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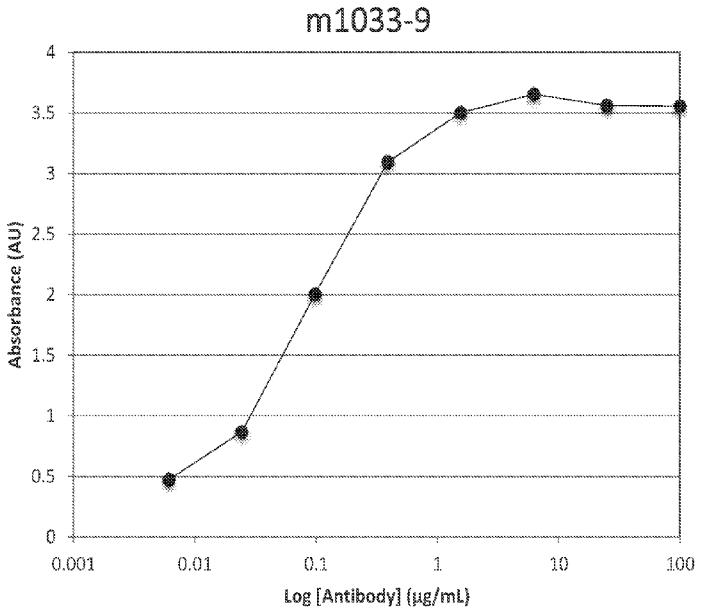

FIG. 1

(57) Abstract: Human monoclonal antibodies that specifically bind CD33 are described. Antibody conjugates that include the CD33-specific monoclonal antibodies (or antigen-binding fragments) are also described. Methods for the detection, diagnosis and treatment of CD33-positive cancer are further described.

[Continued on next page]

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HUMAN MONOCLONAL ANTIBODIES SPECIFIC FOR CD33 AND METHODS OF THEIR USE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority under 35 U.S.C. Section 119(e) to U.S. Provisional Patent Application No. 62/527,165, filed June 30, 2017, the entire contents of which are incorporated herein by reference.

SEQUENCE LISTING

The instant application contains a Sequence Listing which has been submitted electronically in ASCII format and is hereby incorporated by reference in its entirety. Said ASCII copy, created on June 27, 2018, is named Sequence_Listing.txt and is 20 kilobytes in size.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was created in the performance of a Cooperative Research and Development Agreement with the National Institutes of Health, an Agency of the Department of Health and Human Services. The Government of the United States has certain rights in this invention.

FIELD

This disclosure concerns CD33-specific monoclonal antibodies and conjugates thereof. This disclosure further concerns use of the monoclonal antibodies and conjugates, such as for the diagnosis and treatment of CD33-positive cancers.

BACKGROUND

CD33 is a transmembrane receptor expressed on cells of myeloid lineage, and some lymphoid cells. CD33, which is also known as Siglec-3 (sialic acid binding Ig-like lectin 3), binds sialic acids and is a member of the SIGLEC family of lectins. The extracellular portion of CD33 includes two immunoglobulin domains (an IgV domain and an IgC2 domain), while the intracellular portion contains immunoreceptor tyrosine-based inhibitor motifs (ITIMs) that are implicated in inhibition of cellular activity.

Acute myeloid leukemia (AML) is a heterogeneous disease characterized by the occurrence of abnormal blasts of different maturation stages in the bone marrow, leading to disruption of normal hematopoiesis. It has been previously reported that AML blasts express high levels of CD33. Thus, CD33 has been the target of several AML-directed therapies.

SUMMARY

Disclosed herein are six human CD33-specific monoclonal antibodies isolated from phage display libraries. The disclosed antibodies, referred to herein as m1033-9, m1033-10, m1033-12, m1033-15, m1033-2 and m1033-4, bind to soluble recombinant CD33 and cell-surface CD33 with high affinity.

Provided herein are monoclonal antibodies that bind, such as specifically bind, CD33. In some embodiments, the monoclonal antibodies include one or more complementarity determining region (CDR) sequences of m1033-9, m1033-10, m1033-12, m1033-15, m1033-2 or m1033-4. Also provided herein are conjugates that include a disclosed CD33-specific monoclonal antibody or antigen-binding fragment thereof. In some examples, provided are immunoconjugates, multi-specific antibodies, antibody-drug conjugates (ADCs), antibody-nanoparticles, conjugates or fusion proteins that include a monoclonal antibody or antigen-binding fragment disclosed herein. Compositions that include a CD33-specific monoclonal antibody or antigen-binding fragment and a pharmaceutically acceptable carrier are also provided by the present disclosure.

Also provided herein are nucleic acid molecules and vectors encoding the CD33-specific monoclonal antibodies, immunoconjugates, multi-specific antibodies and fusion proteins disclosed herein.

Methods of treating a CD33-positive cancer in a subject, and methods of inhibiting metastasis of a CD33-positive cancer in a subject are also provided. In some embodiments, the methods include administering to the subject a monoclonal antibody or antigen-binding fragment disclosed herein, or administering to the subject an immunoconjugate, ADC, multi-specific antibody, antibody-nanoparticle conjugate or fusion protein comprising a monoclonal antibody (or antigen-binding fragment) disclosed herein.

Further provided herein are methods of detecting expression of CD33 in a sample. In some embodiments, the method includes contacting the sample with a monoclonal antibody or antigen-binding fragment disclosed herein, and detecting binding of the antibody to the sample. Also provided are methods of diagnosing a subject as having a CD33-positive cancer. In some embodiments, the method includes contacting a sample from the subject with a CD33-specific

monoclonal antibody antigen-binding fragment disclosed herein, and detecting binding of the antibody to the sample.

The foregoing and other objects, features, and advantages of the invention will become more apparent from the following detailed description, which proceeds with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing binding of m1033-9 scFv to human recombinant CD33, as measured by ELISA.

FIGS. 2A-2C are FACS plots showing binding of m1033-9 scFv to CD33-negative ALL cell line RS4;11 (FIG. 2A), CD33-positive AML cell line MV4-11 (FIG. 2B) and CD33-negative Jurkat T cells (FIG. 2C).

FIG. 3 is a graph showing binding of m1033-10 scFv to human recombinant CD33, as measured by ELISA.

FIGS. 4A-4C are FACS plots showing binding of m1033-10 scFv to CD33-negative ALL cell line RS4;11 (FIG. 4A), CD33-positive AML cell line MV4-11 (FIG. 4B) and CD33-negative Jurkat T cells (FIG. 4C).

FIG. 5 is a graph showing binding of m1033-12 scFv to human recombinant CD33, as measured by ELISA.

FIGS. 6A-6C are FACS plots showing binding of m1033-12 scFv to CD33-negative ALL cell line RS4;11 (FIG. 6A), CD33-positive AML cell line MV4-11 (FIG. 6B) and CD33-negative Jurkat T cells (FIG. 6C).

FIG. 7 is a graph showing binding of m1033-15 scFv to human recombinant CD33, as measured by ELISA.

FIGS. 8A-8C are FACS plots showing binding of m1033-15 scFv to CD33-negative ALL cell line RS4;11 (FIG. 8A), CD33-positive AML cell line MV4-11 (FIG. 8B) and CD33-negative Jurkat T cells (FIG. 8C).

FIG. 9 is a graph showing binding of m1033-2 VH domain antibody to human recombinant CD33, as measured by ELISA.

FIGS. 10A-10C are FACS plots showing binding of m1033-2 VH domain antibody to CD33-negative ALL cell line RS4;11 (FIG. 10A), CD33-positive AML cell line MV4-11 (FIG. 10B) and CD33-negative 293T cells (FIG. 10C).

FIG. 11 is a graph showing binding of m1033-4 VH domain antibody to human recombinant CD33, as measured by ELISA.

FIGS. 12A-12C are FACS plots showing binding of m1033-2 VH domain antibody to CD33-negative ALL cell line RS4;11 (FIG. 12A), CD33-positive AML cell line MV4-11 (FIG. 12B) and CD33-negative CHO cells (FIG. 12C).

SEQUENCE LISTING

The nucleic and amino acid sequences listed in the accompanying sequence listing are shown using standard letter abbreviations for nucleotide bases, and three letter code for amino acids, as defined in 37 C.F.R. 1.822. Only one strand of each nucleic acid sequence is shown, but the complementary strand is understood as included by any reference to the displayed strand.

In the accompanying sequence listing:

SEQ ID NO: 1 is a nucleic acid sequence encoding the m1033-9 VH domain.

SEQ ID NO: 2 is the amino acid sequence of the m1033-9 VH domain.

SEQ ID NO: 3 is a nucleic acid sequence encoding the m1033-9 VL domain.

SEQ ID NO: 4 is the amino acid sequence of the m1033-9 VH domain.

SEQ ID NO: 5 is a nucleic acid sequence encoding the m1033-10 VH domain.

SEQ ID NO: 6 is the amino acid sequence of the m1033-10 VH domain.

SEQ ID NO: 7 is a nucleic acid sequence encoding the m1033-10 VL domain.

SEQ ID NO: 8 is the amino acid sequence of the m1033-10 VH domain.

SEQ ID NO: 9 is a nucleic acid sequence encoding the m1033-12 VH domain.

SEQ ID NO: 10 is the amino acid sequence of the m1033-12 VH domain.

SEQ ID NO: 11 is a nucleic acid sequence encoding the m1033-12 VL domain.

SEQ ID NO: 12 is the amino acid sequence of the m1033-12 VH domain.

SEQ ID NO: 13 is a nucleic acid sequence encoding the m1033-15 VH domain.

SEQ ID NO: 14 is the amino acid sequence of the m1033-15 VH domain.

SEQ ID NO: 15 is a nucleic acid sequence encoding the m1033-15 VL domain.

SEQ ID NO: 16 is the amino acid sequence of the m1033-15 VH domain.

SEQ ID NO: 17 is a nucleic acid sequence encoding single domain antibody m1033-2.

