for treating an inflammatory disorder in a subject.

10 The present invention thus further relates to a method for treating an inflammatory disorder in a subject, comprising administering to the subject the immunogenic product, composition, pharmaceutical composition, medicament, vaccine composition or emulsion of the invention.

The present invention further relates to a method for inducing an immune response against
15 IL-4, IL-13 or both in a subject, comprising administering to the subject the immunogenic product, composition, pharmaceutical composition, medicament, or vaccine composition of the invention.

The present invention further relates to a method for inducing in a subject the production of antibodies that inhibits the biological activity or neutralizes the biological activity of
20 IL-4, IL-13 or both, comprising administering to the subject the immunogenic product, composition, pharmaceutical composition, medicament, or vaccine composition of the invention. In one embodiment, the antibodies are polyclonal antibodies.

In one embodiment, the subject is affected, preferably is diagnosed, with an inflammatory disorder, in particular with a disorder associated with aberrant IL-4 and/or IL-13
25 expression or activity.

In one embodiment, the subject is a human. Preferably, according to this embodiment, the at least one cytokine comprised in the immunogenic product of the invention is human.

In one embodiment, the subject is a non-human mammal (such as, for example, a pet).
5 Preferably, according to this embodiment, the at least one cytokine comprised in the immunogenic product of the invention originates from said non-human mammal.

In one embodiment, the inflammatory disorder is a disorder associated with aberrant IL-4 and/or IL-13 expression or activity.

Examples of inflammatory disorder include, but are not limited to, asthma (either allergic
10 or non-allergic), allergic conditions (such as, for example, food allergies, venom allergy, cat allergy, drug allergy, hyper IgE syndrome, allergic rhinitis, allergic conjunctivitis and allergic enterogastritis), atopic disorders (such as, for example, atopic dermatitis, urticaria (including chronic idiopathic urticaria and chronic spontaneous urticaria), eczema), bullous pemphigoid, respiratory disorders (such as allergic and nonallergic asthma,
15 chronic obstructive pulmonary disease (COPD)), nasal polyposis and other conditions involving airway inflammation (such as, for example, eosinophilia, fibrosis and excess mucus production including cystic fibrosis and pulmonary fibrosis, systemic sclerosis (SSc)); inflammatory and/or autoimmune disorders or conditions, gastrointestinal disorders or conditions (such as, for example, inflammatory bowel diseases (IBD) and
20 eosinophilic esophagitis (EE), and eosinophilic-mediated gastrointestinal disease, ulcerative colitis, Crohn's disease and systemic lupus erythematosus); systemic lupus erythematosus, liver disorders or conditions (such as, for example, cirrhosis, and hepatocellular carcinoma), scleroderma; fibrotic diseases or disorders (such as, for example, fibrosis of the liver (such as, for example, fibrosis caused by a hepatitis B and/or
25 C virus)), scleroderma; solid tumors or cancers such as leukemia (such as, for example, B cell chronic lymphocytic leukaemia), glioblastoma, lymphoma (such as, for example, Hodgkin's lymphoma) and mastocytosis.

In one embodiment, the inflammatory disorder is selected from the group comprising asthma (e.g., allergic asthma), atopic dermatitis, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, food allergy, nasal polyposis and eosinophilic esophagitis.

5 In one embodiment, the inflammatory disorder is selected from the group comprising asthma (e.g., allergic asthma), atopic dermatitis, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis and food allergy.

In one embodiment, the inflammatory disorder is allergy, asthma, or atopic dermatitis.

In one embodiment, the inflammatory disorder is allergic asthma.

10 In one embodiment, the inflammatory disorder is a solid tumor. In one embodiment, the method of the present invention is for preventing metastasis from solid tumor.

The present invention further relates to a method for inducing desensitization of a subject allergic to a specific antigen, wherein said method comprises administering to the subject the immunogenic product, composition, pharmaceutical composition, medicament, or vaccine composition of the invention and said allergen.

15 As used herein, the term “desensitization”, also known as allergen immunotherapy, desensitization or hypo-sensitization or allergy vaccination, refers to a medical treatment for environmental allergies, such as allergic asthma. Such treatment involves exposing people to larger and larger amounts of allergen in an attempt to reduce the immune system's response in presence of allergen.

20 Examples of allergens include, but are not limited to inhaled allergens, ingested allergens and contact allergens.

Examples of inhaled allergens include, but are not limited to, allergens from Astigmata (e.g., *Acarus siro* (Storage mite, Aca s 13), *Blomia tropicalis* (Mite, Blo t), *Dermatophagoides farinae* (American house dust mite, Der f), *Dermatophagoides microceras* (House dust mite, Der m), *Dermatophagoides pteronyssinus* (European house dust mite, Der p), *Euroglyphus maynei* (House dust mite, Eur m), *Glycyphagus*

25

domesticus (Storage mite, Gly d 2), Lepidoglyphus destructor (Storage mite, Lep d),
 Tyrophagus putrescentiae (Storage mite, Tyr p)); Blattaria (*e.g.*, Blattella germanica
 (German cockroach, Bla g), Periplaneta americana (American cockroach, Per a));
 Coleoptera (*e.g.*, Harmonia axyridis (Asian ladybeetle, Har a)), Diptera (*e.g.*, Aedes
 5 aegypti (Yellow fever mosquito, Aed a), Chironomus kiiensis (Midge, Chi k),
 Chironomus thummi thummi (Midge, Chi t), Forcipomyia taiwana (Biting midge, For t),
 Glossina morsitans (Savannah Tsetse fly, Glo m), Hemiptera: Triatoma protracta
 (California kissing bug, Tria p)), Hymenoptera (*e.g.*, Apis cerana (Eastern hive bee, Api
 c), Apis dorsata (Giant honeybee, Api d), Apis mellifera (Honey bee, Api m), Bombus
 10 pennsylvanicus (Bumble bee, Bom p), Bombus terrestris (Bumble bee, Bom t),
 Dolichovespula arenaria (Yellow hornet, Dol a), Dolichovespula maculata (White face
 hornet, Dol m), Myrmecia pilosula (Australian jumper ant, Myr p), Polistes annularis
 (Wasp, Pol a), Polistes dominulus (Mediterranean paper wasp, Pol d), Polistes exclamans
 (Wasp, Pol e), Polistes fuscatus (Wasp, Pol f), Polistes gallicus (Wasp, Pol g), Polistes
 15 metricus (Wasp, Pol m), Polybia paulista (Wasp, Pol p), Polybia scutellaris (Wasp, Pol
 s), Solenopsis geminata (Tropical fire ant, Sol g), Solenopsis invicta (Red imported fire
 ant, Sol i), Solenopsis richteri (Black fire ant, Sol r), Solenopsis saevissima (Brazilian fire
 ant, Sol s), Vespa crabro (European hornet, Vesp c), Vespa mandarinia (Giant asian
 hornet, Vesp m), Vespula fiavopilosa (Yellow jacket, Vesp f), Vespula germanica
 20 (Yellow jacket, Vesp g), Vespula maculifrons (Yellow jacket, Vesp m), Vespula
 pennsylvanica (Yellow jacket, Vesp p), Vespula squamosa (Yellow jacket, Vesp s),
 Vespula vidua (Wasp, Vesp vi), Vespula vulgaris (Yellow jacket, Vesp v)), Ixodida (*e.g.*,
 Argas reflexus (Pigeon tick, Arg r)), Lepidoptera (*e.g.*, Bombyx niori (Silk moth, Bomb
 n), Plodia interpunctella (Indianmeal moth, Plo i), Thaumatococcus pityocampa (Pine
 25 processionary moth, Tha p)), Thysanura (*e.g.*, Lepisma saccharina (Silverfish, Lep s)),
 Siphonaptera (*e.g.*, Ctenocephalides felis felis (Cat flea, Cte f)), Carnivora (*e.g.*, Canis
 familiaris (dog, Can f), Felis domesticus (cat, Fel d)); Lagomorpha (*e.g.*, Oryctolagus
 cuniculus (rabbit, Ory c), Perissodactyla: Equus caballus (domestic horse, Equ c)),
 Pleuronectiformes (*e.g.*, Lepidorhombus whiffiagonis (Megrim, Whiff, Gallo, Lep w)),
 30 Rodentia (*e.g.*, Cavia porcellus (guinea pig, Cav p), Mus musculus (mouse, Mus m),
 Rattus norvegicus (rat, Rat n)); Coniferales: Chamaecyparis obtusa (Japanese cypress, Cha
 o), Cupressus arizonica (Cypress, Cup a), Cryptomeria japonica (Sugi, Cry j), Cupressus

sempervirens (Common cypress, Cup s), Juniperus ashei (Mountain cedar, Jun a),
 Juniperus oxycedrus (Prickly juniper, Jun o), Juniperus sabinoides (Mountain cedar, Jun
 s), Juniperus virginiana (Eastern red cedar, Jun v)); Gentianales (e.g., Catharanthus roseus
 (Rosy periwinkle, Cat r)); Poales (e.g., Anthoxanthum odoratum (Sweet vernal grass, Ant
 5 o 1), Cynodon dactylon (Bermuda grass, Cyn d 1, Cyn d 7, Cyn d 12, Cyn d 15, Cyn d
 22w, Cyn d 23, Cyn d 24), Dactylis glomerata (Orchard grass, Dae g 1, Dae g 2, Dae g 3,
 Dae g 4, Dae g 5), Festuca pratensis (Meadow fescue, Fes p 4)), Holcus lanatus (Velvet
 grass, Hol l 1, Hol l 5), Hordeum vulgare (Barley, Hor v 1, Hor v 5, Hor v 12, Hor v 15,
 Hor v 16, Hor v 17, Hor v 21), Lolium perenne (Rye grass, Lol p 1, Lol p 2, Lol p 3, Lol
 10 p 4, Lol p 5, Lol p 11), Oryza sativa (Rice, Ory s 1, Ory s 12), Paspalum notatum (Bahia
 grass, Pas n 1), Phalaris aquatica (Canary grass, Pha a 1, Pha a 5), Phleum pratense
 (Timothy, Phl p 1, Phl p 2, Phl p 4, Phl p 5, Phl p 6, Phl p 7, Phl p 11, Phl p 12, Phl p 13),
 Poa pratensis (Kentucky blue grass, Poa p 1, Poa p 5), Secale cereale (Rye, Sec c 1, Sec
 c 20), Sorghum halepense (Johnson grass, Sor h 1), Triticum aestivum (Wheat, Tri a 12,
 15 Tri a 14, Tri a 185, Tri a 19, Tri a 25, Tri a 26, Tri a 27, Tri a 28, Tri a 29, Tri a 30), Zea
 mays (Maize, Zea m 1, Zea m 12, Zea m 14, Zea m 25), Fagales: Alnus glutinosa (Alder,
 Aln g 1, Aln g 4), Betula verrucosa (Birch, Bet v 1, Bet v 2, Bet v 3, Bet v 4, Bet v 5, Bet
 v 6, Bet v 7), Carpinus betuhxs (Hornbeam, Car b 1)); Lamiales (e.g., Fraxinus excelsior
 (Ash, Fra e 1), Ligustrum vulgare (Privet, Lig v), Syringa vulgaris (Lilac, Syr v));
 20 Malpighiales (e.g., Hevea brasiliensis (para rubber tree (latex), Hev b 1, Hev b 2, Hev b
 3, Hev b 4, Hev b 5, Hev b 6, Hev b 7, Hev b 8, Hev b 9, Hev b 10, Hev b 11, Hev b 12,
 Hev b 13)); Proteales (e.g., Platanus acerifolia (London plane tree, Pla a 1, Pla a 2, Pla a
 3), Platanus orientalis (Oriental plane, Pla or 1, Pla or 2, Pla or 3)).

In one embodiment, the inhaled allergen is selected from the group comprising or
 25 consisting of Acarus siro (Storage mite, Aca s 13), Dermatophagoides farinae (American
 house dust mite, Der f), Dermatophagoides microceras (House dust mite, Der m),
 Dermatophagoides pteronyssinus (European house dust mite, Der p), Euroglyphus
 maynei (House dust mite, Eur m), Glycyphagus domesticus (Storage mite, Gly d 2),
 Polistes annularis (Wasp, Pol a), Polistes dominulus (Mediterranean paper wasp, Pol d),
 30 Polistes exclamans (Wasp, Pol e), Polistes fuscatus (Wasp, Pol f), Polistes gallicus (Wasp,
 Pol g), Polistes metricus (Wasp, Pol m), Polybia paulista (Wasp, Pol p), Polybia

scutellaris (Wasp, Pol s), *Felis domesticus* (cat, Fel d), Poales and *Betula verrucosa* (Birch, Bet v 1, Bet v 2, Bet v 3, Bet v 4, Bet v 5, Bet v 6, Bet v 7).

Examples of ingested allergens include, but are not limited to, allergens from Fungi Ascomycota, such as, for example, Dothideales (*e.g.*, *Alternaria alternata* (*Alternaria rot* fungus, Alt a), *Cladosporium cladosporioides* (Cla c), *Cladosporium herbarum* (Cla h), *Curvularia lunata* (Cur l), - Eurotiales: *Aspergillus flavus* (Asp fl), *Aspergillus fumigatus* (Asp f), *Aspergillus niger* (Asp n), *Aspergillus oryzae* (Asp o), *Penicillium brevicompactum* (Pen b), *Penicillium chrysogenum* (Pen ch), *Penicillium citrinum* (Pen c), *Penicillium oxalicum* (Pen o)), Hypocreales (*e.g.*, *Fusarium culmorum* (Fus c));
 10 Onygenales (*e.g.*, *Trichophyton rubrum* (Tri r), *Trichophyton tonsurans* (Tri t), Saccharomycetales: *Candida albicans* (Yeast, Cand a), *Candida boidinii* (Yeast, Cand b)); Tuberculariales (*e.g.*, *Epicoccum purpurascens* (Epi p)), allergens from Fungi Basidiomycota, such as, for example, Hymenomycetes (*e.g.*, *Coprinus comatus* (Shaggy mane, Cop c), *Psilocybe cubensis* (Magic mushroom, Psi c), Urediniomycetes (*e.g.*,
 15 *Rhodotorula mucilaginosa* (Yeast, Rho m)); Ustilaginomycetes (*e.g.*, *Malassezia furfur* (Pityriasis versicolor infect. Agent, Mala f), *Malassezia sympodialis* (Mala s)); antibiotics (such as, for example, Penicillins, Cephalosporins, Aminosides, Quinolones, Macrolides, Tetracycline, Sulfamids); drugs (such as, for example, acetylsalicylic acid, vaccines, morphines and derivatives); vitamins such as, for example, vitamin K1; and food
 20 allergens (such as, for example, allergen from milk, egg, peanut, tree nut (walnut, cashew, etc.), fish, shellfish, soy, wheat, and carrot, apple, pear, avocado, apricot, peach).

In one embodiment, the ingested allergen is a food allergen.

In one embodiment, the food allergen is selected from the group comprising or consisting of allergen from milk, egg, peanut, tree nut (walnut, cashew, etc.), fish, shellfish, soy,
 25 wheat, and carrot, apple, pear, avocado, apricot, peach.

Examples of contact allergens include, but are not limited to, heavy metals (such as, for example, nickel, chrome, gold), latex, haptens such as, for example halothane, hydralazine.

In one embodiment, the allergen is selected from the group comprising or consisting of
Acarus siro (Storage mite, Aca s 13), Dermatophagoides farinae (American house dust
mite, Der f), Dermatophagoides microceras (House dust mite, Der m), Dermatophagoides
pteronyssinus (European house dust mite, Der p), Euroglyphus maynei (House dust mite,
5 Eur m), Glycyphagus domesticus (Storage mite, Gly d 2), Polistes annularis (Wasp, Pol
a), Polistes dominulus (Mediterranean paper wasp, Pol d), Polistes exclamans (Wasp, Pol
e), Polistes fuscatus (Wasp, Pol f), Polistes gallicus (Wasp, Pol g), Polistes metricus
(Wasp, Pol m), Polybia paulista (Wasp, Pol p), Polybia scutellaris (Wasp, Pol s), Felis
domesticus (cat, Fel d), Poales and Betula verrucosa (Birch, Bet v 1, Bet v 2, Bet v 3,
10 Bet v 4 , Bet v 5, Bet v 6, Bet v 7) and food allergens.

The present invention also further relates to a method for increasing the efficacy and/or
for decreasing the duration of a desensitization of a subject allergic to a specific allergen,
wherein said subject is treated by desensitization, and is further administered with the
immunogenic product, composition, pharmaceutical composition, medicament, or
15 vaccine composition of the invention.

In one embodiment, in the methods of the present invention, the subject is administered
first with the immunogenic product, composition, pharmaceutical composition,
medicament, or vaccine composition of the invention, and second with the allergen.

In one embodiment, in the methods of the present invention, the subject is administered
20 first with the allergen, and second with the immunogenic product, composition,
pharmaceutical composition, medicament, or vaccine composition of the invention.

In another embodiment, in the method of the present invention, the subject receives a
combined administration of the immunogenic product, composition, pharmaceutical
composition, medicament, or vaccine composition of the invention, and of the allergen.

25 The present invention further relates to a composition, pharmaceutical composition,
medicament or vaccine as described hereinabove, wherein said composition,
pharmaceutical composition, medicament or vaccine further comprises at least one
allergen.

In one embodiment, a therapeutically effective amount of at least one immunogenic product of the invention is administered or is to be administered to the subject. In one embodiment, the therapeutically effective amount corresponds to an amount of total proteins determined using a Bradford protein assay as well known in the art.

- 5 In one embodiment, the amount of the immunogenic product to be administered to the subject induces an immunoprotective response without significant adverse effects.

In one embodiment, the amount of the immunogenic product to be administered to the subject induces an allergen desensitization without significant adverse effects.

- 10 Optimal amounts of components for the immunogenic product of the invention can be ascertained by standard studies involving observation of appropriate immune responses in subjects. Following an initial vaccination, subjects can receive one or several booster immunizations adequately spaced.

In one embodiment, the treatment consists of a single dose or a plurality of doses over a period of time.

- 15 In one embodiment of the invention, the subject to be treated is administrated at least twice in a month with the therapeutically effective amount of immunogenic product as described here above.

- 20 In another embodiment of the invention, the subject to be treated is administrated twice in 1 month with a therapeutically effective amount of the immunogenic product of the invention. In this embodiment, the subject may be administrated once at day 0 and the second time between day 7 and day 28. In one embodiment, the subject is administrated once at day 0 and the second time at day 28.

- 25 In another embodiment of the invention, the subject to be treated is administrated three times in 1 month with a therapeutically effective amount of the immunogenic product of the invention. In this embodiment, the subject to be treated may be administrated once at day 0, the second time between day 7 and day 14 and the third time between day 21 and day 28. In one embodiment, the subject is administrated once at day 0, the second time at day 7 and the third time at day 28.

In another embodiment of the invention, the subject to be treated may be further administrated once every three months with the therapeutically effective amount of the immunogenic product of the invention.

5 In one embodiment of the invention, the subject to be treated is administered three times in one month as described here above, and then further administered once every three months with the therapeutically effective amount of the immunogenic product of the invention.

10 In another embodiment of the invention, the subject to be treated may be further administrated with a therapeutically effective amount of the immunogenic product as described here above when the amount of antibodies against IL-4 is undetectable in a serum sample obtained from the subject.

15 In another embodiment of the invention, the subject to be treated may be further administrated with a therapeutically effective amount of the immunogenic product as described here above when the amount of antibodies against IL-13 is undetectable in a serum sample obtained from the subject.

20 In another embodiment of the invention, the subject to be treated may be further administrated with a therapeutically effective amount of the immunogenic product as described here above when the amount of antibodies against IL-4 and IL-13 are undetectable in a serum sample obtained from the subject.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a scheme of the chemical conjugation of sGMBS-modified IL-4 or IL-13 and SATA-labeled carrier protein through thiol-maleimide addition for the manufacturing of the immunogenic products of the present invention.

25 **Figure 2** is a combination of graphs showing the antigenicity of muIL-4 and muIL-13 immunogenic products. Capture was performed with anti-CRM₁₉₇ antibody (A, C) or anti-KLH antibody (B, D) and detection with biotinylated polyclonal anti-muIL-4

antibody (A, B) or biotinylated polyclonal anti-muIL-13 antibody (C, D). Represented OD values are OD means of duplicates.

Figure 3 is a study scheme of immunizations in Balb/c mice. Four immunizations at days 0, 7, 28 and 49 of immunogenic product (with CRM₁₉₇ or KLH as carrier protein), unconjugated muIL-4 or muIL-13 + CRM₁₉₇ and CRM₁₉₇ alone and PBS, all emulsified in squalene adjuvant and i.m. injected in 10 mice per group except for control group only 5 mice. Blood samples were performed before dosing and at day 39 and day 120.

Figure 4 is a combination of graphs showing anti-muIL-4 (A), anti muIL-13 (B), anti-CRM₁₉₇(C) and anti-KLH (D) antibody titers in mice sera. Ten mice per group were used in immunogenic products groups and 5 mice in control groups. Bars represent median.

Figure 5 is a graph showing the muIL-4 neutralizing capacities in mice sera. Ten mice per group were used in immunogenic products groups and 5 mice in control groups. Bars represent median.

Figure 6 is a graph showing muIL-13 neutralizing capacities in mice sera. Ten mice per group were used in immunogenic products groups and 5 mice in control groups. Bars represent median.

Figure 7 is a study scheme of immunizations and asthma sensitization in Balb/c mice.

Figure 8 is a combination of graphs showing anti-muIL-4 (A) and anti-muIL-13 (B) antibodies titers in mice sera. Twelve mice per group. Bars represent median.

Figure 9 is a combination of graphs showing muIL-4 (A) and muIL-13 (B) neutralizing capacities in mice sera. Twelve mice per group. Bars represent median.

Figure 10 is a graph showing an airway hyperresponsiveness to inhaled methacholine. Enhanced pause (Penh) values were measured by non-invasive whole body plethysmography. Data were obtained using 7-8 mice per group for HDM sensitized/challenged mice and n=16 for PBS controls. * or ** or ***; P< 0.5 or 0.1 or 0.001 vs. CRM₁₉₇-HDM group, using unpaired Mann-Whitney U test.

Figure 11 is a combination of graphs showing the circulating IgE levels in serum collected before vaccination (A) and 24 hours after the last challenge with HDM or PBS (B). Data were obtained using 7-8 mice per group for HDM sensitized/challenged mice and n=16 for PBS controls. ***: $P < 0.001$ vs. CRM₁₉₇-HDM group, using unpaired
5 Mann-Whitney U test.

Figure 12 is a combination of graphs showing the levels of CD45⁺ cells (A) and eosinophils (B) in BAL collected 24 h after the last challenge with HDM. Data were obtained using 7-8 mice per group for HDM sensitized/challenged mice and n=16 for PBS controls. * or ** or ***: $P < 0.5$ or 0.1 or 0.001 vs. CRM₁₉₇-HDM group, using
10 unpaired Mann-Whitney U test.

Figure 13 is a combination of graphs showing the antigenicity of IL-4 immunogenic product (A), IL-13 immunogenic product (B) and Combo immunogenic product (A and B). Capture was performed with anti-CRM₁₉₇ antibody and detection with biotinylated polyclonal anti-huIL-4 antibody (A) or biotinylated polyclonal anti-huIL-13 antibody (B).
15 Represented OD values are OD means of duplicates.

Figure 14 is a study scheme of immunization in Balb/c mice.

Figure 15 is a combination of graphs showing the anti-IL-4 (A) and anti-IL-13 (B) antibody titers in mice sera. Ten mice per group. Bars represent median.

Figure 16 is a combination of graphs showing the anti-IL-4 (A) and anti-IL-13 (B)
20 neutralizing capacities in mice sera. Ten mice per group. Bars represent median.

EXAMPLES

The present invention is further illustrated by the following examples.

The present invention relates to an immunogenic product using CRM₁₉₇ as a carrier
25 protein. The properties of the immunogenic product of the invention are illustrated by the following examples. In addition, the product of the invention was compared to

immunogenic product made with KLH to distinguish the present invention from previous art and to show its superiority to previous art.

CRM₁₉₇ is a non-toxic form of diphtheria toxin without toxic activity due to a single base substitution, in its toxin domain, from glycine to glutamate in position 52 (Uchida *et al.* 1973 J Biol Chem). As an alternative, Keyhole Limpet Hemocyanin (KLH), a copper-containing protein that is found in arthropods and mollusca (Swaminathan *et al.* 2014), was also tested and compared to CRM₁₉₇.

The immunogenic products of the invention were produced using the manufacturing process developed below.

10 A thiol-maleimide conjugation is employed for the preparation of IL-4 and IL-13 immunogenic products. Sulfhydryl moieties were introduced on the carrier protein CRM₁₉₇ with SATA and subsequent hydroxylamine deprotection, while the cytokine muIL-4 or muIL-13 were derivatized by sGMBS, a maleimide-containing agent. Both SATA and sGMBS are heterobifunctional crosslinkers containing a NHS-ester, which
15 reacts with primary amines (such as ϵ -amino groups of lysine residues and protein N-termini). An overview of the immunogenic product synthesis via thiol-maleimide conjugation is provided in **Figure 1**.

Example 1: Preparation of the murine IL-4 and IL-13 immunogenic products of the invention with the two carrier proteins

20 ***a) Carrier protein functionalization***

CRM₁₉₇ or KLH was diluted in the modification buffer comprising 70 mM sodium phosphate buffer, 150 mM NaCl, 5 mM EDTA (pH 7.2). SATA was diluted in DMSO to reach a 100 mM concentration. Then, SATA was added to CRM₁₉₇ or KLH and after 30 minutes of incubation on a nutator at room temperature, SATA in excess was removed
25 using ZebaTM desalting spin column, according to the manufacturer's instructions.

Subsequently, hydroxylamine was diluted in the same buffer at 500 mM. Then, CRM₁₉₇-SATA or KLH-SATA was incubated with the hydroxylamine solution at a 50 mM final

concentration, during 2 hours on a nutator at room temperature. Finally, the mixture was desalted and reagents in excess were removed using Zeba™ desalting spin column.

b) muIL-4 and muIL-13 functionalization

5 muIL-4 or muIL-13 was dissolved in modification buffer (70 mM sodium phosphate buffer, 150 mM NaCl, 5 mM EDTA, pH 7.2). sGMBS was diluted in modification buffer at 10 mM. Then, sGMBS was added to muIL-4 or muIL-13 and after one hour of incubation on a nutator at room temperature, sGMBS in excess was removed using Zeba™ desalting spin column.

c) Conjugation

10 After CRM₁₉₇, KLH, muIL-4 and muIL-13 functionalization, protein contents of each preparation were determined by Bradford assay.

Functionalized CRM₁₉₇ or functionalized KLH was added to functionalized muIL-4 or functionalized muIL-13 at a molar ratio of 1:2 (carrier: muIL-4 or carrier: muIL-13) and 1:20 respectively. The ratio 1:20 for KLH was chosen based on the difference of
15 molecular weight between KLH and CRM₁₉₇ (CRM₁₉₇ ~ 58 kDa vs KLH subunit used in this manufacturing ~ 400 kDa) and based on previous experience in making IFN immunogenic product, a vaccine currently evaluated in a phase IIb clinical trial in lupus patients (NCT02665364) allowing to mix similar quantity of cytokine and carrier in all manufacturings.

20 Individual immunogenic product preparations were incubated overnight at 4 °C, on a nutator. The resulting immunogenic products were then concentrated using Amicon (3 kDa-cut-off membrane), 0.22 µm-filtered and kept at 4 °C.

d) Control (unconjugated cytokines and CRM₁₉₇)

25 As controls, two mixtures (called unconjugated cytokines and CRM₁₉₇) were prepared without proteins functionalization:

- muIL-4 and CRM₁₉₇ were mixed at a molar ratio of 1:2 (CRM₁₉₇:cytokine). The mix was prepared at 700 µg/mL, without using any coupling reagent.
- muIL-13 and CRM₁₉₇ were mixed at a molar ratio of 1:2 (CRM₁₉₇:cytokine). The mix was prepared at 700 µg/mL, without using any coupling reagent.

5 Both mixtures were 0.22 µm-filtered and stored at 4 °C.

e) Immunogenic product quantifications

Concentrations of muIL-4 immunogenic product and muIL-13 immunogenic product were determined by Coomassie Plus (Bradford) Protein Assay according to the manufacturer instructions.

10 **Example 2: Antigenicity of the murine products**

A sandwich ELISA was performed to evaluate the cytokine coupling to the carrier protein and also to evaluate whether epitopes are preserved during the manufacturing process.

Briefly, capture antibody (anti-carrier protein antibody) was coated in 96-well plates. After a blocking step with 2% (w/v) casein in PBS, immunogenic product samples were
15 added and 2-fold serially diluted. After 90 minutes of incubation at 37 °C, bound immunogenic products were detected using biotinylated anti-muIL-4 antibody (polyclonal goat IgG anti-muIL-4) or biotinylated anti-muIL-13 antibody (polyclonal goat IgG anti-muIL-13) and then revealed with streptavidin-HRP and OPD substrate. The enzymatic reaction was stopped with sulfuric acid and optical density (OD) was read at
20 490 nm. Results are shown in **Figure 2**.

This test confirmed that the immunogenic products of the invention comprises muIL-4 or muIL-13 coupled to CRM₁₉₇ or KLH. Furthermore, these results confirm that the immunogenic products are antigenic (*i.e.* recognized by anti-muIL-4 or anti-muIL-13 antibodies).

Example 3: Immunogenicity of the immunogenic products

Immunogenic products were administered in mice as an emulsion with a squalene-based adjuvant. Immunogenic products were diluted with PBS to the desired concentration and dilutions were mixed with an equal volume of adjuvant.

5 Mice immunization protocol

Each Balb/c mouse received four intramuscular (i.m.) injections of immunogenic products (with CRM₁₉₇ or KLH) or controls such as PBS, the unconjugated cytokines with CRM₁₉₇ or CRM₁₉₇ alone, all emulsified (1:1) with a squalene-based adjuvant. Injections were performed on days 0, 7, 28 and 49 as detailed in **Table 1** and **Figure 3**.

10 First immunization was performed at 7 weeks of age.

Table 1. Dose schedule of administrations

Article	Number of mice per group	Day	Dose/injection (µg)	Adjuvant
muIL-4 immunogenic product (CRM ₁₉₇)	10	0 / 7 / 28 / 49	30 / 30 / 10 / 10	Squalene oil-in-water adjuvant
muIL-4 immunogenic product (KLH)	10	0 / 7 / 28 / 49	30 / 30 / 10 / 10	
muIL-13 immunogenic product (CRM ₁₉₇)	10	0 / 7 / 28 / 49	30 / 30 / 10 / 10	
muIL-13 immunogenic product (KLH)	10	0 / 7 / 28 / 49	30 / 30 / 10 / 10	
Unconjugated muIL-4 + CRM ₁₉₇	5	0 / 7 / 28 / 49	30 / 30 / 10 / 10	
Unconjugated muIL-13 + CRM ₁₉₇	5	0 / 7 / 28 / 49	30 / 30 / 10 / 10	
CRM ₁₉₇	5	0 / 7 / 28 / 49	30 / 30 / 10 / 10	
DPBS	5	0 / 7 / 28 / 49	-	

Blood collections were performed before dosing and at days 39, 60 and 120. Serum samples were prepared after coagulation at room temperature and centrifugation to remove the clot. Mice were sacrificed by lethal anesthesia at day 120.