SEQ ID NO: 18 is the amino acid sequence of single domain antibody m1033-2.

SEQ ID NO: 19 is a nucleic acid sequence encoding single domain antibody m1033-4.

SEQ ID NO: 20 is the amino acid sequence of single domain antibody m1033-4.

DETAILED DESCRIPTION

I. Abbreviations

ADC	antibody-drug conjugate
CDR	complementarity determining region

ELISA	enzyme linked immunosorbent assay
FACS	fluorescent activated cell sorting
HRP	horseradish peroxidase
MOI	multiplicity of infection
NK	natural killer
OD	optical density
PBD	pyrrolobenzodiazepine
PE	*Pseudomonas* exotoxin
RIA	radioimmunoassay
scFv	single chain variable fragment
TMB	3,3,5,5′-tetramethylbenzidine
VH	variable heavy
VL	variable light

II. Terms and Methods

Unless otherwise noted, technical terms are used according to conventional usage. Definitions of common terms in molecular biology may be found in Benjamin Lewin, *Genes V*, published by Oxford University Press, 1994 (ISBN 0-19-854287-9); Kendrew *et al.* (eds.), *The Encyclopedia of Molecular Biology*, published by Blackwell Science Ltd., 1994 (ISBN 0-632-02182-9); and Robert A. Meyers (ed.), *Molecular Biology and Biotechnology: a Comprehensive Desk Reference*, published by VCH Publishers, Inc., 1995 (ISBN 1-56081-569-8).

In order to facilitate review of the various embodiments of the disclosure, the following explanations of specific terms are provided:

Acute myeloid leukemia (AML): An aggressive form of leukemia characterized by the overproduction of myeloblasts. AML is also known as acute myeloblastic leukemia, acute myelogenous leukemia and acute nonlymphocytic leukemia (ANLL).

Antibody: A polypeptide ligand comprising at least one variable region that recognizes and binds (such as specifically recognizes and specifically binds) an epitope of an antigen. Mammalian immunoglobulin molecules are composed of a heavy (H) chain and a light (L) chain, each of which has a variable region, termed the variable heavy (V_H) region and the variable light (V_L) region, respectively. Together, the V_H region and the V_L region are responsible for binding the antigen recognized by the antibody. There are five main heavy chain classes (or isotypes) of mammalian immunoglobulin, which determine the functional activity of an antibody molecule: IgM, IgD, IgG, IgA and IgE. Antibody isotypes not found in mammals include IgX, IgY, IgW and IgNAR. IgY is the primary antibody produced by birds and reptiles, and has some

functionally similar to mammalian IgG and IgE. IgW and IgNAR antibodies are produced by cartilaginous fish, while IgX antibodies are found in amphibians.

Antibody variable regions contain "framework" regions and hypervariable regions, known as "complementarity determining regions" or "CDRs." The CDRs are primarily responsible for binding to an epitope of an antigen. The framework regions of an antibody serve to position and align the CDRs in three-dimensional space. The amino acid sequence boundaries of a given CDR can be readily determined using any of a number of well-known numbering schemes, including those described by Kabat *et al.* (*Sequences of Proteins of Immunological Interest*, U.S. Department of Health and Human Services, 1991; the "Kabat" numbering scheme), Chothia *et al.* (see Chothia and Lesk, *J Mol Biol* 196:901-917, 1987; Chothia *et al.*, *Nature* 342:877, 1989; and Al-Lazikani *et al.*, (JMB 273,927-948, 1997; the "Chothia" numbering scheme), and the ImMunoGeneTics (IMGT) database (see, Lefranc, *Nucleic Acids Res* 29:207-9, 2001; the "IMGT" numbering scheme). The Kabat and IMGT databases are maintained online.

A "single-domain antibody" refers to an antibody having a single domain (a variable domain) that is capable of specifically binding an antigen, or an epitope of an antigen, in the absence of an additional antibody domain. Single-domain antibodies include, for example, V_H domain antibodies, V_{NAR} antibodies, camelid V_HH antibodies, and V_L domain antibodies. V_{NAR} antibodies are produced by cartilaginous fish, such as nurse sharks, wobbegong sharks, spiny dogfish and bamboo sharks. Camelid V_HH antibodies are produced by several species including camel, llama, alpaca, dromedary, and guanaco, which produce heavy chain antibodies that are naturally devoid of light chains.

A "monoclonal antibody" is an antibody produced by a single clone of lymphocytes or by a cell into which the coding sequence of a single antibody has been transfected. Monoclonal antibodies are produced by methods known to those of skill in the art. Monoclonal antibodies include humanized monoclonal antibodies.

A "chimeric antibody" has framework residues from one species, such as human, and CDRs (which generally confer antigen binding) from another species.

A "humanized" antibody is an immunoglobulin including a human framework region and one or more CDRs from a non-human (for example a mouse, rabbit, rat, shark or synthetic) immunoglobulin. The non-human immunoglobulin providing the CDRs is termed a "donor," and the human immunoglobulin providing the framework is termed an "acceptor." In one embodiment, all CDRs are from the donor immunoglobulin in a humanized immunoglobulin. Constant regions need not be present, but if they are, they must be substantially identical to human immunoglobulin constant regions, *i.e.*, at least about 85-90%, such as about 95% or more identical. Hence, all parts of a humanized immunoglobulin, except possibly the CDRs, are

substantially identical to corresponding parts of natural human immunoglobulin sequences. A humanized antibody binds to the same antigen as the donor antibody that provides the CDRs. Humanized or other monoclonal antibodies can have additional conservative amino acid substitutions which have substantially no effect on antigen binding or other immunoglobulin functions.

Antibody-drug conjugate (ADC): A molecule that includes an antibody (or antigen-binding fragment of an antibody) conjugated to a drug, such as a cytotoxic agent. ADCs can be used to specifically target a drug to cancer cells through specific binding of the antibody to a tumor antigen expressed on the cell surface. Exemplary drugs for use with ADCs include anti-microtubule agents (such as maytansinoids, auristatin E and auristatin F) and interstrand crosslinking agents (*e.g.*, pyrrolobenzodiazepines; PDBs).

Anti-microtubule agent: A type of drug that blocks cell growth by stopping mitosis. Anti-microtubule agents, also referred to as "anti-mitotic agents," are used to treat cancer.

Binding affinity: Affinity of an antibody for an antigen. In one embodiment, affinity is calculated by a modification of the Scatchard method described by Frankel *et al.*, *Mol. Immunol.*, 16:101-106, 1979. In another embodiment, binding affinity is measured by an antigen/antibody dissociation rate. In another embodiment, a high binding affinity is measured by a competition radioimmunoassay. In another embodiment, binding affinity is measured by ELISA. In another embodiment, antibody affinity is measured by flow cytometry. An antibody that "specifically binds" an antigen (such as CD33) is an antibody that binds the antigen with high affinity and does not significantly bind other unrelated antigens.

Bispecific antibody: A recombinant protein that includes antigen-binding fragments of two different monoclonal antibodies, and is thereby capable of binding two different antigens. In some embodiments, bispecific antibodies are used for cancer immunotherapy by simultaneously targeting, for example, both CTLs (such as a CTL receptor component such as CD3) or effector natural killer (NK) cells, and a tumor antigen. Similarly, a **multi-specific antibody** is a recombinant protein that includes antigen-binding fragments of at least two different monoclonal antibodies, such as two, three or four different monoclonal antibodies.

CD33: A transmembrane receptor expressed primarily by myeloid cells, but also by some lymphoid cells. CD33, which is also known as Siglec-3 (sialic acid binding Ig-like lectin 3), binds sialic acids and is a member of the SIGLEC family of lectins.

CD33-positive cancer: A cancer in which the cells express higher levels of CD33 than a control, such as non-cancer cells or a reference value. Expression of CD33 can be detected using, for example, any immunoassay known in the art, such as by ELISA, FACS, Western blot or immunohistochemistry of tumor cells. A CD33-expressing cancer can also be identified by

diagnosing a subject with a particular type of cancer that is known to express CD33, such as AML, a lymphoma or a squamous cell carcinoma.

Chemotherapeutic agent: Any chemical agent with therapeutic usefulness in the treatment of diseases characterized by abnormal cell growth. Such diseases include tumors, neoplasms, and cancer as well as diseases characterized by hyperplastic growth such as psoriasis. In one embodiment, a chemotherapeutic agent is an agent of use in treating AML. In one embodiment, a chemotherapeutic agent is a radioactive compound. One of skill in the art can readily identify a chemotherapeutic agent of use (see for example, Slapak and Kufe, *Principles of Cancer Therapy*, Chapter 86 in Harrison's Principles of Internal Medicine, 14th edition; Perry *et al.*, *Chemotherapy*, Ch. 17 in Abeloff, Clinical Oncology 2nd ed., © 2000 Churchill Livingstone, Inc; Baltzer, L., Berkery, R. (*eds.*): *Oncology Pocket Guide to Chemotherapy*, 2nd ed. St. Louis, Mosby-Year Book, 1995; Fischer, D.S., Knobf, M.F., Durivage, H.J. (eds): *The Cancer Chemotherapy Handbook*, 4th ed. St. Louis, Mosby-Year Book, 1993). Combination chemotherapy is the administration of more than one agent to treat cancer. One example is the administration of an antibody that binds CD33 used in combination with a radioactive or chemical compound.

Complementarity determining region (CDR): A region of hypervariable amino acid sequence that defines the binding affinity and specificity of an antibody.

Conjugate: In the context of the present disclosure, a "conjugate" is an antibody or antibody fragment (such as an antigen-binding fragment) covalently linked to an effector molecule or a second protein (such as a second antibody). The effector molecule can be, for example, a drug, toxin, therapeutic agent, detectable label, protein, nucleic acid, lipid, nanoparticle, carbohydrate or recombinant virus. An antibody conjugate is often referred to as an "immunoconjugate." When the conjugate comprises an antibody linked to a drug (*e.g.*, a cytotoxic agent), the conjugate is often referred to as an "antibody-drug conjugate" or "ADC." Other antibody conjugates include, for example, multi-specific (such as bispecific or trispecific) antibodies and chimeric antigen receptors (CARs).