Determination of anti-cytokines and anti-carrier proteins antibodies titers by ELISA

Serum samples of immunized mice were assessed for the presence of anti-cytokines antibodies and anti-carrier protein antibodies by ELISA.

5 Briefly, muIL-4, muIL-13, CRM₁₉₇ or KLH were coated in 96-well plates. After blocking with casein, serum samples were added, and two-fold serially diluted. After incubation at 37°C, bound antibodies were detected with HRP-conjugated anti-mouse IgG and plates were revealed using OPD substrate. The reaction was stopped with sulfuric acid and then absorbance at 490 nm was recorded.

10 Positive controls used for anti-muIL-4 antibody, anti-muIL-13 antibody, anti-KLH antibody and anti-CRM₁₉₇ antibody titers were respectively, the rat monoclonal anti-muIL-4 IgG1 antibody, the mouse monoclonal anti-muIL13 antibody, pool of sera collected from mice immunized with KLH and the anti-diphtheria toxin A mouse monoclonal IgG1.

15 Samples were analyzed starting at dilution 500 dil⁻¹ up to 256,000 dil⁻¹, except for pre-immune sera analyzed only at 500 dil⁻¹.

Anti-muIL-4, anti-muIL-13, anti-CRM₁₉₇ and anti-KLH titers were expressed as serum dilutions leading to half maximal OD.

20 Results are presented in **Figure 4**. In all groups treated with immunogenic products as well as for mice injected with adjuvanted DPBS or carrier protein or unconjugated preparations, no anti-muIL-4, no anti-muIL-13 no anti-KLH and no anti-CRM₁₉₇ were detected before dosing. In addition, no anti-cytokine or anti-carrier antibodies were detected at any timepoint in mice receiving adjuvanted DPBS.

25 Anti-CRM₁₉₇ titers were detected in all groups treated with CRM₁₉₇ control at days 39, 60 and 120 as well as in group treated with unconjugated muIL-4 + CRM₁₉₇ or with unconjugated muIL-13 + CRM₁₉₇. Anti-muIL-4, anti-muIL-13 and anti-CRM₁₉₇ titers were detected in all groups treated with the immunogenic products made with CRM₁₉₇ at days 39, 60 and 120. Anti-muIL-4, anti-muIL-13 and anti-KLH titers were detected but not in all mice in all groups treated with immunogenic products made with KLH at days

39, 60 and 120. Of note, the level of anti-IL-4 antibodies were higher in mice immunized with immunogenic products made with CRM₁₉₇ than with the immunogenic products made with KLH.

muIL-4 neutralization Bioassay

5 The antibodies induced by administrations of muIL-4 immunogenic products were further assessed for their anti-muIL-4 neutralizing capacities in a proliferative assay using CTLL-2 cells adapted from Soman *et al*, 2009. Briefly, CTLL-2 cells were grown in presence of IL-2 at 10 ng/mL final with RPMI supplemented with 2 mM glutamine, 1 mM sodium pyruvate, 1 mM HEPES, 100 units/mL penicillin, 100 µg/mL streptomycin and 10 %
10 (v/v) FBS. For neutralization bioassays, IL-2 was replaced by muIL-4. Therefore, potential neutralizing muIL-4 antibodies induced after immunogenic products injections will prevent CTLL-2 growth.

Serum samples were added at 1/200 final and positive control polyclonal anti-muIL-4 antibody at 1 µg/mL final, and were 2-fold serially diluted in 25 µL per well RPMI +
15 10 % (v/v) FBS in culture plates. muIL-4 was then added at 2 ng/mL final to serum samples and incubated for 1 hour at room temperature. Then 20,000 CTLL-2 cells were added to pre-incubated samples (serum or positive control plus muIL-4). Plates were incubated for 48 h at 37 °C, 5 % CO₂ in a humidified incubator. Cell viability was quantified by MTS/PMS assay. Forty microliters per well of MTS/PMS were added and
20 after 4 h at 37 °C, 5 % CO₂ in a humidified incubator, OD was read at 490 nm.

NC₅₀ results were expressed as the serum dilution factor (dil⁻¹) neutralizing 50 % of muIL-4 activity in presence of serum. The NC₅₀ is determined by interpolating the serum dilution resulting in a 50 % of IL-4 activity on the abscissa axis. Of note, a mouse is considered as a responder in this experiment if NC₅₀ ≥ 200 dil⁻¹.

25 None of the mouse exhibited anti-muIL-4 neutralizing antibodies before dosing (**Figure 5** and **Table 2**). In the control groups, no anti-muIL-4 antibodies having a neutralizing capacity were detected at any time point. For mice immunized with immunogenic product made with CRM₁₉₇, antibodies with neutralizing capacities against muIL-4 were

detectable in 9 out of 10 mice. In contrast, in mice immunized with the immunogenic product made with KLH the level of anti-IL-4 neutralizing antibodies were lower at any time point than the one observed when CRM₁₉₇ was the carrier and fewer sera exhibited neutralizing antibodies (at best time point only 6 sera exhibited neutralizing capacity (at day 120)). These results demonstrated that treatment with muIL-4 immunogenic product made with CRM₁₉₇ was more immunogenic than the conjugated vaccine made with KLH.

Table 2. NC₅₀ responders towards IL-4

	muIL-4 immunogenic product (CRM ₁₉₇)				muIL-4 immunogenic product (KLH)				muIL-4 + CRM ₁₉₇ (unconjugated)			
	D0	D39	D60	D120	D0	D39	D60	D120	D0	D39	D60	D120
Responders (NC ₅₀ > 200 dil-1)	0/10	5/10	7/10	9/10	0/10	2/10	4/10	6/10	0/5	0/5	0/5	0/5
	CRM ₁₉₇				PBS							
	D0	D39	D60	D120	D0	D39	D60	D120				
Responders (NC ₅₀ > 200 dil-1)	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5				

muIL-13 neutralization Bioassay

Antibodies induced by administrations of muIL-13 immunogenic product were assessed for their neutralizing capacities by muIL-13 neutralization bioassay before dosing and at days 39, 60 and 120.

The neutralizing capacities of anti-muIL-13 antibodies were evaluated using a HEK-Blue™ IL-4/IL-13 reporter gene bioassay (InvivoGen # hkb-il413) by monitoring the activation of the STAT6 pathway. In response to this activation, this cell line produces secreted embryonic alkaline phosphatase (SEAP) which can be quantified using QUANTI-Blue™ (at $\lambda = 625$ nm). Therefore, potential neutralizing muIL-13 antibodies induced after immunogenic products injections will prevent STAT6 pathway activation and can be evaluated.

Briefly, HEK-Blue™ IL-4/IL-13 cells were plated in an assay medium composed of DMEM GlutaMAX™ supplemented with 10 % (v/v) FBS, 10 mM HEPES, 50 U/mL

penicillin and 50 µg/mL streptomycin. Then a mix of muIL-13 (at 2 ng/mL final concentration) and two-fold serially diluted serum sample starting at 1/100 final or control antibody two fold serially diluted from 1 µg/mL final (polyclonal goat anti-muIL-13 antibody) were added to 40,000 HEK-Blue™ IL-4/IL-13 cells. Plates were incubated 24 h
 5 at 37 °C, in a 5 % CO₂ humidified incubator. Then, in new flat-bottom plates, 10 µL per well of cell supernatant were added to 90 µL per well of QUANTI-Blue™ and after 1 h at 37 °C, in a 5 % CO₂ humidified incubator, absorbances were read at 625 nm.

NC₅₀ results were expressed as the serum dilution factor (dil⁻¹) neutralizing 50 % of muIL-13 activity in presence of serum. The NC₅₀ is determined by interpolating the serum
 10 dilution resulting in a 50 % of muIL-13 activity on the abscissa axis. Of note, a mouse is considered as a responder in this experiment if NC₅₀ ≥ 100 dil⁻¹.

No muIL-13 neutralizing antibodies were detected before dosing in all groups as well as in control groups at any time point (**Figure 6** and **Table 3**). Mice treated with the immunogenic product made with CRM₁₉₇ produced antibodies with detectable
 15 neutralizing capacities against muIL-13 (**Figure 6** and **Table 3**). In mice immunized with immunogenic product made with KLH, no mice sera exhibited neutralizing antibodies against muIL-13. Of note, even if one mouse exhibited anti-muIL-13 antibodies as assessed by ELISA in the unconjugated muIL-13 and CRM₁₉₇ group (**Figure 4-B**), these antibodies were not neutralizing antibodies. These results demonstrated that treatment
 20 with the immunogenic product made with CRM₁₉₇ is more immunogenic than the one made with KLH.

Table 3. NC₅₀ responders towards IL-13

	muIL-13 immunogenic product (CRM ₁₉₇)				muIL-13 immunogenic product (KLH)				muIL-13 + CRM ₁₉₇ (unconjugated)			
	D0	D39	D60	D120	D0	D39	D60	D120	D0	D39	D60	D120
Responders (NC ₅₀ > 100 dil ⁻¹)	0/10	5/10	4/10	5/10	0/10	0/10	0/10	0/10	0/5	0/5	0/5	0/5
	CRM ₁₉₇				PBS							
	D0	D39	D60	D120	D0	D39	D60	D120				
Responders (NC ₅₀ > 100 dil ⁻¹)	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5				

As expected, no neutralizing anti-muIL-4 and anti-muIL-13 antibodies were detected in the CRM₁₉₇ and DPBS control groups at any time point. In the control groups where the cytokines and CRM₁₉₇ were mixed without chemical functionalization (unconjugated), immunization did not elicit anti-muIL-4 and anti-muIL-13 neutralizing antibodies, highlighting that conjugation between cytokine and carrier protein is mandatory to break B cell self-tolerance against cytokines. Moreover, for mice immunized with the immunogenic product made with KLH no anti-IL-13 neutralizing antibodies was observed while for mice immunized with immunogenic product made with CRM₁₉₇, antibodies with neutralizing capacities against muIL-13 were detectable in 5 out of 10 mice. These results demonstrated that treatment with muIL-13 immunogenic product made with CRM₁₉₇ was more immunogenic than the conjugated vaccine made with KLH.

Example 4: Residual activities of immunogenic products

Residual activity of muIL-4 immunogenic products

The residual activities of muIL-4 immunogenic products were assessed as described below (adapted from Soman *et al*, 2009).

Briefly, CTLL-2 cells are grown with IL-2. Culture medium was constituted of RPMI medium supplemented with IL-2 at 10 ng/mL final and 10 % (v/v) FBS.

For residual activity bioassays, IL-2 was replaced by muIL-4. Immunogenic products (with CRM₁₉₇ or KLH) of the invention and muIL-4 control were two-fold serially diluted in RPMI + 10 % (v/v) FBS in 96-well plates beginning at 1000 ng/mL until 4 ng/mL for immunogenic products and 10 ng/mL until 0.04 ng/mL final for muIL-4. As a positive control, six wells with muIL-4 at 10 ng/mL were added and used as the maximum cell proliferation control. These samples are added to 20,000 CTLL-2 cells per well and plates were incubated for 48 h at 37 °C, 5 % CO₂ in a humidified incubator. Cell proliferation was quantified by MTS/PMS assay. Forty microliters per well of MTS/PMS were added and after 4 h at 37 °C, 5 % CO₂ in a humidified incubator, plates were read at 490 nm.

The effective dose 50 (ED₅₀) value corresponds to the amount of immunogenic product or cytokine resulting in 50 % of maximum cell signal. The value is determined by

interpolating the 50 % of maximum cell signal onto the abscissa axis using the $y = ax + b$ formula from the curve passing by the dilution points surrounding the 50 % inflexion point.

The inactivation factor was calculated by dividing the ED_{50} of the tested immunogenic product by the mean ED_{50} of the muIL-4 control standard curves.

Table 4. ED_{50} and inactivation factors

Articles	ED_{50} [ng.mL ⁻¹]	muIL-4 control ED_{50} [ng.mL ⁻¹]	Inactivation factor
muIL-4 immunogenic product (CRM ₁₉₇)	620.3	1.67	370
muIL-4 immunogenic product (KLH)	21.5	1.03	21

As shown in **Table 4**, muIL-4 residual activity was more reduced in immunogenic product made with CRM₁₉₇ compared to the one prepared with KLH (much higher inactivation factor for muIL-4 immunogenic product prepared with CRM₁₉₇).

10 ***Residual activity of muIL-13 immunogenic products***

The residual activity of muIL-13 immunogenic products was monitored using HEK-Blue™ IL-4/IL-13 reporter cell line as described below.

Briefly, muIL-13 immunogenic products and muIL-13 control were two-fold serially diluted in assay medium (DMEM, 10 % (v/v) FBS, 10 mM HEPES buffer, 50 U/mL penicillin, 50 µg/mL streptomycin) in round bottom plates beginning at 250 ng/mL and 10 ng/mL final, respectively. These mixes were added to 40,000 HEK-Blue™ IL-4/IL-13 cells per well. Plates were incubated 24 h at 37 °C, in a 5 % CO₂ humidified incubator. Then, in new flat bottom plates, 10 µL per well of culture supernatant were added to 90 µL per well of QUANTI-Blue™ and after 1 h at 37 °C, in a 5 % CO₂ humidified incubator, ODs were read at 625 nm.

The effective dose 50 (ED₅₀) value, corresponding to the amount of the immunogenic product (or IL-13) resulting in 50% of maximum signal recorded for the considered samples, is determined by interpolating the OD_{max}/2 values to the corresponding sample concentrations using a four parameter logistic (4PL) nonlinear regression from the whole
5 dilution points.

The inactivation factors were calculated by dividing the ED₅₀ of the muIL-13 immunogenic products by the corresponding ED₅₀ of the muIL-13 control standard curves.

Table 5. ED₅₀ and inactivation factors

Articles	ED ₅₀ [ng.mL ⁻¹]	muIL-13 control ED ₅₀ [ng.mL ⁻¹]	Inactivation factor
muIL-13 immunogenic product (CRM ₁₉₇)	737	0.31	2369
muIL-13 immunogenic product (KLH)	297	0.41	723

10 As shown in **Table 5**, muIL-13 residual activity was more reduced in immunogenic product made with CRM₁₉₇ compared to the one prepared with KLH (much higher inactivation factor for muIL-13 immunogenic product prepared with CRM₁₉₇).

Intensity of the immune response against anti-IL-4 and anti-IL-13 was higher when the immunogenic product was made with CRM₁₉₇ compared the one made with KLH as a
15 carrier. In addition, cytokines residual activities were more reduced in immunogenic product made with CRM₁₉₇ compared to those prepared with KLH. From these results, we decided to perform a proof of concept with the products of the invention made with CRM₁₉₇ as a carrier protein. In addition, in allergy, both IL-4 and IL-13 are involved, so we decided to introduce a group of mice that would receive an immunogenic product
20 comprising both IL-4 and IL-13 conjugates with CRM₁₉₇. From now on, all the immunogenic products will be manufactured with CRM₁₉₇ as a carrier protein and their mixture will refer to Combo immunogenic product.

Example 5: Efficacy of the immunogenic product of the invention in an allergy mouse model

Among all allergies, allergic asthma and food allergy are major public health problems now each affecting more than 300 million people worldwide. Allergies are considered to
5 result from a breakdown of tolerance, resulting in type 2 immune responses characterized by the production of TH2 cytokines such as IL-4 and IL-13, high levels of IgE antibodies, and infiltration and expansion of immune cells (in particular mast cells, basophils, eosinophils and T cells) within the inflamed tissue.

House dust mite (HDM) is a major source of allergen that affects more than 50% of
10 allergic patients (Meyer *et al.* 1994). In mice, repeated intranasal challenges with HDM reproduced key features of human chronic asthma including airway hyperresponsiveness (AHR), airflow obstruction, airway wall remodeling, mucus production and inflammatory responses in the lungs characterized by high levels of eosinophils.

Preparation of muIL-4/IL-13 immunogenic products

15 ***a) CRM₁₉₇ functionalization***

CRM₁₉₇ was diluted in the modification buffer comprising 70 mM sodium phosphate buffer, 150 mM NaCl, 5 mM EDTA (pH 7.2). SATA was diluted in DMSO to reach a 100 mM concentration. Then, SATA was added to CRM₁₉₇ and after 30 minutes of incubation on a nutator at room temperature, SATA in excess was removed using Zeba™
20 desalting spin column, according to the manufacturer's instructions.

Subsequently, hydroxylamine was diluted in the same buffer at 500 mM. Then, CRM₁₉₇-SATA was incubated with the hydroxylamine solution at a 50 mM final concentration, during 2 hours on a nutator at room temperature. Finally, the mixture was desalted and reagents in excess were removed using Zeba™ desalting spin column.

25 ***b) muIL-4 and muIL-13 functionalization***

muIL-4 was dissolved in modification buffer (70 mM sodium phosphate buffer, 150 mM NaCl, 5 mM EDTA, pH 7.2). sGMBS was diluted in modification buffer at 10 mM. Then,

sGMBS was added to muIL-4 and after one hour of incubation on a nutator at room temperature, sGMBS in excess was removed using Zeba™ desalting spin column.

muIL-13 was dissolved in modification buffer (70 mM sodium phosphate buffer, 150 mM NaCl, 5 mM EDTA, pH 7.2). sGMBS was diluted in modification buffer at 10 mM. Then,
5 sGMBS was added to muIL-13 and after one hour of incubation on a nutator at room temperature, sGMBS in excess was removed using Zeba™ desalting spin column.

c) Conjugation

After CRM₁₉₇, muIL-4 and muIL-13 functionalization, protein contents of each preparation were determined by Bradford assay.

10 Functionalized CRM₁₉₇ was added to functionalized muIL-4 or functionalized muIL-13 at a molar ratio of 1:2 (carrier:muIL-4) and 1:4 (or carrier:muIL-13). Individual immunogenic product preparations were incubated overnight at 4 °C, on a nutator. The resulting immunogenic products were then concentrated using Amicon® (3 kDa-cut-off membrane), 0.22 µm-filtered and kept at 4 °C.

15 *d) Immunogenic product quantifications*

Concentrations of muIL-4 immunogenic product and muIL-13 immunogenic product were determined by Coomassie Plus (Bradford) Protein Assay according to the manufacturer instructions.

muCombo immunogenic product preparation

20 Independently synthesized muIL-4 immunogenic product and muIL-13 immunogenic product were mixed together in a 1-1 weight ratio after the concentration and 0.22 µm sterile-filtration steps and resulting muCombo immunogenic product was stored at 4°C.

Mice immunization, allergic asthma protocol and blood sampling

Each Balb/c mouse received four intramuscular (i.m.) injections of immunogenic
25 products alone or muCombo immunogenic product or CRM₁₉₇ alone, as control, all

emulsified with squalene-based adjuvant on days 0, 7, 28 and 55 as detailed in **Table 6** and **Figure 7**. First immunization was performed on mice at 7 weeks of age.

Table 6. Dose schedule of administrations

Article	Number of mice per group	Days	Dose (µg)	Adjuvant
muIL-4 immunogenic product	12	0 / 7 / 28 / 55	30 / 30 / 10 / 10	Squalene oil-in-water adjuvant
muIL-13 immunogenic product	12	0 / 7 / 28 / 55	30 / 30 / 10 / 10	
muCombo immunogenic product	12	0 / 7 / 28 / 55	30 / 30 / 10 / 10	
CRM ₁₉₇	12	0 / 7 / 28 / 55	15 / 15 / 5 / 5	

- 5 Thirty-nine days after first immunogenic product immunization, chronic airway inflammation was induced in mice by three intra nasal injections of 100 µg HDM from *Dermatophagoides farinae* (purchased from Greer) on days 39, 43 and 46. Starting on day 50, mice were challenged by intranasal injections with 25 µg HDM twice weekly (total of 9 challenges).
- 10 Blood collections were performed seven days before dosing, at days 39, 64 and 24 hours after the last HDM challenge (mice sacrifice). Serum samples were prepared as previously described and were stored at -20 °C until analysis.

In this study were evaluated:

- Immunogenicity of the injected products by ELISA and bioassay,
- 15 - Airway hyperresponsiveness (AHR) measured by whole body plethysmography,
- Biological markers: circulating IgE levels in serum by ELISA, airway inflammation in lung and bronchoalveolar lavage (BAL) by FACS analysis and airway histology and inflammatory cell infiltration.

a) Immunogenicity of the injected products by ELISA and bioassay

Antibody titers of anti-muIL-4 and anti-muIL-13 were measured by ELISA (as described above) from mice sera collected in the four treated groups.

No cytokine antibody titers were detected before dosing in all groups and in CRM₁₉₇ receiving group at all time points. Anti-muIL-4 antibody titers were detected in all mice at all time points after muIL-4 immunogenic product and muCombo immunogenic product immunization (**Figure 8-A**). Higher levels were observed in mice receiving muIL-4 immunogenic product compared to muCombo immunogenic product. Anti-muIL-13 antibody titers were detected in mice starting at D39 and with 100% responding mice at D65 in muIL-13 immunogenic product group (**Figure 8-B**). In muCombo immunogenic product group, anti-muIL-13 antibodies were also detected as soon as D39 and with 9 out of 12 responding mice at D65. Overall, higher antibody titers were observed in sera after immunization with muIL-4 and muIL-13 immunogenic products than with muCombo immunogenic product, as expected since mice in the muCombo group received half the individual immunogenic product dose (**Figure 14**).

The neutralization activity of each immunogenic products was assessed in vitro using two different bioassays as described above. Of note, a mouse is considered as a responder in this experiment if NC₅₀ is ≥ 200 dil⁻¹ for IL-4 and ≥ 100 dil⁻¹ for IL-13.

High neutralizing capacities against muIL-4 were observed in mice immunized with muIL-4 immunogenic product and muCombo immunogenic product (**Figure 9-A** and **Table 7**), n= 11 out of 12 or n= 9 out of 12 at least one time point, respectively.

Table 7. NC₅₀ responders towards IL-4.

	muIL-4 immunogenic product			muCombo immunogenic product			CRM ₁₉₇		
	D0	D39	D65	D0	D39	D65	D0	D39	D65
Responders (NC ₅₀ > 200 dil ⁻¹)	0/12	10/12	11/12	0/12	7/12	9/12	0/12	0/12	0/12

Interestingly, one year after immunization with muIL-4 or muCombo immunogenic product, anti-IL-4 antibodies were still detected in mice (**data not shown**).

Neutralizing capacities against muIL-13 in mice immunized with muIL-13 immunogenic product and muCombo immunogenic product were also induced with n= 10 out of 12 or n= 7 out of 12 at least one time point, respectively (**Figure 9-B** and **Table 8**).

Table 8. NC₅₀ responders towards IL-13

	muIL-13 immunogenic product			muCombo immunogenic product			CRM ₁₉₇		
	D0	D39	D65	D0	D39	D65	D0	D39	D65
Responders (NC ₅₀ > 100 dil-1)	0/12	8/12	10/12	0/12	3/12	7/12	0/12	0/12	0/12

Interestingly, one year after immunization with muIL-13 or muCombo immunogenic product, anti-IL-13 antibodies were still detected in mice (**data not shown**).

Of note, co-injection of muIL-4 and/or muIL-13 and CRM₁₉₇ without prior chemical coupling did not elicit anti-IL-4 and anti-IL-13 antibodies, highlighting that conjugation between cytokine and carrier protein is mandatory to break B cell self-tolerance against cytokines.

Different classes (including in particular IgG1, IgG2a, IgG2b, IgG3, IgA, IgE and IgM) of anti-IL-4 and anti-IL-13 antibodies were produced after immunization, mostly IgG1 (**data not shown**).

15 *b) Airway hyperresponsiveness (AHR) measured by whole body plethysmography*

Twenty-four hours after the last challenge, AHR was evaluated by whole body plethysmography. Responses to methacholine, a bronchoconstrictor agent, were measured in conscious mice.

Different doses of methacholine were administered by aerosol: 0 mg/mL, 3.5 mg/mL, 20 7 mg/mL and 14 mg/mL. Enhanced pause (Penh) has been used to evaluate changes in pulmonary function (Hamelmann et al., 1997). This measurement conceptualized the phase shift between the thoracic flow and the nasal flow curves: increased phase shift correlated with increased respiratory system resistance. Penh is calculated by the formula $Penh = (Te/RT-1) \times PEF/PIF$, where Te is expiratory time, RT the relaxation time, PEF

the peak expiratory flow, and PIF is peak inspiratory flow. Penh values were recorded during 5 minutes after each methacholine challenge and the maximum value during the period is reported in the graphic.

A high bronchoconstriction in mice sensitized with HDM in CRM₁₉₇ control group was observed (**Figure 10**). The bronchoconstriction was partially inhibited with muIL-13 immunogenic product and muIL-4 immunogenic product while it was almost abrogated in mice immunized with muCombo immunogenic product showing the high protective effect of the products of the invention. Indeed, the level of residual bronchoconstriction observed in the muCombo group was similar to the one observed in HDM-unsensitized mice (circle in **Figure 10**).

These results were confirmed using invasive airway response measurements. Indeed, HDM-treated control mice exhibited significantly increased changes in lung resistance and elastance upon methacholine challenge, as compared to the PBS-treated control group while these two features were partially reduced in mice treated with muIL-4, muIL-13 or muCombo immunogenic product (**data not shown**).

Altogether, these results indicate that AHR can be blocked upon dual vaccination against IL-4 and IL-13.

c) Biological markers

Circulating IgE levels in serum by ELISA

Total circulating IgE levels were measured by ELISA following manufacturer's instructions (Mouse IgE ELISA Quantitation Set, Bethyl Labs E90-115) before immunogenic product vaccination and 24 hours after the last HDM challenge (**Figure 11**).

No circulating IgE were detected before vaccination. Twenty-four hours after the last challenge with HDM, total circulating IgE were induced due to HDM sensitization (**Figure 11-B**). The levels were reduced in all the immunogenic products receiving groups, demonstrating the protection effect of the products of the invention compared to

CRM₁₉₇ immunized mice. Of note, similar results were obtained when only HDM-specific IgE were measured by ELISA (**data not shown**).

HDM-treated mice also present elevated levels of HDM-specific IgG antibodies. However, these levels were not affected by treatment with muIL-4 and/or muIL-13
5 immunogenic product (**data not shown**).

Airway inflammation in lung and bronchoalveolar lavage (BAL)

A detailed time-course analysis of cellular changes in lung and bronchoalveolar lavage (BAL) of mice sensitized with HDM or PBS was carried out.

Inflammatory cells from BAL were analyzed by FACS using the following antibodies
10 (**Table 9**): CD45-FITC, Ly6G-PE, CD11b-VG, SiglecF-PECy7, B220-APC and CD3-APC according to manufacturer's instructions.

Antibody	Provider – Catalog number (Clone)
Ly6G-PE	BD Pharmingen - 561104 (Clone 1A8, Rat IgG _{2a} , κ)
CD3-APC	BD Pharmingen - 561826 (Clone 145-2C11, Armenian Hamster IgG1, κ)
CD45-FITC	Miltenyi 130-110-658 (Clone REA737, recombinant human IgG1)
SiglecF-PECy7	Miltenyi 130-112-334 (Clone REA798, recombinant human IgG1)
CD11b-VG	Miltenyi 130-110-559 (Clone REA713, recombinant human IgG1)
B220-APC	Miltenyi 130-102-259 (Clone RA3-6B2, rat IgG2a κ)

In lung of control mice, chronic intranasal exposure to HDM resulted in significant increases in the numbers of CD45⁺ cells infiltration of hematopoietic origin mainly constituted of eosinophils (CD45⁺, Ly6G⁻, CD11b⁺, SiglecF⁺), as compared to PBS-
15 treated animals (**data not shown**). Interestingly, immunogenic products vaccination prevented eosinophils infiltration among CD45⁺ infiltrating cells, especially in the muCombo immunogenic product group that exhibited a statistically significant decrease.

In bronchoalveolar lavage, HDM sensitization resulted in an inflammatory response characterized by CD45⁺ cells infiltration of hematopoietic origin mainly constituted of
20 eosinophils (CD45⁺, Ly6G⁻, CD11b⁺, SiglecF⁺) (**Figure 12**). Interestingly, immunogenic products vaccination prevented eosinophils infiltration among CD45⁺

infiltrating cells, especially in the muCombo immunogenic product group that exhibited a statistically significant decrease.

Interestingly, vaccination with immunogenic products of the invention had no effect on the level of eosinophils in the blood (**data not shown**), indicating that the reduced airway eosinophilia observed in vaccinated mice is a consequence of reduced eosinophil recruitment to the lungs rather than systemic effects on the numbers of eosinophils or eosinophil progenitors.

Airway histology

The effects of sensitization and vaccination on airway was examined by histological analyses. Briefly, left lung was excised post mortem, fixed with 4% PFA for 24 h at room temperature, and preserved in 70% ethanol. Longitudinal sections were done and stained with:

- Hematoxylin and Eosin (H&E) for assessment of leukocyte infiltration,
- Toluidine Blue for quantification of mast cell numbers, or
- Periodic acid Schiff (PAS) staining for assessment of goblet cells hyperplasia and mucus production.

Globally, these lung histological analyses confirm that vaccination with muIL-4, muIL-13 or muCombo immunogenic product in HDM-treated animals significantly reduced the numbers of leucocytes and intraepithelial mast cells, as compared to non-vaccinated HDM-treated animals (**data not shown**).

PAS histological analyses also confirm that vaccination with muIL-4, muIL-13 or muCombo immunogenic product in HDM-treated animals significantly reduced the goblet cell hyperplasia/mucus secretion, as compared to non-vaccinated HDM-treated animals (**data not shown**). These results support that the immunogenic products (in particular muIL-13 and muCombo immunogenic products) may control mucus hypersecretion induced by HDM sensitization.

In conclusion, we have demonstrated that the products of the invention made with CRM₁₉₇ were immunogenic and induced anti-cytokine neutralizing antibodies whether injected alone or in combination (muCombo immunogenic product). The presence of anti-cytokine neutralizing antibodies was associated with a reduction of HDM-induced AHR, measured by Penh value following methacholine inhalation. In addition, these anti-cytokine neutralizing antibodies were able to limit circulating IgE levels as well as mast cells number in lung and eosinophils infiltration in airways.

Consequently, these results demonstrate that the immunogenic products of the invention are capable to break B cell tolerance against IL-4 and IL-13 and suggest that these immunogenic products may represent promising new therapeutic strategies in the treatment of asthma and/or allergy, and in particular in the treatment of allergic asthma.