Conservative variant: "Conservative" amino acid substitutions are those substitutions that do not substantially affect or decrease the affinity of a protein, such as an antibody to CD33. For example, a monoclonal antibody that specifically binds CD33 can include at most about 1, at most about 2, at most about 5, and most about 10, or at most about 15 conservative substitutions and specifically bind the CD33 polypeptide. The term "conservative variant" also includes the use of a substituted amino acid in place of an unsubstituted parent amino acid, provided that antibody specifically binds CD33. Non-conservative substitutions are those that reduce an activity or binding to CD33.

Conservative amino acid substitution tables providing functionally similar amino acids are well known to one of ordinary skill in the art. The following six groups are examples of amino acids that are considered to be conservative substitutions for one another:

1) Alanine (A), Serine (S), Threonine (T);

2) Aspartic acid (D), Glutamic acid (E);

3) Asparagine (N), Glutamine (Q);

4) Arginine (R), Lysine (K);

5) Isoleucine (I), Leucine (L), Methionine (M), Valine (V); and

6) Phenylalanine (F), Tyrosine (Y), Tryptophan (W).

Contacting: Placement in direct physical association; includes both in solid and liquid form.

Cytotoxic agent: Any drug or compound that kills cells.

Cytotoxicity: The toxicity of a molecule, such as an immunotoxin, to the cells intended to be targeted, as opposed to the cells of the rest of an organism. In one embodiment, in contrast, the term "toxicity" refers to toxicity of an immunotoxin to cells other than those that are the cells intended to be targeted by the targeting moiety of the immunotoxin, and the term "animal toxicity" refers to toxicity of the immunotoxin to an animal by toxicity of the immunotoxin to cells other than those intended to be targeted by the immunotoxin.

Degenerate variant: In the context of the present disclosure, a "degenerate variant" refers to a polynucleotide encoding a CD33 polypeptide or an antibody that binds CD33 that includes a sequence that is degenerate as a result of the genetic code. There are 20 natural amino acids, most of which are specified by more than one codon. Therefore, all degenerate nucleotide sequences are included as long as the amino acid sequence of the CD33 polypeptide or antibody that binds CD33 encoded by the nucleotide sequence is unchanged.

Diagnostic: Identifying the presence or nature of a pathologic condition, such as cancer. Diagnostic methods differ in their sensitivity and specificity. The "sensitivity" of a diagnostic assay is the percentage of diseased individuals who test positive (percent of true positives). The "specificity" of a diagnostic assay is one minus the false positive rate, where the false positive rate is defined as the proportion of those without the disease who test positive. While a particular diagnostic method may not provide a definitive diagnosis of a condition, it suffices if the method provides a positive indication that aids in diagnosis. "Prognostic" is the probability of development (*e.g.*, severity) of a pathologic condition, such as AML, a lymphoma or a squamous cell carcinoma.

Drug: Any compound used to treat, ameliorate or prevent a disease or condition in a subject. In some embodiments herein, the drug is an anti-cancer agent, for example a cytotoxic agent, such as an anti-mitotic or anti-microtubule agent.

Effector molecule: The portion of a chimeric molecule that is intended to have a desired effect on a cell to which the chimeric molecule is targeted. Effector molecule is also known as an effector moiety (EM), therapeutic agent, or diagnostic agent, or similar terms. Therapeutic agents (or drugs) include such compounds as nucleic acids, proteins, peptides, amino acids or derivatives, glycoproteins, radioisotopes, lipids, carbohydrates, or recombinant viruses. Nucleic acid therapeutic and diagnostic moieties include antisense nucleic acids, derivatized oligonucleotides for covalent cross-linking with single or duplex DNA, and triplex forming oligonucleotides. Alternatively, the molecule linked to a targeting moiety, such as an anti-CD33 antibody, may be an encapsulation system, such as a liposome or micelle that contains a therapeutic composition such as a drug, a nucleic acid (such as an antisense nucleic acid), or another therapeutic moiety that can be shielded from direct exposure to the circulatory system. Means of preparing liposomes attached to antibodies are well known to those of skill in the art (see, for example, U.S. Patent No. 4,957,735; and Connor *et al.*, *Pharm Ther* 28:341-365, 1985). Diagnostic agents or moieties include radioisotopes and other detectable labels. Detectable labels useful for such purposes are also well known in the art, and include radioactive isotopes such as ^{35}S, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{19}F, ^{99m}Tc, ^{131}I, ^{3}H, ^{14}C, ^{15}N, ^{90}Y, ^{99}Tc, ^{111}In and ^{125}I, fluorophores, chemiluminescent agents, and enzymes.

Epitope: An antigenic determinant. These are particular chemical groups or peptide sequences on a molecule that are antigenic, *i.e.* that elicit a specific immune response. An antibody specifically binds a particular antigenic epitope on a polypeptide, such as CD33.

Framework region: Amino acid sequences interposed between CDRs. Framework regions include variable light and variable heavy framework regions. The framework regions serve to hold the CDRs in an appropriate orientation for antigen binding.

Fusion protein: A protein comprising at least a portion of two different (heterologous) proteins.

Heterologous: Originating from a separate genetic source or species.

Immune response: A response of a cell of the immune system, such as a B cell, T cell, or monocyte, to a stimulus. In one embodiment, the response is specific for a particular antigen (an "antigen-specific response"). In one embodiment, an immune response is a T cell response, such as a $CD4^+$ response or a $CD8^+$ response. In another embodiment, the response is a B cell response, and results in the production of specific antibodies.

Immunoconjugate: A covalent linkage of an effector molecule to an antibody or functional fragment thereof. The effector molecule can be a detectable label or an immunotoxin. Specific, non-limiting examples of toxins include, but are not limited to, abrin, ricin, *Pseudomonas* exotoxin (PE, such as PE35, PE37, PE38, and PE40), diphtheria toxin (DT), botulinum toxin, or modified toxins thereof, or other toxic agents that directly or indirectly inhibit cell growth or kill cells. For example, PE and DT are highly toxic compounds that typically bring about death through liver toxicity. PE and DT, however, can be modified into a form for use as an immunotoxin by removing the native targeting component of the toxin (such as the domain Ia of PE and the B chain of DT) and replacing it with a different targeting moiety, such as an antibody. A "chimeric molecule" is a targeting moiety, such as a ligand or an antibody, conjugated (coupled) to an effector molecule. The term "conjugated" or "linked" refers to making two polypeptides into one contiguous polypeptide molecule. In one embodiment, an antibody is joined to an effector molecule. In another embodiment, an antibody joined to an effector molecule is further joined to a lipid or other molecule to a protein or peptide to increase its half-life in the body. The linkage can be either by chemical or recombinant means. In one embodiment, the linkage is chemical, wherein a reaction between the antibody moiety and the effector molecule has produced a covalent bond formed between the two molecules to form one molecule. A peptide linker (short peptide sequence) can optionally be included between the antibody and the effector molecule. Because immunoconjugates were originally prepared from two molecules with separate functionalities, such as an antibody and an effector molecule, they are also sometimes referred to as "chimeric molecules." The term "chimeric molecule," as used herein, therefore refers to a targeting moiety, such as a ligand or an antibody, conjugated (coupled) to an effector molecule.

Immunoliposome: A liposome with antibodies or antibody fragments conjugated to its surface. Immunoliposomes can carry cytotoxic agents or other drugs to antibody-targeted cells, such as tumor cells.

Interstrand crosslinking agent: A type of cytotoxic drug capable of binding covalently between two strands of DNA, thereby preventing DNA replication and/or transcription.

Isolated: An "isolated" biological component, such as a nucleic acid, protein (including antibodies) or organelle, has been substantially separated or purified away from other biological components in the environment (such as a cell) in which the component naturally occurs, *i.e.*, other chromosomal and extra-chromosomal DNA and RNA, proteins and organelles. Nucleic acids and proteins that have been "isolated" include nucleic acids and proteins purified by standard purification methods. The term also embraces nucleic acids and proteins prepared by recombinant expression in a host cell as well as chemically synthesized nucleic acids.

Label: A detectable compound or composition that is conjugated directly or indirectly to another molecule, such as an antibody or a protein, to facilitate detection of that molecule. Specific, non-limiting examples of labels include fluorescent tags, enzymatic linkages, and radioactive isotopes. In one example, a "labeled antibody" refers to incorporation of another molecule in the antibody. For example, the label is a detectable marker, such as the incorporation of a radiolabeled amino acid or attachment to a polypeptide of biotinyl moieties that can be detected by marked avidin (for example, streptavidin containing a fluorescent marker or enzymatic activity that can be detected by optical or colorimetric methods). Various methods of labeling polypeptides and glycoproteins are known in the art and may be used. Examples of labels for polypeptides include, but are not limited to, the following: radioisotopes or radionucleotides (such as ^{35}S, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{19}F, ^{99m}Tc, ^{131}I, ^{3}H, ^{14}C, ^{15}N, ^{90}Y, ^{99}Tc, ^{111}In and ^{125}I), fluorescent labels (such as fluorescein isothiocyanate (FITC), rhodamine, lanthanide phosphors), enzymatic labels (such as horseradish peroxidase, beta-galactosidase, luciferase, alkaline phosphatase), chemiluminescent markers, biotinyl groups, predetermined polypeptide epitopes recognized by a secondary reporter (such as a leucine zipper pair sequences, binding sites for secondary antibodies, metal binding domains, epitope tags), or magnetic agents, such as gadolinium chelates. In some embodiments, labels are attached by spacer arms of various lengths to reduce potential steric hindrance.

Linker: In some cases, a linker is a peptide within an antibody binding fragment (such as an Fv fragment) which serves to indirectly bond the variable heavy chain to the variable light chain. "Linker" can also refer to a peptide serving to link a targeting moiety, such as an antibody, to an effector molecule, such as a cytotoxin or a detectable label.