Interestingly, individual immunogenic products were active but superior beneficial effects on asthma and/or allergy symptoms (and in particular on allergic asthma symptoms) and biological markers were observed when the immunogenic products were combined (muCombo immunogenic product).

Example 6: Preparation of the human immunogenic products of the invention

The preparation of human IL-4 immunogenic product, IL-13 immunogenic product and Combo immunogenic product was carried out following the same manufacturing process as described above, using the human cytokines IL-4 and IL-13 instead of the murine cytokines.

Preparation of IL-4 and IL-13 immunogenic product

a) CRM₁₉₇ functionalization

CRM₁₉₇ functionalization was performed as described for the murine product.

b) IL-4 and IL-13 functionalization

IL-4 or IL-13 dissolved in the buffer (70 mM sodium phosphate buffer, 150 mM NaCl, 5 mM EDTA, pH 7.2) were reacted with sGMBS previously dissolved at a 10 mM concentration in buffer. After one hour of reaction at room temperature with mild
5 agitation, excess sGMBS was removed by Zeba desalting column.

c) Conjugation

After CRM₁₉₇, IL-4 and IL-13 functionalization, protein contents of each preparation were determined by Bradford assay. Functionalized CRM₁₉₇ was added to functionalized IL-4 or functionalized IL-13 at a molar ratio of 1:4 (carrier:IL-4 or carrier:IL-13).
10 Individual immunogenic product preparations were incubated overnight at 4 °C on a nutator. The conjugates were submitted to desalting column to remove potential impurities, such as remaining hydroxylamine, from previous steps. Resulting immunogenic product was concentrated and filtered through a 0.22 µm filter and stored at 4°C.

15 Preparation of Combo immunogenic product

Preparation of Combo immunogenic product can be performed using two different ways: by incubating both modified cytokines concomitantly with the modified carrier protein (simultaneous synthesis) or by mixing two independently synthesized IL-4 and IL-13 immunogenic products (mix preparation).

20 Combo immunogenic product preparation via simultaneous synthesis***a) CRM₁₉₇ functionalization***

CRM₁₉₇ functionalization was performed as described for the murine product.

b) IL-4 and IL-13 functionalization

IL-4 or IL-13 functionalization was performed as described for individual immunogenic
25 product preparation.

c) Conjugation

After CRM₁₉₇, IL-4 and IL-13 functionalization, protein contents of each preparation were determined by Bradford assay. All three modified proteins in phosphate buffer, 150 mM NaCl, 5 mM EDTA, pH 7.2 were mixed at a 2-2-1 molar ratio IL-4-IL-13-
5 CRM₁₉₇. The reaction was carried out at 4°C overnight. The conjugate was submitted to desalting column to remove potential impurities, such as remaining hydroxylamine, from previous steps. Resulting immunogenic product was concentrated and filtered through a 0.22 µm filter and stored at 4°C.

Combo immunogenic product preparation via mix preparation

10 Independently synthesized IL-4 and IL-13 immunogenic products were mixed together in a 1-1 weight ratio after the concentration and 0.22 µm sterile-filtration steps. Combo immunogenic product was stored at 4°C until used.

Example 7: Antigenicity of the human product

A sandwich ELISA was performed to evaluate the cytokine coupling to the carrier protein
15 and also evaluating whether epitopes are preserved during the manufacturing process. The protocol used was the same as described hereabove using biotinylated anti-human IL-4 and IL-13 antibodies.

Results are shown in **Figure 13**. This test confirmed that the immunogenic product of the invention comprises IL-4 or IL-13 coupled to CRM₁₉₇. Furthermore, these results confirm
20 that the immunogenic product is antigenic (*i.e.*, recognized by anti-IL-4 or anti-IL-13 antibody), as well as in Combo immunogenic product.

Example 8: Immunogenicity of the human product

Mice immunization protocol

Each Balb/c mouse (10 mice per group) received four intramuscular (i.m.) injections of
25 immunogenic product emulsified with squalene-based adjuvant on days 0, 7, 28 and 49 all performed at a 4 µg dose, as detailed in **Figure 14**. First immunization was performed

at 7 weeks of age. Blood collections were carried out before dosing, and at days 38, 59, 90 and 120. Serum samples were prepared after coagulation at room temperature and centrifugation to remove the clot.

Determination of anti-IL4 and anti-IL-13 antibodies titers by ELISA

- 5 Anti-cytokines antibody titers were measured by ELISA from mice sera collected in each group.

The determination of each antibody titers in sera after immunization with immunogenic products or combo-immunogenic product were assessed as described above by coating human IL-4 and IL-13 on the 96-well plates.

- 10 No cytokine antibody titers were detected before dosing in all groups. Anti-IL-4 antibody titers were detected in all mice at all time points after IL-4 immunogenic product and muCombo immunogenic product immunizations (**Figure 15-A**). Similar levels were observed in mice receiving IL-4 immunogenic product and Combo immunogenic product, indicating that we might have reached the plateau of the immune response. Anti-
- 15 IL-13 antibody titers were detected in all mice at all time points after immunization in IL-13 immunogenic product group (**Figure 15-B**). In Combo immunogenic product group, anti-IL-13 antibodies were also detected as soon as D38 and in 8 out of 10 mice at D59. Higher anti-IL-13 antibody titers were observed in sera after immunization with IL-13 immunogenic product than with Combo immunogenic product, since mice in the Combo
- 20 group received half the individual immunogenic product dose.

Determination of neutralizing capacities after immunizations

Anti-IL-4 and anti-IL-13 neutralizing capacities were assessed using HEK-Blue™ IL-4/IL-13 reporter cell line as described above. Of note, in this experiment, a mouse is considered as a responder if NC₅₀ is ≥ 200 dil⁻¹ for IL-4 and ≥ 100 dil⁻¹ for IL-13.

- 25 High neutralizing capacities against IL-4 were observed in groups immunized with IL-4 immunogenic product and Combo immunogenic product with 100% of responding mice at all time points after immunization (**Figure 16-A and Table 10**).

Table 10. NC₅₀ responders towards IL-4

	IL-4 immunogenic product					Combo immunogenic product				
	D0	D38	D59	D90	D120	D0	D38	D59	D90	D120
Responders (NC ₅₀ > 200 dil-1)	0/10	10/10	10/10	10/10	10/10	0/10	10/10	10/10	10/10	10/10

Antibodies with neutralizing capacities against IL-13 were also induced in mice immunized with IL-13 immunogenic product and Combo immunogenic product with 100% of responding mice at D59 (**Figure 16-B** and **Table 11**).

5 **Table 11.** NC₅₀ responders towards IL-13

	IL-13 immunogenic product					Combo immunogenic product				
	D0	D38	D59	D90	D120	D0	D38	D59	D90	D120
Responders (NC ₅₀ > 200 dil-1)	0/10	9/10	10/10	9/10	9/10	0/10	9/10	10/10	10/10	10/10

Collectively, products of the invention were capable of inducing high anti-cytokines antibody titers with strong neutralizing capacities.

Residual activity of human immunogenic products

The residual activities of human IL-4 immunogenic product, IL-13 immunogenic product and Combo immunogenic product were monitored using HEK-Blue™ IL-4/IL-13 reporter cell line as described above for the residual activity of IL-4 and IL-13.

Table 12. ED₅₀ and inactivation factors towards IL-4

Articles	ED ₅₀ [ng.mL ⁻¹]	IL-4 control ED ₅₀ [ng.mL ⁻¹]	Inactivation factor
IL-4 immunogenic product	231	0.043	5287
Combo immunogenic product	382	0.043	8765

Table 13. ED₅₀ and inactivation factors towards IL-13

Articles	ED ₅₀ [ng.mL ⁻¹]	IL-13 control ED ₅₀ [ng.mL ⁻¹]	Inactivation factor
IL-13 immunogenic product	444	0.258	1848
Combo immunogenic product	268	0.258	1116

As shown in **Table 12** and **Table 13**, inactivation factors towards IL-4 or IL-13 in the human immunogenic products were all greater than 1000 (and up to 8765), indicating that cytokines residual activities in the immunogenic products were reduced by a minimum of three orders of magnitude compared to native cytokines.

These highly reduced residual activities are an important element supporting the safety profile of the products of the invention.

Example 9: Therapeutic efficacy of the immunogenic product of the invention in a mouse model of food allergy model

Food allergy is a major health issue in westernized countries with increasing prevalence over the last decades and a lack of curative treatment. Several major food staples, including milk, peanut, soy and wheat can induce food allergic reactions. Food allergies reflect a failure of oral tolerance of innocuous food allergens, resulting in the development of a dysregulated Th2-immune response, the secretion of Th2 cytokines (mostly IL-4 and IL-13), the secretion of allergen specific-IgE and the recruitment of effector cells to the gastrointestinal (GI) tract.

The therapeutic efficacy of the immunogenic product of the invention in food allergy was investigated using IL-4raF709 mutant mice. IL-4raF709 mice carry a gain-of-function mutation in the IL-4 receptor (IL-4R) alpha chain that disrupts the binding of the Src homology domain 2 containing protein tyrosine phosphatase 1 (SHP-1) to the receptor subunit and leads to augmented signal transducer and activator of transcription 6 (STAT6) activation by IL-4 and IL-13. These mice exhibit enhanced Th2 cell responses and IgE

production. Thus, this mutation is prototypic of a number of human IL-4R α polymorphisms that promote receptor signaling and are associated with atopy.

Preparation of muIL-4/IL-13 and muCombo immunogenic products

muIL-4, muIL-13 and muCombo immunogenic products are synthesized as described
5 herein above.

Mice immunization, food allergy model, anaphylaxis response, histological analyses and blood sampling

Each IL-4raF709 mutant mice were immunized with muIL-4, muIL-13 or muCombo immunogenic products or CRM₁₉₇, as a control, all emulsified with squalene-based
10 adjuvant on days 0, 7, 28 and then boosted.

In parallel, mice were sensitized by oral gavage with either PBS or with 23 mg of Peanut (PE) butter, corresponding to 5 mg of peanut protein, suspended in 250 μ l of 0.1 M sodium bicarbonate (pH 8.0). Mice were challenged with an enteral bolus of 450 mg peanut butter (100 mg protein), diluted in water (Burton et al., 2014).

15 Just after the challenge, core body temperature was followed during one hour as well as the onset of diarrhea.

A clinical score was also determined: 0, no clinical symptom; 1, repetitive mouth/ear scratching and ear canal digging with hind legs; 2, decreased activity, self-isolation, puffiness around eyes and/or mouth; 3, periods of motionless for more than one minute,
20 lying prone on stomach; 4, no response to whisker stimuli, reduced or no response to prodding; 5, tremor convulsion or death.

Sections of intestinal tissues were collected for histological analyses (*e.g.*, mast cell quantification).

Blood was also collected to study the level of inflammation (*e.g.*, mast cell degranulation product), antibody levels (*e.g.*, anti-cytokines titers, neutralizing capacities, allergen-specific-IgG and -IgE and total IgE).
25

Example 10: Therapeutic efficacy of the immunogenic product of the invention in a mouse model of atopic dermatitis

Atopic dermatitis (AD) is a chronic or chronically relapsing, pruritic inflammatory skin disease. The incidence of AD has dramatically increased for the past three decades in industrialized countries. Immunological abnormalities of AD are generally characterized by sensitization with various allergens (*e.g.*, foods, aeroallergens, microbes, and autoallergens), high serum IgE levels, and skin lesions with apoptotic keratinocytes and infiltration with immune cells that secrete Th2 cytokines such as IL-4, IL-5 and IL-13.

The therapeutic efficacy of the immunogenic products of the invention in AD was investigated by using an animal model in which repeated epicutaneous application of a house dust mite (HDM) extract and staphylococcal enterotoxin B induces eczematous skin lesions.

Preparation of muIL-4/IL-13 and muCombo immunogenic products

muIL-4, muIL-13 and muCombo immunogenic products are synthesized as described herein above.

Mice immunization, atopic dermatitis induction, clinical severity measurement, histological analyses and blood sampling

Mice were immunized with muIL-4, muIL-13 or muCombo immunogenic products or CRM₁₉₇, as a control, all emulsified with squalene-based adjuvant.

In parallel, atopic dermatitis was induced as previously described in Ando *et al.* (J Invest Dermatol. 2013 Dec;133(12):2695-2705). Briefly, solutions of 500 ng of Staphylococcal enterotoxin (SEB) and 10 µg of Dermatophagoides farinae extract (Der f is a house dust mite, HDM) were applied on a gauze pad placed on the shaved area. This portion of the back skin was occluded with a Tegaderm™ Transparent Dressing using bandages. Three days later, the dressings were replaced with a new one. After an additional 4 days had passed, the dressings were removed and the mice were kept without treatment for the next

week. The one-week Der f/SEB treatment was repeated two more times, thus mice were the subjected to three cycles of such treatment.

Clinical severity was scored by an investigator who did not know the identities of mice 2 days after removing the dressings in the last cycle. Clinical scores were based on the severity (0, no symptoms; 1, mild; 2, intermediate; 3, severe) of four possible symptoms (redness, bleeding, eruption, and scaling). Maximum possible score is 12.

Mice were euthanized immediately after scoring, back skin specimens corresponding to the treated areas were obtained for histological analyses of epidermal thickness and eosinophilia. Blood was also collected to study the level of inflammation and antibody levels (*e.g.*, anti-cytokines titers, neutralizing capacities, allergen-specific-IgG and -IgE and total IgE).

Example 11: Therapeutic efficacy of the immunogenic product of the invention in a mouse model of chronic obstructive pulmonary disease (COPD)

COPD is characterized by the progressive airflow limitation commonly associated with exaggerated inflammatory responses to inhaled irritants, which leads to the chronic obstructive bronchitis and the destruction of lung parenchyma, termed emphysema.

Several animal models of COPD have been established to elucidate possible mechanisms underlying the initiation and progression of COPD. Here, a protease-induced model was used to assess the therapeutic efficacy of the immunogenic product of the invention in COPD.

Preparation of muIL-4/IL-13 and muCombo immunogenic products

muIL-4, muIL-13 and muCombo immunogenic products are synthesized as described herein above.

Mice immunization, atopic dermatitis induction, leukocyte quantification and histological analyses

Mice were immunized with muIL-4, muIL-13 or muCombo immunogenic products or CRM₁₉₇, as a control, all emulsified with squalene-based adjuvant.

- 5 In parallel, intranasal instillation of elastolytic enzymes, such as porcine pancreatic elastase was used to trigger COPD-like symptoms such as, for example, emphysema formation. Briefly, BALB/c mice were intranasally treated with 0.6 U porcine pancreatic elastase in 30μL of PBS (Shibata *et al. Proc Natl Acad Sci USA*. 2018 Dec 18;115(51):13057-13062).
- 10 In a first experiment, mice were euthanized on day 5 for assessment of leukocytes: Number of leukocytes (*e.g.*, monocytes, macrophages, neutrophils, T cells, B cells and eosinophils) was quantified by flow cytometry in bronchoalveolar lavage (BAL) fluids and single cell suspensions of lung cells. An additional assessment of leukocyte infiltration in the lungs was performed by histological examinations of lung tissues
- 15 previously stained with hematoxylin and eosin (H&E). Blood was also collected to study the level of inflammation and antibody levels (*e.g.*, anti-cytokines titers, neutralizing capacities).

- In a second experiment, mice were sacrificed on day 21 after elastase treatment for assessment of lung emphysema by histology in H&E-stained lung tissue sections, using
- 20 mean linear intercept (MLI) as an indicator of lung airspace enlargement. Blood was also collected to study the level of inflammation and antibody levels (*e.g.*, anti-cytokines titers, neutralizing capacities, allergen-specific-IgG and -IgE and total IgE).

Example 12: Therapeutic efficacy of the immunogenic product of the invention in a mouse model of pulmonary fibrosis

- 25 Pulmonary fibrosis represents a broad spectrum of diseases that are characterized by different degrees of lung inflammation, excessive proliferation of lung fibroblasts, and increased lung collagen content.

The therapeutic efficacy of the immunogenic product of the invention in pulmonary fibrosis was investigated using an animal model in which bleomycin (BLM) administration in lungs leads to secretion of proinflammatory cytokines and chemokines, recruitment of leukocytes, increased collagen production, remodeling, and fibrosis lung inflammation.

Preparation of muIL-4/IL-13 and muCombo immunogenic products

muIL-4, muIL-13 and muCombo immunogenic products are synthesized as described herein above.

Mice immunization, pulmonary fibrosis induction, leukocyte quantification and histological analyses

Mice were immunized with muIL-4, muIL-13 or muCombo immunogenic products or CRM₁₉₇, as a control, all emulsified with squalene-based adjuvant.

In parallel, pulmonary fibrosis was induced in C57BL/6 mice as described previously by Reber *et al.* (J Immunol 2014 Feb 15;192(4):1847-54). Briefly, pulmonary fibrosis was induced by intranasal (i.n.) administration of BLM hydrochloride (0.1 mg in 25 µl PBS; 12.5 µl/nostril).

Body weight was monitored 5 times per week until the end of the experiment and mice were euthanized 7 days or 14 days after BLM treatment for assessment of lung fibrosis.

Number of leukocytes (*e.g.*, monocytes, macrophages, neutrophils, T cells, B cells and eosinophils) was quantified by flow cytometry in bronchoalveolar lavage (BAL) fluids and single cell suspensions of lung cells.

Histological examinations of lung tissues stained with hematoxylin and eosin (for assessment of leukocyte infiltration), masson trichrome (for assessment of fibrosis), or toluidine blue (for assessment of mast cell numbers) were performed.

Blood was also collected to study the level of inflammation and antibody levels (*e.g.*, anti-cytokines titers, neutralizing capacities).

CLAIMS

1. An immunogenic product comprising at least one cytokine conjugated with a carrier protein, wherein the at least one cytokine is selected from the group comprising IL-4, IL-13 and mixtures thereof, and wherein the carrier protein is CRM₁₉₇.
5
2. The immunogenic product according to claim 1, wherein the at least one cytokine is IL-4.
3. The immunogenic product according to claim 1 or claim 2, wherein the at least one cytokine is IL-13.
- 10 4. The immunogenic product according to any one of claims 1 to 3, comprising CRM₁₉₇ coupled with both IL-4 and IL-13.
5. A composition comprising at least one immunogenic product according to any one of claims 1 to 4.
6. The composition according to claim 5, comprising a mixture of at least two immunogenic products according to any one of claims 1 to 4.
15
7. The composition according to claim 5 or claim 6, comprising a mixture of an immunogenic product comprising IL-4 and CRM₁₉₇ with an immunogenic product comprising IL-13 and CRM₁₉₇.
8. The composition according to any one of claims 5 to 7, comprising a mixture of an immunogenic product comprising IL-4 and CRM₁₉₇ with an immunogenic product comprising IL-13 and CRM₁₉₇ at a weight ratio ranging from about 10:1 to about 1:10.
20
9. The composition according to any one of claims 5 to 8, further comprising at least one pharmaceutically acceptable excipient and/or at least one adjuvant.
- 25 10. The composition according to any one of claims 5 to 9, being an emulsion.

11. A method for producing an immunogenic product according to any one of claims 1 to 4, the method comprising steps of:
- a) contacting the at least one cytokine with a heterobifunctional crosslinker containing a NHS-ester, preferably N-[γ -maleimidobutyryloxy]-succinimide ester (sGMBS);
 - b) contacting the carrier protein with a heterobifunctional crosslinker containing a NHS-ester, preferably N-succinimidyl-S-acetylthioacetate (SATA) to generate a carrier-SATA complex;
 - c) contacting the sGMBS-cytokine complex obtained at step (a) with the carrier SATA complex obtained at step (b).
12. An immunogenic product according to any one of claims 1 to 4 or a composition according to any one of claims 5 to 10, for treating an inflammatory disorder, preferably wherein said disorder is associated with aberrant IL-4 and/or IL-13 expression or activity.
13. The immunogenic product or the composition for use according to claim 12, wherein the inflammatory disorder is selected from the group comprising asthma (either allergic or non-allergic), allergic conditions (such as, for example, food allergies, venom allergy, allergy to animals, drug allergy, hyper IgE syndrome, allergic rhinitis, allergic conjunctivitis and allergic enterogastritis), atopic disorders (such as, for example, atopic dermatitis, urticaria (including chronic idiopathic urticaria and chronic spontaneous urticaria), eczema), bullous pemphigoid, respiratory disorders (such as allergic and nonallergic asthma, chronic obstructive pulmonary disease (COPD)), nasal polyposis and other conditions involving airway inflammation (such as, for example, eosinophilia, fibrosis and excess mucus production including cystic fibrosis and pulmonary fibrosis, systemic sclerosis (SSc)); inflammatory and/or autoimmune disorders or conditions, gastrointestinal disorders or conditions (such as, for example, inflammatory bowel diseases (IBD) and eosinophilic esophagitis (EE), and eosinophilic-mediated gastrointestinal disease, ulcerative colitis and Crohn's disease); systemic lupus erythematosus, liver disorders or conditions (such as, for example, cirrhosis, and hepatocellular

carcinoma), scleroderma; fibrotic diseases or disorders (such as, for example, fibrosis of the liver (such as, for example, fibrosis caused by a hepatitis B and/or C virus)), scleroderma; solid tumors or cancers such as leukemia (such as, for example, B cell chronic lymphocytic leukaemia), glioblastoma, lymphoma (such as, for example, Hodgkin's lymphoma) and mastocytosis.

- 5
14. The immunogenic product or the composition for use according to any one of claims 12 to 13, wherein the inflammatory disorder is selected from asthma (e.g., allergic asthma), atopic dermatitis, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, food allergy, nasal polyposis and eosinophilic esophagitis,
- 10 preferably wherein said inflammatory disorder is allergy, asthma, or atopic dermatitis.
15. The immunogenic product or the composition for use according to any one of claims 12 to 13, wherein the immunogenic product or the composition induces desensitization toward an allergen.
- 15 16. An immunogenic product according to any one of claims 1 to 4 or a composition according to any one of claims 5 to 10 for inducing desensitization of a subject allergic to a specific antigen, wherein said immunogenic product or composition and said specific antigen are to be administered to the allergic subject.