The terms "conjugating," "joining," "bonding" or "linking" refer to making two polypeptides into one contiguous polypeptide molecule, or to covalently attaching a radionuclide or other molecule to a polypeptide, such as an scFv. In the specific context, the terms include reference to joining a ligand, such as an antibody moiety, to an effector molecule. The linkage can be either by chemical or recombinant means. "Chemical means" refers to a reaction between the antibody moiety and the effector molecule such that there is a covalent bond formed between the two molecules to form one molecule.

Lymphoma: A group of blood cell tumors that develop from lymphocytes. The two main categories of lymphoma are Hodgkin's lymphoma and non-Hodgkin's lymphoma.

Neoplasia, malignancy, cancer or tumor: A neoplasm is an abnormal growth of tissue or cells that results from excessive cell division. Neoplastic growth can produce a tumor. The amount of a tumor in an individual is the "tumor burden" which can be measured as the number,

volume, or weight of the tumor. A tumor that does not metastasize is referred to as "benign." A tumor that invades the surrounding tissue and/or can metastasize is referred to as "malignant."

Operably linked: A first nucleic acid sequence is operably linked with a second nucleic acid sequence when the first nucleic acid sequence is placed in a functional relationship with the second nucleic acid sequence. For instance, a promoter, such as the CMV promoter, is operably linked to a coding sequence if the promoter affects the transcription or expression of the coding sequence. Generally, operably linked DNA sequences are contiguous and, where necessary to join two protein-coding regions, in the same reading frame.

Pharmaceutical agent: A chemical compound or composition capable of inducing a desired therapeutic or prophylactic effect when properly administered to a subject or a cell.

Pharmaceutically acceptable carriers: The pharmaceutically acceptable carriers of use are conventional. *Remington's Pharmaceutical Sciences*, by E.W. Martin, Mack Publishing Co., Easton, PA, 15th Edition, 1975, describes compositions and formulations suitable for pharmaceutical delivery of the antibodies disclosed herein.

In general, the nature of the carrier will depend on the particular mode of administration being employed. For instance, parenteral formulations usually comprise injectable fluids that include pharmaceutically and physiologically acceptable fluids such as water, physiological saline, balanced salt solutions, aqueous dextrose, glycerol or the like as a vehicle. For solid compositions (such as powder, pill, tablet, or capsule forms), conventional non-toxic solid carriers can include, for example, pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. In addition to biologically neutral carriers, pharmaceutical compositions to be administered can contain minor amounts of non-toxic auxiliary substances, such as wetting or emulsifying agents, preservatives, and pH buffering agents and the like, for example sodium acetate or sorbitan monolaurate.

Preventing, treating or ameliorating a disease: "Preventing" a disease refers to inhibiting the full development of a disease. "Treating" refers to a therapeutic intervention that ameliorates a sign or symptom of a disease or pathological condition after it has begun to develop, such as a reduction in tumor burden or a decrease in the number of size of metastases. "Ameliorating" refers to the reduction in the number or severity of signs or symptoms of a disease, such as cancer.

Purified: The term purified does not require absolute purity; rather, it is intended as a relative term. Thus, for example, a purified peptide preparation is one in which the peptide or protein is more enriched than the peptide or protein is in its natural environment within a cell. In one embodiment, a preparation is purified such that the protein or peptide represents at least 50% of the total peptide or protein content of the preparation. Substantial purification denotes

purification from other proteins or cellular components. A substantially purified protein is at least 60%, 70%, 80%, 90%, 95% or 98% pure. Thus, in one specific, non-limiting example, a substantially purified protein is 90% free of other proteins or cellular components.

Pyrrolobenzodiazepine (PBD): A class of sequence-selective DNA minor-groove binding crosslinking agents originally discovered in *Streptomyces* species. PDBs are significantly more potent than systemic chemotherapeutic drugs. The mechanism of action of PBDs is associated with their ability to form an adduct in the minor groove of DNA, thereby interfering with DNA processing. In the context of the present disclosure, PBDs include naturally produced and isolated PBDs, chemically synthesized naturally occurring PBDs, and chemically synthesized non-naturally occurring PBDs. PBDs also include monomeric, dimeric and hybrid PBDs (for a review see Gerratana, *Med Res Rev* 32(2):254-293, 2012).

Recombinant: A recombinant nucleic acid or protein is one that has a sequence that is not naturally occurring or has a sequence that is made by an artificial combination of two otherwise separated segments of sequence. This artificial combination is often accomplished by chemical synthesis or by the artificial manipulation of isolated segments of nucleic acids, for example, by genetic engineering techniques.

Sample (or biological sample): A biological specimen containing genomic DNA, RNA (including mRNA), protein, or combinations thereof, obtained from a subject. Examples include, but are not limited to, peripheral blood, tissue, cells, urine, saliva, tissue biopsy, fine needle aspirate, surgical specimen, and autopsy material. In one example, a sample includes a tumor biopsy.

Sequence identity: The similarity between amino acid or nucleic acid sequences is expressed in terms of the similarity between the sequences, otherwise referred to as sequence identity. Sequence identity is frequently measured in terms of percentage identity (or similarity or homology); the higher the percentage, the more similar the two sequences are. Homologs or variants of a polypeptide or nucleic acid molecule will possess a relatively high degree of sequence identity when aligned using standard methods.

Methods of alignment of sequences for comparison are well known in the art. Various programs and alignment algorithms are described in: Smith and Waterman, *Adv. Appl. Math.* 2:482, 1981; Needleman and Wunsch, *J. Mol. Biol.* 48:443, 1970; Pearson and Lipman, *Proc. Natl. Acad. Sci. U.S.A.* 85:2444, 1988; Higgins and Sharp, *Gene* 73:237, 1988; Higgins and Sharp, *CABIOS* 5:151, 1989; Corpet *et al.*, *Nucleic Acids Research* 16:10881, 1988; and Pearson and Lipman, *Proc. Natl. Acad. Sci. U.S.A.* 85:2444, 1988. Altschul *et al.*, *Nature Genet.* 6:119, 1994, presents a detailed consideration of sequence alignment methods and homology calculations.

The NCBI Basic Local Alignment Search Tool (BLAST) (Altschul *et al.*, *J. Mol. Biol.* 215:403, 1990) is available from several sources, including the National Center for Biotechnology Information (NCBI, Bethesda, MD) and on the internet, for use in connection with the sequence analysis programs blastp, blastn, blastx, tblastn and tblastx. A description of how to determine sequence identity using this program is available on the NCBI website on the internet.

Homologs and variants of a V_H of an antibody that specifically binds a CD33 polypeptide are typically characterized by possession of at least about 75%, for example at least about 80%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity counted over the full length alignment with the amino acid sequence of the antibody using the NCBI Blast 2.0, gapped blastp set to default parameters. For comparisons of amino acid sequences of greater than about 30 amino acids, the Blast 2 sequences function is employed using the default BLOSUM62 matrix set to default parameters, (gap existence cost of 11, and a per residue gap cost of 1). When aligning short peptides (fewer than around 30 amino acids), the alignment should be performed using the Blast 2 sequences function, employing the PAM30 matrix set to default parameters (open gap 9, extension gap 1 penalties). Proteins with even greater similarity to the reference sequences will show increasing percentage identities when assessed by this method, such as at least 80%, at least 85%, at least 90%, at least 95%, at least 98%, or at least 99% sequence identity. When less than the entire sequence is being compared for sequence identity, homologs and variants will typically possess at least 80% sequence identity over short windows of 10-20 amino acids, and may possess sequence identities of at least 85% or at least 90% or 95% depending on their similarity to the reference sequence. Methods for determining sequence identity over such short windows are available at the NCBI website on the internet. One of skill in the art will appreciate that these sequence identity ranges are provided for guidance only; it is entirely possible that strongly significant homologs could be obtained that fall outside of the ranges provided.

Small molecule: A molecule, typically with a molecular weight less than about 1000 Daltons, or in some embodiments, less than about 500 Daltons, wherein the molecule is capable of modulating, to some measurable extent, an activity of a target molecule.

Squamous cell carcinoma (SCC): A type of cancer that begins in squamous cells, which are thin, flat cells that look like fish scales. Squamous cells are found in the tissue that forms the surface of the skin, the lining of the hollow organs of the body, and the passages of the respiratory and digestive tracts. SCC is also called epidermoid carcinoma.

Subject: Living multi-cellular vertebrate organisms, a category that includes both human and veterinary subjects, including human and non-human mammals.

Synthetic: Produced by artificial means in a laboratory, for example a synthetic nucleic acid or protein (for example, an antibody) can be chemically synthesized in a laboratory.

Therapeutically effective amount: A quantity of a specific substance sufficient to achieve a desired effect in a subject being treated. For instance, this can be the amount necessary to inhibit or suppress growth of a tumor. In one embodiment, a therapeutically effective amount is the amount necessary to eliminate, reduce the size, or prevent metastasis of a tumor. When administered to a subject, a dosage will generally be used that will achieve target tissue concentrations (for example, in tumors) that has been shown to achieve a desired *in vitro* effect.

Toxin: A molecule that is cytotoxic for a cell. Toxins include abrin, ricin, *Pseudomonas* exotoxin (PE), diphtheria toxin (DT), botulinum toxin, saporin, restrictocin or gelonin, or modified toxins thereof. For example, PE and DT are highly toxic compounds that typically bring about death through liver toxicity. PE and DT, however, can be modified into a form for use as an immunotoxin by removing the native targeting component of the toxin (such as domain Ia of PE or the B chain of DT) and replacing it with a different targeting moiety, such as an antibody.

Vector: A nucleic acid molecule as introduced into a host cell, thereby producing a transformed host cell. A vector may include nucleic acid sequences that permit it to replicate in a host cell, such as an origin of replication. A vector may also include one or more selectable marker genes and other genetic elements known in the art.