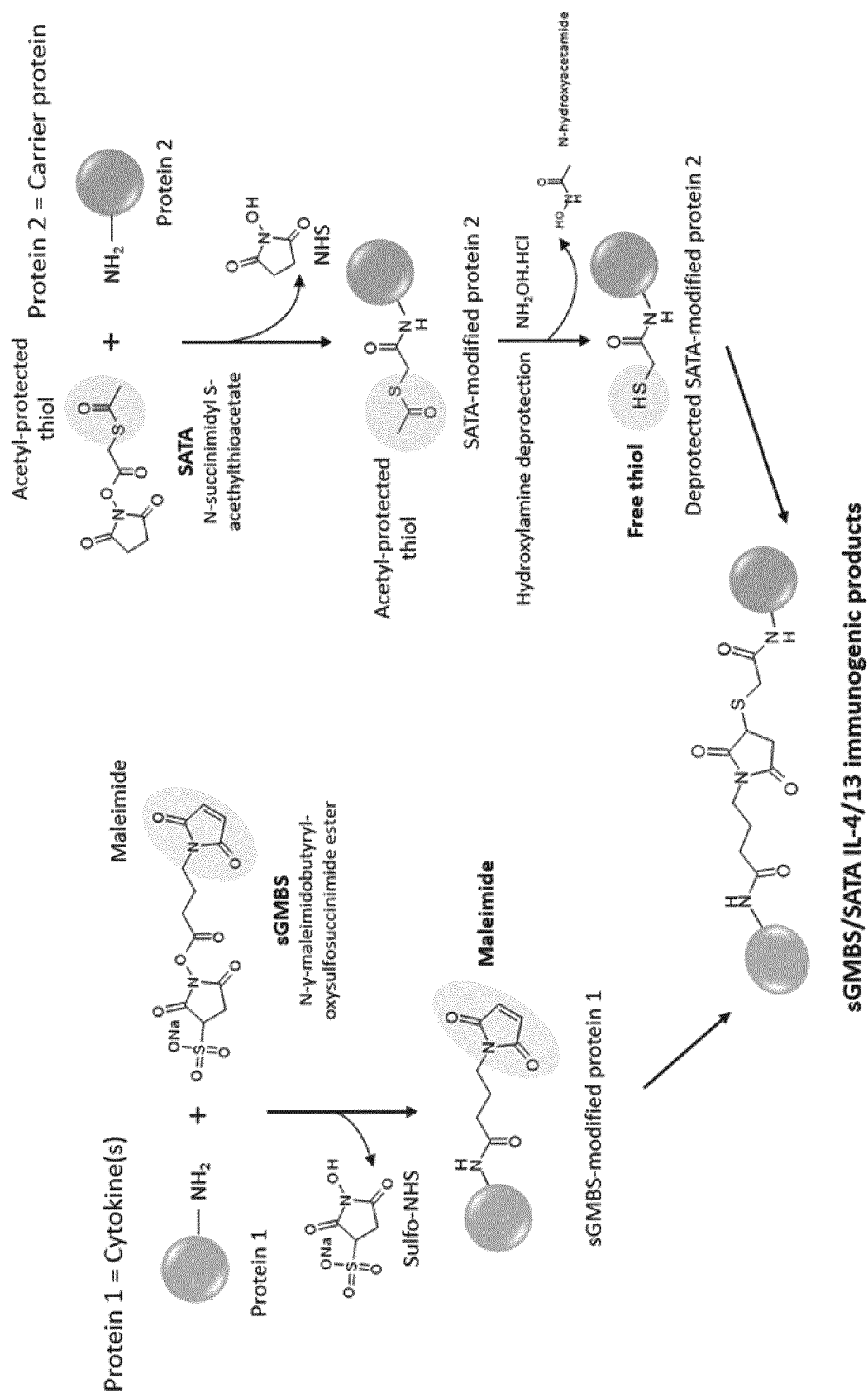


FIG. 1

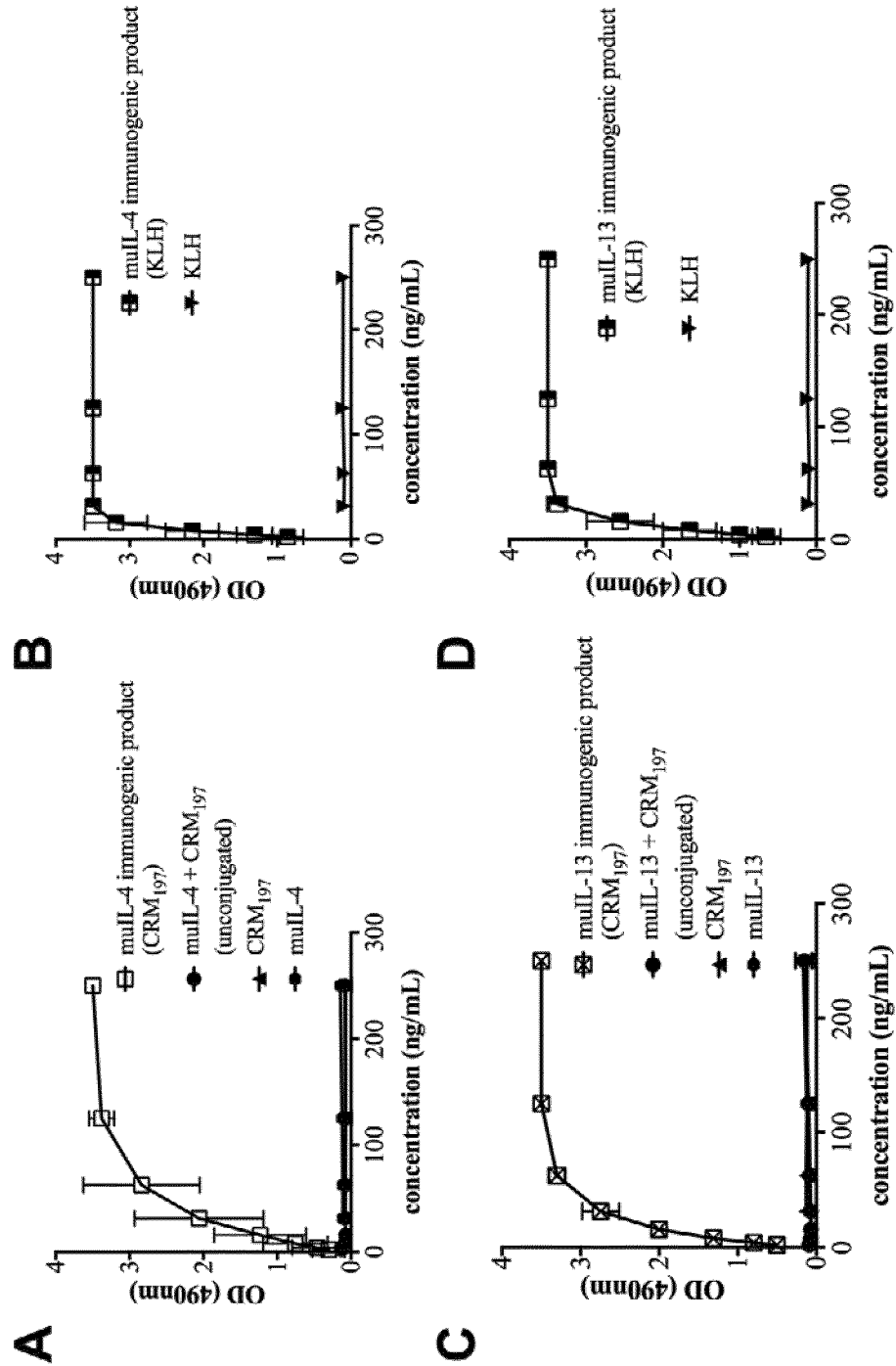


FIG. 2

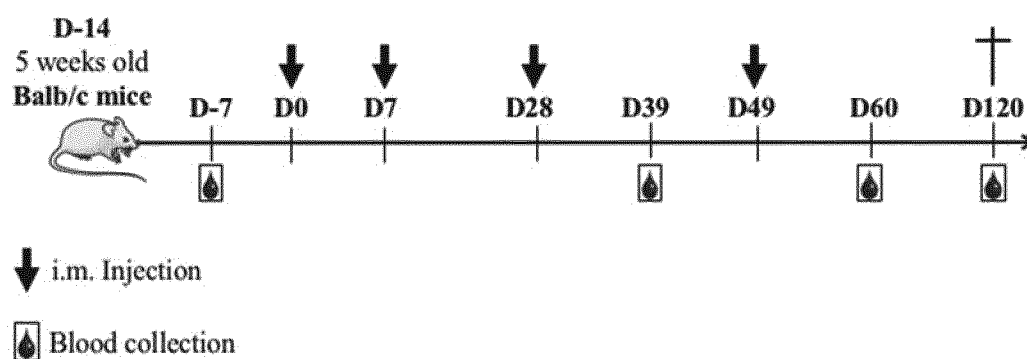


FIG. 3

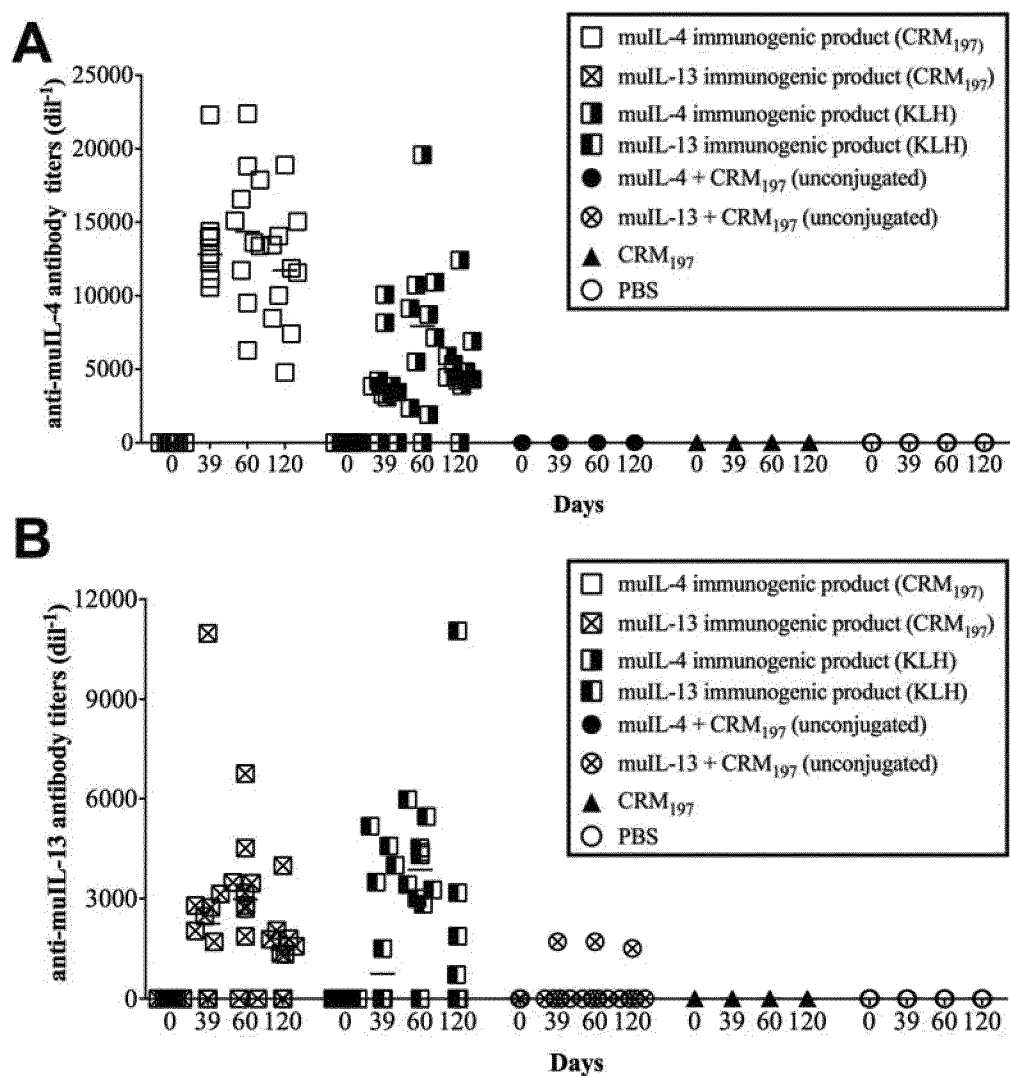


FIG. 4A-B

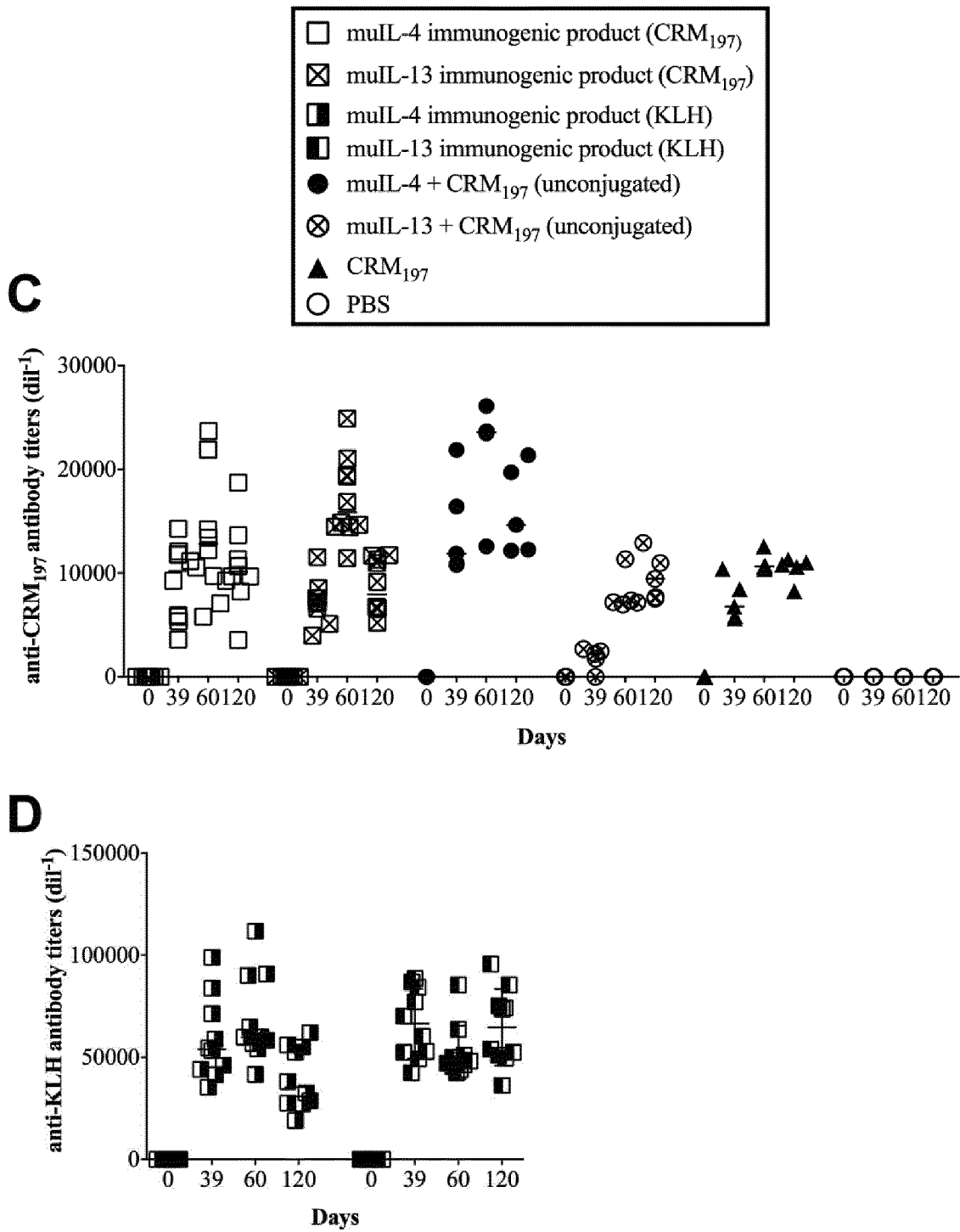


FIG. 4C-D

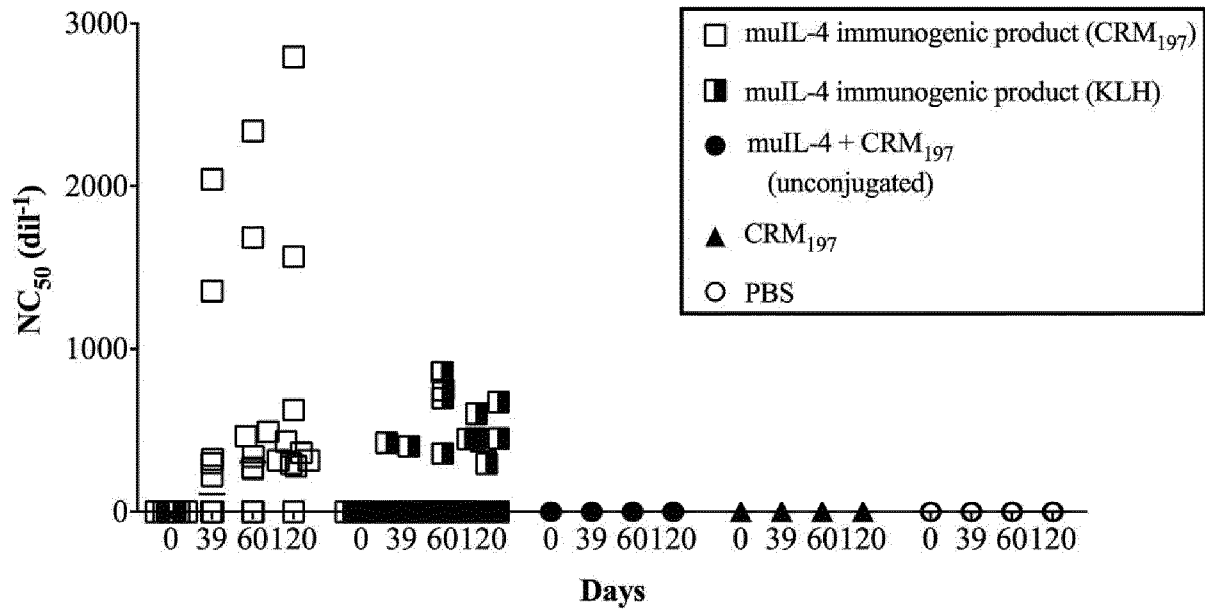


FIG. 5

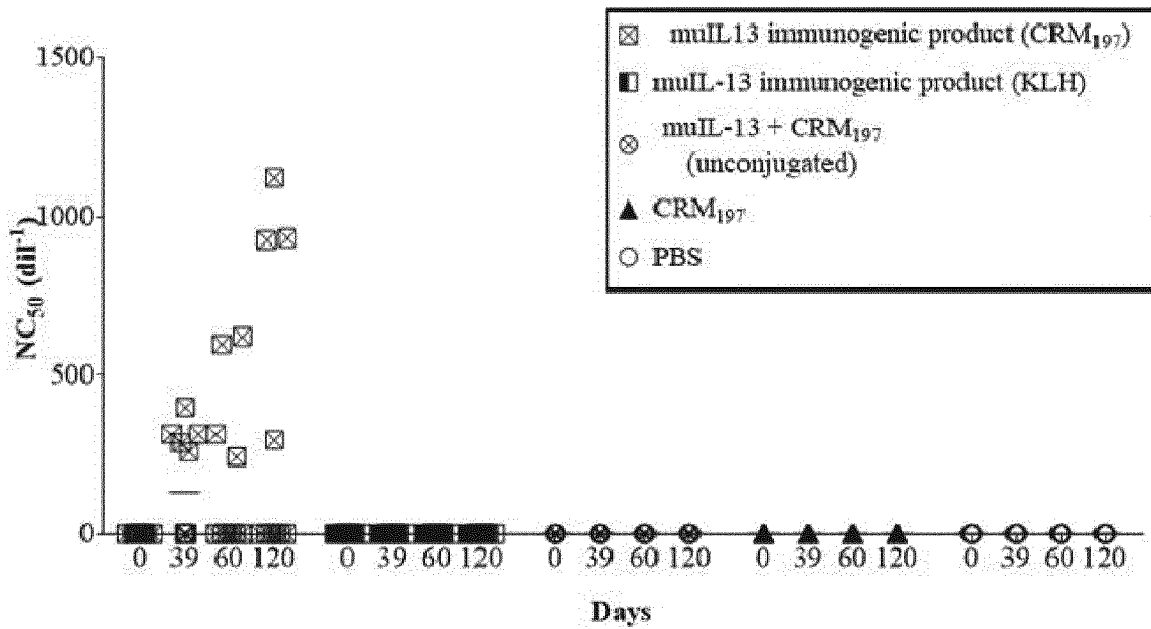


FIG. 6

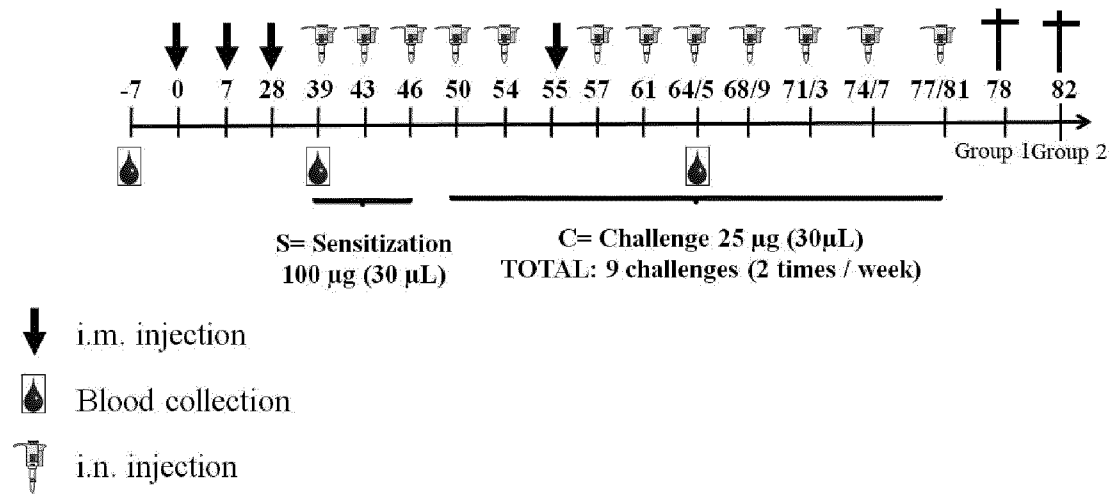


FIG. 7

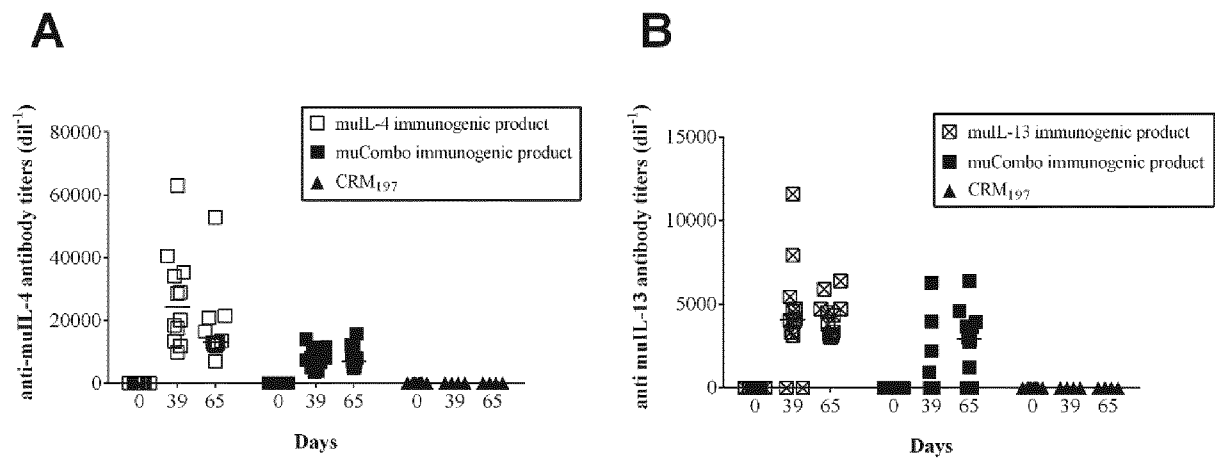


FIG. 8

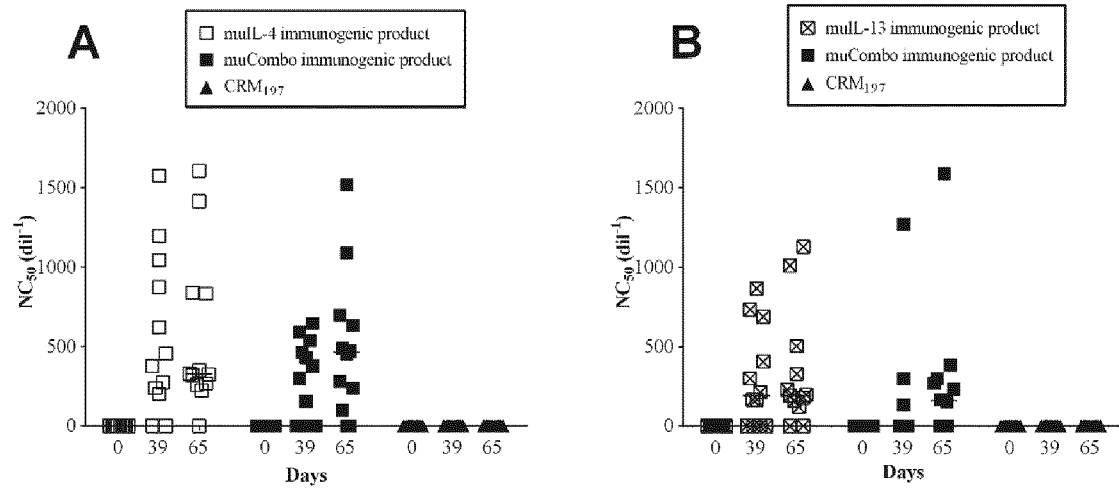


FIG. 9

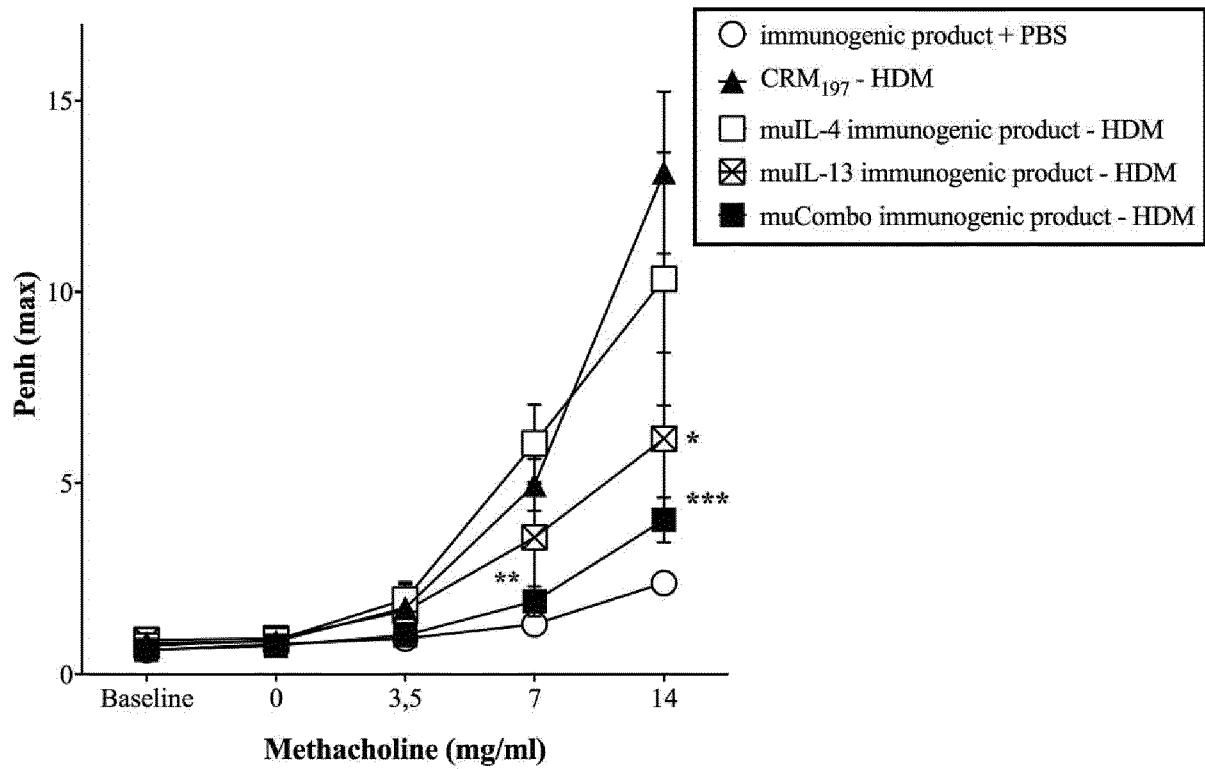


FIG. 10

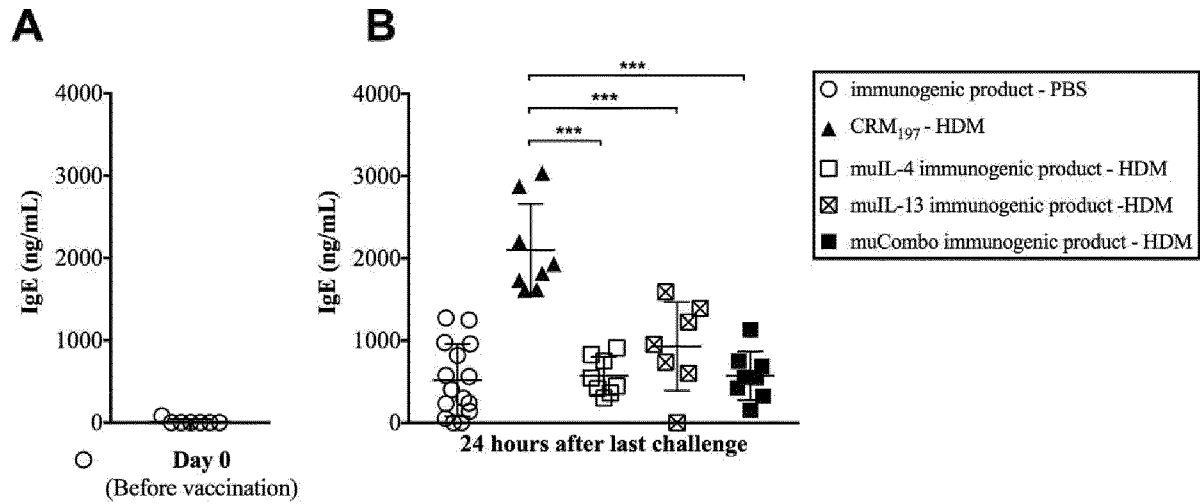


FIG. 11

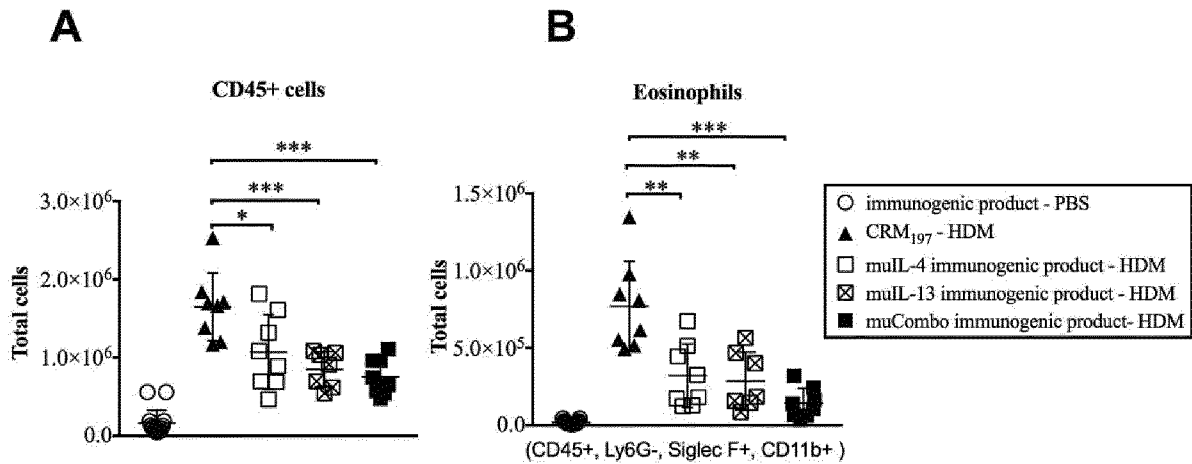


FIG. 12

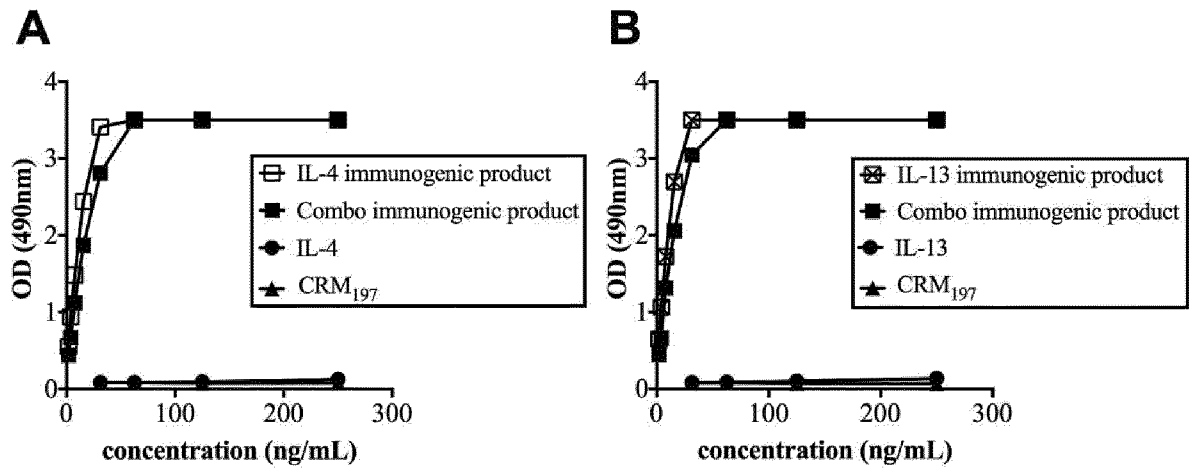


FIG. 13

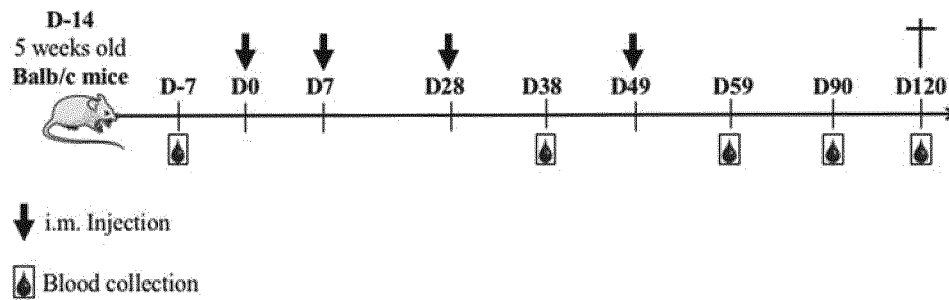


FIG. 14

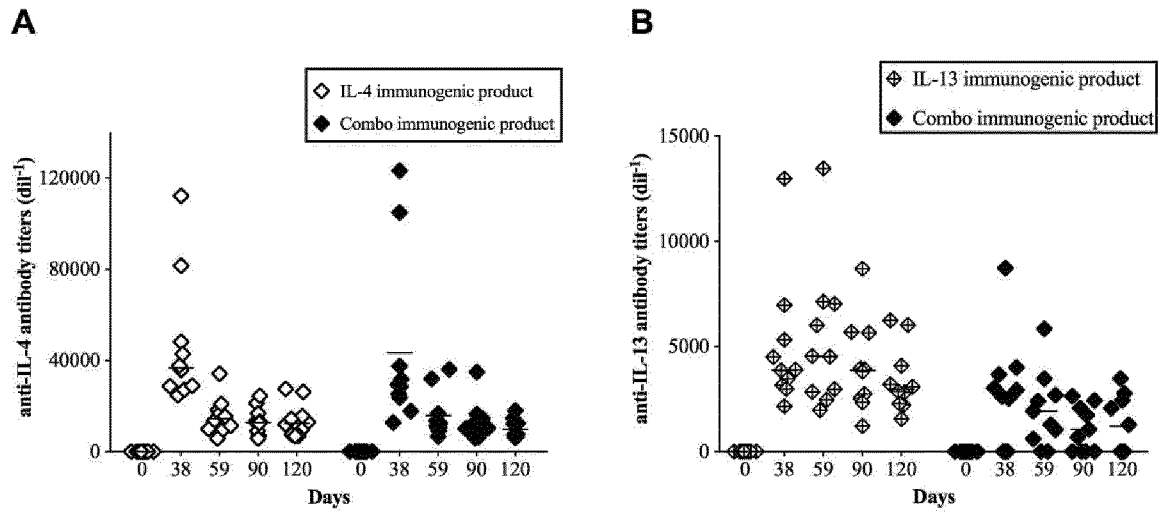


FIG. 15

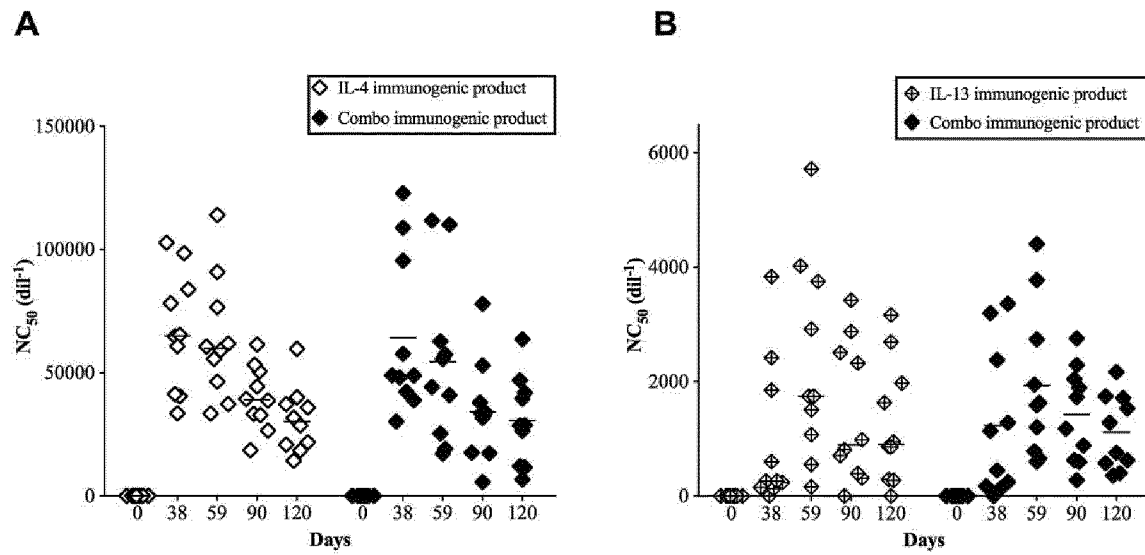


FIG. 16