Unless otherwise explained, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The singular terms "a," "an," and "the" include plural referents unless context clearly indicates otherwise. "Comprising A or B" means including A, or B, or A and B. It is further to be understood that all base sizes or amino acid sizes, and all molecular weight or molecular mass values, given for nucleic acids or polypeptides are approximate, and are provided for description. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present disclosure, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including explanations of terms, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

III. Human Monoclonal Antibodies Specific for CD33

Described herein are six human CD33-specific monoclonal antibodies isolated from scFv and VH domain phage display libraries. The disclosed antibodies, referred to herein as m1033-9,

m1033-10, m1033-12, m1033-15, m1033-2 and m1033-4, bind to soluble recombinant CD33 and cell-surface CD33 with high affinity.

The nucleotide and amino acid sequences of the VH and VL domains of antibodies m1033-9, m1033-10, m1033-12 and m1033-15, and the VH domain of single-domain antibodies m1033-2 and m1033-4, are provided below. In the amino acid sequences below, the CDR regions according to IMGT are shown in bold underline and the residues of CDR1, CDR2 and CDR3 are indicated below each VH domain and VL domain sequence. One of skill in the art could readily determine the CDR boundaries using alternative numbering schemes, such as the Kabat or Chothia numbering schemes.

m1033-9 VH (SEQ ID NO: 1)

caggtgcagctggtgcaatctggggcagaggtgaaaaagcccggggagtctctgaggatctcctgtaagggttctggattcagttttcccac
ctactggatcggctgggtgcgccagatgcccgggaaaggcctggagtggatggggatcatctatcctggtgactctgataccagatacagc
ccgtccttccaaggccaggtcaccatctcagccgacaagtccatcagcaccgcctacctgcagtggagcagcctgaaggcctcggacacc
gccatgtattactgtgcgagactagttggagatggctacaatacgggggcttttgatatctggggccaagggacaatggtcaccgtctcttca

m1033-9 VH (SEQ ID NO: 2)

QVQLVQSGAEVKKPGESLRISCKGS**GFSFPTY**WIGWVRQMPGKGLEWMGI**IYPGDSDT**
RYSPSFQGQVTISADKSISTAYLQWSSLKASDTAMYYC**ARLVGDGYNTGAFDI**WGQGT
MVTVSS

CDR1 = residues 26-32, CDR2 = residues 51-58, and CDR3 = residues 97-111

m1033-9 VL (SEQ ID NO: 3)

gatattgtgatgacccacactccactctctgtccgtcacccctggacagccggcctccatctcctgcaagtctagtcagagcctcctgcata
gtaatggaaagacctatttgtattggtacctgcagaagccaggccagcctccacagctcctgatctatggagcttccaaccggttctctggagt
gccagacaggttcagtggcagcgggtcagggacagatttcacactgaaaatcagccgggtggaggctgaggatgttggggtttattactgc
atgcaaagtatacagcttcctatcaccttcggccaagggacacgactggagattaaa

m1033-9 VL (SEQ ID NO: 4)

DIVMTHTPLSLSVTPGQPASISCKSS**QSLLHSNG**KTYLYWYLQKPGQPPQLLIY**GAS**NRF
SGVPDRFSGSGSGTDFTLKISRVEAEDVGVYYC**MQSIQLPIT**FGQGTRLEIK

CDR1 = residues 27-34, CDR2 = residues 55-57, and CDR3 = residues 94-102

m1033-10 VH (SEQ ID NO: 5)

caggtacagctgcagcagtcaggtccaggactggtgaagccctcgcagaccctctcactcacctgtgccatctccggggacagtgtctcta

gcaacactgctgcttggaactggatcaggcagtccccatcgagaggccttgagtggctgggaaggacatactacaggtccaagtggtataa
tgattatgcagtccctgtgaaaagtcgaataaccatcaacccagacacatccaagaaccagttctccctgcagctgaactctgtgactcccga
ggacacggctgtgtattactgtgcaagagaaacgtattactatggttcggggagttattgggatgcttttgatatctggggccaagggaccac
ggtcaccgtctcctca

m1033-10 VH (SEQ ID NO: 6)

QVQLQQSGPGLVKPSQTLSLTCAIS**GDSVSSNTAA**WNWIRQSPSRGLEWLGR**TYYRSK**
WYNDYAVPVKSRITINPDTSKNQFSLQLNSVTPEDTAVYYC**ARETYYYGSGSYWDAFD**
IWGQGTTVTVSS

CDR1 = residues 26-35, CDR2 = residues 53-61, and CDR3 = residues 100-117

m1033-10 VL (SEQ ID NO: 7)

cagtctgtcgtgacgcagccgccctcagtgtctgcggccccaggacagaaggtcaccatctcctgctctggaagcagctccaacattggga
ataattatgtatcctggtaccagcagctcccaggcacggcccccaaactcttcatctataaaaataatcagcggccctcagaggtccctgacc
gattctctggctccaagtctggcacctcagcctccctggccatcagtgggctccagtctgacgatgaggctgactactactgtgcagcatggg
atgacaggctgaatggatatgtcttcggaactgggaccaaggtcaccgtccta

m1033-10 VL (SEQ ID NO: 8)

QSVVTQPPSVSAAPGQKVTISCSGS**SSNIGNNY**VSWYQQLPGTAPKLFIY**KNN**QRPSEVP
DRFSGSKSGTSASLAISGLQSDDEADYYC**AAWDDRLNGYV**FGTGTKVTVL

CDR1 = residues 26-35, CDR2 = residues 51-53, and CDR3 = residues 90-100

m1033-12 VH (SEQ ID NO: 9)

caggtacagctgcagcagtcaggtccaggactggtgaagccctcgcagaccctctcactcacctgtgccatctccggggacagtgtctcta
gcaacagtgctgcttggaactggatcaggcagtccccatcgagaggccttgagtggctgggagggacatactacaggtccaagtggtataa
tgattatgcagtatctgtgaaaagtcgaataattatcaacgcagacacatcgaagaaccagttctccctgcagctgaactctgtgactcccgag
gacacggctgtgtattactgtgcgaggggatattactatgatagtaccgactggttcgacccctggggccagggaaccctggtcaccgtctc
ctca

m1033-12 VH (SEQ ID NO: 10)

QVQLQQSGPGLVKPSQTLSLTCAIS**GDSVSSNSAA**WNWIRQSPSRGLEWLGG**TYYRSK**
WYNDYAVSVKSRIIINADTSKNQFSLQLNSVTPEDTAVYYC**ARGYYYDSTDWFDP**WG
QGTLVTVSS

CDR1 = residues 26-35, CDR2 = residues 53-61, and CDR3 = residues 100-113

m1033-12 VL (SEQ ID NO: 11)

tcttctgagctgactcaggacccaactgtgtctgtggccttgggacagacagtcaggatcacatgccaaggagacagcctcagaagctatta
tgcaagctggtaccagcagaagccaggacaggcccctgtacttgtcatctatggtaaaaacaaccggccctcagggatcccagaccgattc
tctggctccagctcaggaaacacagcttccttgaccatcactggggctcaggcggaagatgaggctgactattactgttcctcccgggacgg
cagtggtcatccatatctcttcggacctgggaccaaggtcaccgttctt

m1033-12 VL (SEQ ID NO: 12)

SSELTQDPTVSVALGQTVRITCQGD**SLRSYY**ASWYQQKPGQAPVLVIY**GKN**NRPSGIPD
RFSGSSSGNTASLTITGAQAEDEADYYC**SSRDGSGHPYL**FGPGTKVTVL

CDR1 = residues 26-31, CDR2 = residues 49-51, and CDR3 = residues 88-98

m1033-15 VH (SEQ ID NO: 13)

gaggtccagctggtgcagtctggagcagaggtgaaaaagcccggggagtctctgaagatctcctgtaagggttctggatacagctttacca
gctactggatcggctgggtgcgccagatgcccgggaaaggcctggagtggatggggatcatctatcctggtgactctgataccagatacag
cccgtccttccaaggccaggtcaccatctcagccgacaagtccatcagcaccgcctacctgcagtggagcagcctgaaggcctcggacac
cgccatgtattactgtgcgagactgactacggctgggggtatggacgtctggggccaagggaccacggtcaccgtctcctca

m1033-15 VH (SEQ ID NO: 14)

EVQLVQSGAEVKKPGESLKISCKGS**GYSFTS**YWIGWVRQMPGKGLEWMGI**IYPGDSDT**
RYSPSFQGQVTISADKSISTAYLQWSSLKASDTAMYYC**ARLTTAGGMDV**WGQGTTVT
VSS

CDR1 = residues 26-31, CDR2 = residues 51-58, and CDR3 = residues 97-107

m1033-15 VL (SEQ ID NO: 15)

gaaattgtgctgactcagtctccactctccctgcccgtcacccttggacagccggcctccatctcctgcaggtctagtcaaagcctcgtacaca
gtgatggaaacacctacttgagttggcttcaccagaggccaggccagcctccaagactcctaatgtataagatttctaaccggttctctggggt
cacagacagattcagtggcagcgggtcagggacagatttcacactgaaaatcagccgggtggaggctgaggatgttggggtttattactgc
atgcaaggtatacacctaccgctcactttcggcggagggaccaagctggagatcaaa

m1033-15 VL (SEQ ID NO: 16)

EIVLTQSPLSLPVTLGQPASISCRSS**QSLVHSDGNTY**LSWLHQRPGQPPRLLMY**KIS**NRFS
GVTDRFSGSGSGTDFTLKISRVEAEDVGVYYC**MQGIHLPLT**FGGGTKLEIK

CDR1 = residues 27-37, CDR2 = residues 55-57, and CDR3 = residues 94-102

m1033-2 (SEQ ID NO: 17)

gaggtgcagctggtggagtctgggggaggcttggtacagcctggagggtccctgagactctcctgtgcagcctctggattcaccttcagtag
ctatggcatgagctgggtccgccaggctccaaggaagggcctggagtggattggggaaatcaatcatagtggaagcaccaactacaaccc
gtccctcaagagtcgagtcaccatctccagagacaattccaagaacacgctgtatctgcaaatgaacagcctgagagccgaggacacagc
cacgtattactgtgcgagacccctcaactactactactactacatggacgtctggggcaaagggaccacggtcaccgtctcctca

m1033-2 (SEQ ID NO: 18)

EVQLVESGGGLVQPGGSLRLSCAAS**GFTFSSYG**MSWVRQAPRKGLEWIGE**INHSGSTN**
YNPSLKSRVTISRDNSKNTLYLQMNSLRAEDTATYYC**ARPLNYYYYYMDV**WGKGTTV
TVSS

CDR1 = residues 26-33, CDR2 = residues 51-58, and CDR3 = residues 96-108

m1033-4 (SEQ ID NO: 19)

gaggtgcagctggtggagtctgggggaggcttggtacagcctggagggtccctgagactctcctgtgcagcctctggattcaccttcagtag
ctatggcatgagctgggtccgccaggctccaagacaagggcttgagtgggtggccaacataaagcaagatggaagtgagaaatactatgc
ggactcagtgaagggccgattcaccatctccagagacaattccaagaacacgctgtatctgcaaatgaacagcctgagagccgaggacac
agccacgtattactgtgcgaaagaaaatgtggactggggccagggcaccctggtcaccgtctcctca

m1033-4 (SEQ ID NO: 20)

EVQLVESGGGLVQPGGSLRLSCAAS**GFTFSSYG**MSWVRQAPRQGLEWVAN**IKQDGSE**
KYYADSVKGRFTISRDNSKNTLYLQMNSLRAEDTATYYC**AKENVD**WGQGTLVSS

CDR1 = residues 26-33, CDR2 = residues 51-58, and CDR3 = residues 97-102

Provided herein are monoclonal antibodies and antigen-binding fragments that bind (such as specifically bind) CD33, such as cell-surface CD33 or soluble CD33. In some embodiments, the monoclonal antibody or antigen-binding fragment includes both a VH domain and a VL domain. In other embodiments, the monoclonal antibody is a VH single-domain monoclonal antibody.

In some embodiments, the monoclonal antibody or antigen-binding fragment that binds CD33 includes at least one CDR sequence from antibody m1033-9, m1033-10, m1033-12, m1033-15, m1033-2 or m1033-4. In some embodiments, the CDR sequences are determined using the IMGT, Kabat or Chothia numbering scheme.

In some embodiments, the CD33-specific monoclonal antibody or antigen-binding fragment includes a VH domain and a VL domain, and the VH domain of the antibody includes one, two or all three CDR sequences of SEQ ID NO: 2, SEQ ID NO: 6, SEQ ID NO: 10 or SEQ

ID NO: 14, and/or the VL domain of the antibody includes one, two or all three CDR sequences of SEQ ID NO: 4, SEQ ID NO: 8, SEQ ID NO: 12 or SEQ ID NO: 16. The CDR sequences of the antibody or antigen-binding fragment can be determined using any numbering scheme know to one of skill in the art, such as the IMGT, Kabat or Chothia numbering scheme.

In some examples, the VH domain of the monoclonal antibody or antigen-binding fragment comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-32, 51-58 and 97-111 of SEQ ID NO: 2; and/or the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 27-34, 55-57 and 94-102 of SEQ ID NO: 4. In other examples, the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-35, 53-61 and 100-117 of SEQ ID NO: 6; and/or the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-35, 51-53 and 90-100 of SEQ ID NO: 8. In other examples, the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-35, 53-61 and 100-113 of SEQ ID NO: 10; and/or the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-31, 49-51 and 88-98 of SEQ ID NO: 12. In yet other examples, the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-31, 51-58 and 97-107 of SEQ ID NO: 14; and/or the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 27-37, 55-57 and 94-102 of SEQ ID NO: 16.

In particular examples, the amino acid sequence of the VH domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 2 and/or the amino acid sequence of the VL domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 4. In other particular examples, the amino acid sequence of the VH domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 6 and/or the amino acid sequence of the VL domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 8. In other particular examples, the amino acid sequence of the VH domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 10 and/or the amino acid sequence of the VL domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 12. In yet other particular examples, the amino acid sequence of the VH domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 14 and/or the amino acid sequence of the VL domain is at least 80%, at least 85%, at least 90%, at least 95%,

at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 16. In some examples, the sequence variation occurs only in the framework residues (not within the CDRs).

In specific non-limiting examples, the amino acid sequence of the VH domain comprises SEQ ID NO: 2 and/or the amino acid sequence of the VL domain comprises SEQ ID NO: 4; the amino acid sequence of the VH domain comprises SEQ ID NO: 6 and/or the amino acid sequence of the VL domain comprises SEQ ID NO: 8; the amino acid sequence of the VH domain comprises SEQ ID NO: 10 and/or the amino acid sequence of the VL domain comprises SEQ ID NO: 12; or the amino acid sequence of the VH domain comprises SEQ ID NO: 14 and/or the amino acid sequence of the VL domain comprises SEQ ID NO: 16.

CD33-specific antigen-binding fragments that include both a VH domain and a VL domain can be, for example, an Fab fragment, an Fab' fragment, an $F(ab)'_2$ fragment, a single chain variable fragment (scFv) or a disulfide stabilized variable fragment (dsFv). In some embodiments, the antigen-binding fragment is a scFv. In some embodiments, the antigen-binding fragment is a scFv.

CD33-specific monoclonal antibodies can be of any isotype, such as IgG, IgM, IgA, IgD or IgE. In some embodiments, the monoclonal antibody is an IgG.

In other embodiments, the CD33-specific monoclonal antibody is a VH single-domain antibody that includes one, two or all three CDR sequences of SEQ ID NO: 18 or SEQ ID NO: 20. In some examples, the VH domain comprises residues 26-33, 51-58 and 96-108 of SEQ ID NO: 18, or residues 26-33, 51-58 and 97-102 of SEQ ID NO: 20. In particular examples, the amino acid sequence of the VH domain is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 18 or SEQ ID NO: 20. In some examples, the sequence variation occurs only in the framework residues (not within the CDRs). In one non-limiting example, the amino acid sequence of the VH domain comprises or consists of the amino acid sequence of SEQ ID NO: 18 or SEQ ID NO: 20.

In some embodiments, the monoclonal antibody or antigen-binding fragment is a fully human antibody or antigen-binding fragment. In some embodiments, the monoclonal antibody or antigen-binding fragment is a chimeric or synthetic antibody or antigen-binding fragment.

Also provided herein are immunoconjugates that include a monoclonal antibody or antigen-binding fragment disclosed herein and an effector molecule. In some embodiments, the effector molecule is a toxin, such as, but not limited to, *Pseudomonas* exotoxin or a variant thereof. In other embodiments, the effector molecule is a detectable label, such as, but not limited to, a fluorophore, an enzyme or a radioisotope. Immunoconjugates are further described in section IV.

Further provided herein are antibody-drug conjugates (ADCs) that include a drug conjugated to a monoclonal antibody or antigen-binding fragment disclosed herein. In some embodiments, the drug is a small molecule, for example an anti-microtubule agent, an anti-mitotic agent and/or a cytotoxic agent. ADCs are further described in section V.

Also provided herein are multi-specific antibodies that include a monoclonal antibody or antigen-binding fragment disclosed herein and at least one additional monoclonal antibody or antigen-binding fragment thereof. In some embodiments, the multi-specific antibody is a bispecific antibody. In other embodiments, the multi-specific antibody is a trispecific antibody. In some embodiments, the at least one additional monoclonal antibody or antigen binding fragment thereof specifically binds a component of the T cell receptor or a natural killer (NK) cell activating receptor. Multi-specific antibodies are further described in section VI.

Further provided herein are antibody-nanoparticle conjugates that include a nanoparticle conjugated to a monoclonal antibody or antigen-binding fragment disclosed herein. In some embodiments, the nanoparticle comprises a polymeric nanoparticle, nanosphere, nanocapsule, liposome, dendrimer, polymeric micelle, or niosome. In some embodiments, the nanoparticle includes a cytotoxic agent. Antibody-nanoparticle conjugates are further described in section VII.

Also provided herein are fusion proteins that include a monoclonal antibody or antigen-binding fragment disclosed herein and a heterologous protein or peptide. In some embodiments, the heterologous protein is an Fc protein. In some examples, the Fc protein is a mouse Fc or a human Fc protein. In some embodiments, the heterologous peptide is not endogenous to humans (for example, the heterologous peptide is a peptide neo-epitope). In some embodiments, the heterologous peptide is about 8 to about 20 amino acids in length. In particular examples, the heterologous peptide is about 14 amino acids in length.

Compositions that include a pharmaceutically acceptable carrier and a monoclonal antibody or antigen-binding fragment, immunoconjugate, ADC, multi-specific antibody, antibody-nanoparticle conjugate, or fusion protein disclosed herein are further provided by the present disclosure.

Also provided are nucleic acid molecules encoding a monoclonal antibody or antigen-binding fragment disclosed herein. In some embodiments, the nucleic acid molecule encodes a VH domain and is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 1, SEQ ID NO: 5, SEQ ID NO: 9, SEQ ID NO: 13, SEQ I DNO: 17 or SEQ ID NO: 19. In some examples, the nucleic acid molecule encoding the VH domain comprises or consists of SEQ ID NO: 1, SEQ ID NO: 5, SEQ ID NO: 9, SEQ ID NO: 13, SEQ I DNO: 17 or SEQ ID NO: 19. In some embodiments, the

nucleic acid molecules encodes a VL domain and is at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98% or at least 99% identical to SEQ ID NO: 3, SEQ ID NO: 7, SEQ ID NO: 11 or SEQ ID NO: 15. In some examples, the nucleic acid molecule encoding the VL domain comprises or consists of SEQ ID NO: 3, SEQ ID NO: 7, SEQ ID NO: 11 or SEQ ID NO: 15. In specific non-limiting examples, the nucleic acid molecule comprises SEQ ID NO: 1 and SEQ ID NO: 3; SEQ ID NO: 5 and SEQ ID NO: 7; SEQ ID NO: 9 and SEQ ID NO: 11; or SEQ ID NO: 13 and SEQ ID NO: 15.

Further provided are nucleic acid molecules encoding an immunoconjugate, multi-specific antibody, or fusion protein disclosed herein.

In some embodiments, the nucleic acid molecule is operably linked to a promoter. Vectors that include the nucleic acid molecules are further provided herein.

Further provided herein are methods of treating a CD33-positive cancer in a subject. In some embodiments, the method includes administering to the subject a monoclonal antibody or antigen-binding fragment, immunoconjugate, ADC, multi-specific antibody, antibody-nanoparticle conjugate, fusion protein, or composition disclosed herein. Also provided is a method of inhibiting metastasis of a CD33-positive cancer in a subject. In some embodiments, the method includes administering to the subject a monoclonal antibody or antigen-binding fragment, immunoconjugate, ADC, multi-specific antibody, antibody-nanoparticle conjugate, fusion protein, or composition disclosed herein. In some examples, the CD33-positive cancer is acute myeloid leukemia (AML). In other examples, the CD33-positive cancer is a lymphoma or a squamous cell carcinoma.

Also provided is a method of detecting expression of CD33 in a sample. In some embodiments, the method includes contacting the sample with a CD33-specific monoclonal antibody or antigen-binding fragment disclosed herein; and detecting binding of the antibody to the sample. In some examples, the monoclonal antibody or antigen-binding fragment is directly labeled. In other examples, the method further includes contacting the monoclonal antibody or antigen-binding fragment with a second antibody, and detecting the binding of the second antibody to the monoclonal antibody or antigen-binding fragment. In some examples, the sample is obtained from a subject suspected of having a CD33-positive cancer. In some examples, the sample is a blood sample or a bone marrow biopsy.

Also provided is a method of diagnosing a subject as having a CD33-positive cancer. In some embodiments, the method includes contacting a sample from the subject with a CD33-specific monoclonal antibody antigen-binding fragment disclosed herein, and detecting binding of the antibody to the sample. An increase in binding of the antibody to the sample as compared

to binding of the antibody to a control sample identifies the subject as having a CD33-positive cancer. In some examples, the sample is a blood sample or a bone marrow biopsy.

IV. Immunoconjugates

The disclosed monoclonal antibodies can be conjugated to a therapeutic agent or effector molecule. Immunoconjugates include, but are not limited to, molecules in which there is a covalent linkage of a therapeutic agent to an antibody. A therapeutic agent is an agent with a particular biological activity directed against a particular target molecule or a cell bearing a target molecule. One of skill in the art will appreciate that therapeutic agents can include various drugs such as vinblastine, daunomycin and the like, cytotoxins such as native or modified *Pseudomonas* exotoxin or diphtheria toxin, encapsulating agents (such as liposomes) that contain pharmacological compositions, radioactive agents such as ^{125}I, ^{32}P, ^{14}C, ^{3}H and ^{35}S and other labels, target moieties and ligands.

The choice of a particular therapeutic agent depends on the particular target molecule or cell, and the desired biological effect. Thus, for example, the therapeutic agent can be a cytotoxin that is used to bring about the death of a particular target cell (such as a tumor cell). Conversely, where it is desired to invoke a non-lethal biological response, the therapeutic agent can be conjugated to a non-lethal pharmacological agent or a liposome containing a non-lethal pharmacological agent.

With the therapeutic agents and antibodies described herein, one of skill can readily construct a variety of clones containing functionally equivalent nucleic acids, such as nucleic acids which differ in sequence but which encode the same effector moiety or antibody sequence. Thus, the present disclosure provides nucleic acids encoding antibodies and conjugates and fusion proteins thereof.

Effector molecules can be linked to an antibody of interest using any number of means known to those of skill in the art. Both covalent and noncovalent attachment means may be used. The procedure for attaching an effector molecule to an antibody varies according to the chemical structure of the effector. Polypeptides typically contain a variety of functional groups; such as carboxylic acid (COOH), free amine ($-NH_2$) or sulfhydryl (-SH) groups, which are available for reaction with a suitable functional group on an antibody to result in the binding of the effector molecule. Alternatively, the antibody is derivatized to expose or attach additional reactive functional groups. The derivatization may involve attachment of any of a number of known linker molecules. The linker can be any molecule used to join the antibody to the effector molecule. The linker is capable of forming covalent bonds to both the antibody and to the effector molecule. Suitable linkers are well known to those of skill in the art and include, but are

not limited to, straight or branched-chain carbon linkers, heterocyclic carbon linkers, or peptide linkers. Where the antibody and the effector molecule are polypeptides, the linkers may be joined to the constituent amino acids through their side groups (such as through a disulfide linkage to cysteine) or to the alpha carbon amino and carboxyl groups of the terminal amino acids.

In some circumstances, it is desirable to free the effector molecule from the antibody when the immunoconjugate has reached its target site. Therefore, in these circumstances, immunoconjugates will comprise linkages that are cleavable in the vicinity of the target site. Cleavage of the linker to release the effector molecule from the antibody may be prompted by enzymatic activity or conditions to which the immunoconjugate is subjected either inside the target cell or in the vicinity of the target site.

In view of the large number of methods that have been reported for attaching a variety of radiodiagnostic compounds, radiotherapeutic compounds, labels (such as enzymes or fluorescent molecules), drugs, toxins, and other agents to antibodies one skilled in the art will be able to determine a suitable method for attaching a given agent to an antibody or other polypeptide.

The antibodies disclosed herein can be derivatized or linked to another molecule (such as another peptide or protein). In general, the antibodies or portion thereof is derivatized such that the binding to the target antigen is not affected adversely by the derivatization or labeling. For example, the antibody can be functionally linked (by chemical coupling, genetic fusion, noncovalent association or otherwise) to one or more other molecular entities, such as another antibody (for example, a bispecific antibody or a diabody), a detection agent, a pharmaceutical agent, and/or a protein or peptide that can mediate association of the antibody or antibody portion with another molecule (such as a streptavidin core region or a polyhistidine tag).

One type of derivatized antibody is produced by cross-linking two or more antibodies (of the same type or of different types, such as to create bispecific antibodies). Suitable crosslinkers include those that are heterobifunctional, having two distinctly reactive groups separated by an appropriate spacer (such as m-maleimidobenzoyl-N-hydroxysuccinimide ester) or homobifunctional (such as disuccinimidyl suberate). Such linkers are commercially available.

The antibody can be conjugated with a detectable marker; for example, a detectable marker capable of detection by ELISA, spectrophotometry, flow cytometry, microscopy or diagnostic imaging techniques (such as computed tomography (CT), computed axial tomography (CAT) scans, magnetic resonance imaging (MRI), nuclear magnetic resonance imaging NMRI), magnetic resonance tomography (MTR), ultrasound, fiberoptic examination, and laparoscopic examination). Specific, non-limiting examples of detectable markers include fluorophores, chemiluminescent agents, enzymatic linkages, radioactive isotopes and heavy metals or

compounds (for example super paramagnetic iron oxide nanocrystals for detection by MRI). For example, useful detectable markers include fluorescent compounds, including fluorescein, fluorescein isothiocyanate, rhodamine, 5-dimethylamine-1-napthalenesulfonyl chloride, phycoerythrin, lanthanide phosphors and the like. Bioluminescent markers are also of use, such as luciferase, green fluorescent protein (GFP) and yellow fluorescent protein (YFP). An antibody or antigen binding fragment can also be conjugated with enzymes that are useful for detection, such as horseradish peroxidase, β- galactosidase, luciferase, alkaline phosphatase, glucose oxidase and the like. When an antibody or antigen binding fragment is conjugated with a detectable enzyme, it can be detected by adding additional reagents that the enzyme uses to produce a reaction product that can be discerned. For example, when the agent horseradish peroxidase is present the addition of hydrogen peroxide and diaminobenzidine leads to a colored reaction product, which is visually detectable. An antibody or antigen binding fragment may also be conjugated with biotin, and detected through indirect measurement of avidin or streptavidin binding. It should be noted that the avidin itself can be conjugated with an enzyme or a fluorescent label.

An antibody may be labeled with a magnetic agent, such as gadolinium. Antibodies can also be labeled with lanthanides (such as europium and dysprosium), and manganese. Paramagnetic particles such as superparamagnetic iron oxide are also of use as labels. An antibody may also be labeled with a predetermined polypeptide epitopes recognized by a secondary reporter (such as leucine zipper pair sequences, binding sites for secondary antibodies, metal binding domains, epitope tags). In some embodiments, labels are attached by spacer arms of various lengths to reduce potential steric hindrance.

An antibody can also be labeled with a radiolabeled amino acid. The radiolabel may be used for both diagnostic and therapeutic purposes. For instance, the radiolabel may be used to detect expression of a target antigen by x-ray, emission spectra, or other diagnostic techniques. Examples of labels for polypeptides include, but are not limited to, the following radioisotopes or radionucleotides: ^{3}H, ^{14}C, ^{15}N, ^{35}S, ^{90}Y, ^{99}Tc, ^{111}In, ^{125}I, ^{131}I.

An antibody can also be derivatized with a chemical group such as polyethylene glycol (PEG), a methyl or ethyl group, or a carbohydrate group. These groups may be useful to improve the biological characteristics of the antibody, such as to increase serum half-life or to increase tissue binding.

Toxins can be employed with the monoclonal antibodies described herein to produce immunotoxins. Exemplary toxins include ricin, abrin, diphtheria toxin and subunits thereof, as well as botulinum toxins A through F. These toxins are readily available from commercial sources (for example, Sigma Chemical Company, St. Louis, MO). Contemplated toxins also

include variants of the toxins described herein (see, for example, see, U.S. Patent Nos. 5,079,163 and 4,689,401). In one embodiment, the toxin is *Pseudomonas* exotoxin (PE) (U.S. Patent No. 5,602,095). As used herein "*Pseudomonas* exotoxin" refers to a full-length native (naturally occurring) PE or a PE that has been modified. Such modifications can include, but are not limited to, elimination of domain Ia, various amino acid deletions in domains Ib, II and III, single amino acid substitutions and the addition of one or more sequences at the carboxyl terminus (for example, see Siegall *et al.*, *J. Biol. Chem.* 264:14256-14261, 1989).

PE employed with the monoclonal antibodies described herein can include the native sequence, cytotoxic fragments of the native sequence, and conservatively modified variants of native PE and its cytotoxic fragments. Cytotoxic fragments of PE include those which are cytotoxic with or without subsequent proteolytic or other processing in the target cell. Cytotoxic fragments of PE include PE40, PE38, and PE35. For additional description of PE and variants thereof, see for example, U.S. Patent Nos. 4,892,827; 5,512,658; 5,602,095; 5,608,039; 5,821,238; and 5,854,044; U.S. Patent Application Publication No. 2015/0099707; PCT Publication Nos. WO 99/51643 and WO 2014/052064; Pai *et al.*, *Proc. Natl. Acad. Sci. USA* 88:3358-3362, 1991; Kondo *et al.*, *J. Biol. Chem.* 263:9470-9475, 1988; Pastan *et al.*, *Biochim. Biophys. Acta* 1333:C1-C6, 1997.

Also contemplated herein are protease-resistant PE variants and PE variants with reduced immunogenicity, such as, but not limited to PE-LR, PE-6X, PE-8X, PE-LR/6X and PE-LR/8X (see, for example, Weldon *et al.*, *Blood* 113(16):3792-3800, 2009; Onda *et al.*, *Proc Natl Acad Sci USA* 105(32):11311-11316, 2008; and PCT Publication Nos. WO 2007/016150, WO 2009/032954 and WO 2011/032022, which are herein incorporated by reference).

In some examples, the PE is a variant that is resistant to lysosomal degradation, such as PE-LR (Weldon *et al.*, *Blood* 113(16):3792-3800, 2009; PCT Publication No. WO 2009/032954). In other examples, the PE is a variant designated PE-LR/6X (PCT Publication No. WO 2011/032022). In other examples, the PE variant is PE with reducing immunogenicity. In yet other examples, the PE is a variant designated PE-LR/8M (PCT Publication No. WO 2011/032022).

Modification of PE may occur in any previously described variant, including cytotoxic fragments of PE (for example, PE38, PE-LR and PE-LR/8M). Modified PEs may include any substitution(s), such as for one or more amino acid residues within one or more T-cell epitopes and/or B cell epitopes of PE, or deletion of one or more T-cell and/or B-cell epitopes (see, for example, U.S. Patent Application Publication No. 2015/0099707).

Contemplated forms of PE also include deimmunized forms of PE, for example versions with domain II deleted (for example, PE24). Deimmunized forms of PE are described in, for

example, PCT Publication Nos. WO 2005/052006, WO 2007/016150, WO 2007/014743, WO 2007/031741, WO 2009/32954, WO 2011/32022, WO 2012/154530, and WO 2012/170617.

The antibodies described herein can also be used to target any number of different diagnostic or therapeutic compounds to cells expressing the tumor or viral antigen on their surface. Thus, an antibody of the present disclosure can be attached directly or via a linker to a drug that is to be delivered directly to cells expressing cell-surface antigen. This can be done for therapeutic, diagnostic or research purposes. Therapeutic agents include such compounds as nucleic acids, proteins, peptides, amino acids or derivatives, glycoproteins, radioisotopes, lipids, carbohydrates, or recombinant viruses. Nucleic acid therapeutic and diagnostic moieties include antisense nucleic acids, derivatized oligonucleotides for covalent cross-linking with single or duplex DNA, and triplex forming oligonucleotides.

Alternatively, the molecule linked to an antibody can be an encapsulation system, such as a nanoparticle, liposome or micelle that contains a therapeutic composition such as a drug, a nucleic acid (for example, an antisense nucleic acid), or another therapeutic moiety that is preferably shielded from direct exposure to the circulatory system. Means of preparing liposomes attached to antibodies are well known to those of skill in the art (see, for example, U.S. Patent No. 4,957,735; Connor *et al.*, *Pharm. Ther.* 28:341-365, 1985).

Antibodies described herein can also be covalently or non-covalently linked to a detectable label. Detectable labels suitable for such use include any composition detectable by spectroscopic, photochemical, biochemical, immunochemical, electrical, optical or chemical means. Useful labels include magnetic beads, fluorescent dyes (for example, fluorescein isothiocyanate, Texas red, rhodamine, green fluorescent protein, and the like), radiolabels (for example, ^{3}H, ^{125}I, ^{35}S, ^{14}C, or ^{32}P), enzymes (such as horseradish peroxidase, alkaline phosphatase and others commonly used in an ELISA), and colorimetric labels such as colloidal gold or colored glass or plastic (such as polystyrene, polypropylene, latex, and the like) beads.

Means of detecting such labels are well known to those of skill in the art. Thus, for example, radiolabels may be detected using photographic film or scintillation counters, fluorescent markers may be detected using a photodetector to detect emitted illumination. Enzymatic labels are typically detected by providing the enzyme with a substrate and detecting the reaction product produced by the action of the enzyme on the substrate, and colorimetric labels are detected by simply visualizing the colored label.

V. Antibody-Drug Conjugates (ADCs)

ADCs are compounds comprised of a tumor antigen-specific antibody (or antigen-binding fragment thereof) and a drug, typically a cytotoxic agent, such as an anti-microtubule agent or

cross-linking agent. Because ADCs are capable of specifically targeting cancer cells, the drug can be much more potent than agents used for standard chemotherapy. The most common cytotoxic drugs currently used with ADCs have an IC_{50} that is 100- to 1000-fold more potent than conventional chemotherapeutic agents. Common cytotoxic drugs include anti-microtubule agents, such as maytansinoids and auristatins (such as auristatin E and auristatin F). Other cytotoxins for use with ADCs include pyrrolobenzodiazepines (PDBs), which covalently bind the minor groove of DNA to form interstrand crosslinks. In many instances, ADCs comprise a 1:2 to 1:4 ratio of antibody to drug (Bander, *Clinical Advances in Hematology & Oncology* 10(8; suppl 10):3-7, 2012).

The antibody and drug can be linked by a cleavable or non-cleavable linker. However, in some instances, it is desirable to have a linker that is stable in the circulation to prevent systemic release of the cytotoxic drug that could result in significant off-target toxicity. Non-cleavable linkers prevent release of the cytotoxic agent before the ADC is internalized by the target cell. Once in the lysosome, digestion of the antibody by lysosomal proteases results in the release of the cytotoxic agent (Bander, *Clinical Advances in Hematology & Oncology* 10(8; suppl 10):3-7, 2012).

One method for site-specific and stable conjugation of a drug to a monoclonal antibody is via glycan engineering. Monoclonal antibodies have one conserved N-linked oligosaccharide chain at the Asn297 residue in the CH2 domain of each heavy chain (Qasba *et al.*, *Biotechnol Prog* 24:520-526, 2008). Using a mutant β1,4-galactosyltransferase enzyme (Y289L-Gal-T1; U.S. Patent Application Publication Nos. 2007/0258986 and 2006/0084162, herein incorporated by reference), 2-keto-galactose is transferred to free GlcNAc residues on the antibody heavy chain to provide a chemical handle for conjugation.

The oligosaccharide chain attached to monoclonal antibodies can be classified into three groups based on the terminal galactose residues – fully galactosylated (two galactose residues; IgG-G2), one galactose residue (IgG-G1) or completely degalactosylated (IgG-G0). Treatment of a monoclonal antibody with β1,4-galactosidase converts the antibody to the IgG-G0 glycoform. The mutant β1,4-galactosyltransferase enzyme is capable of transferring 2-keto-galactose or 2-azido-galactose from their respective UDP derivatives to the GlcNAc residues on the IgG-G1 and IgG-G0 glycoforms. The chemical handle on the transferred sugar enables conjugation of a variety of molecules to the monoclonal antibody via the glycan residues (Qasba *et al.*, *Biotechnol Prog* 24:520-526, 2008).

Provided herein are ADCs that include a drug (such as a cytotoxic agent) conjugated to a monoclonal antibody that binds (such as specifically binds) CD33. In some embodiments, the drug is a small molecule. In some examples, the drug is a cross-linking agent, an anti-

microtubule agent and/or anti-mitotic agent, or any cytotoxic agent suitable for mediating killing of tumor cells. Exemplary cytotoxic agents include, but are not limited to, a PDB, an auristatin, a maytansinoid, dolastatin, calicheamicin, nemorubicin and its derivatives, PNU-159682, anthracycline, vinca alkaloid, taxane, trichothecene, CC1065, camptothecin, elinafide, a combretastain, a dolastatin, a duocarmycin, an enediyne, a geldanamycin, an indolino-benzodiazepine dimer, a puromycin, a tubulysin, a hemiasterlin, a spliceostatin, or a pladienolide, as well as stereoisomers, isosteres, analogs, and derivatives thereof that have cytotoxic activity.

In some embodiments, the ADC comprises a pyrrolobenzodiazepine (PBD). The natural product anthramycin (a PBD) was first reported in 1965 (Leimgruber *et al.*, *J Am Chem Soc*, 87:5793-5795, 1965; Leimgruber *et al.*, *J Am Chem Soc*, 87:5791-5793, 1965). Since then, a number of PBDs, both naturally-occurring and synthetic analogues, have been reported (Gerratana, *Med Res Rev* 32(2):254-293, 2012; and U.S. Patent Nos. 6,884,799; 7,049,311; 7,067,511; 7,265,105; 7,511,032; 7,528,126; and 7,557,099). As one example, PDB dimers recognize and bind to specific DNA sequences, and have been shown to be useful as cytotoxic agents. PBD dimers have been conjugated to antibodies and the resulting ADC shown to have anti-cancer properties (see, for example, US 2010/0203007). Exemplary linkage sites on the PBD dimer include the five-membered pyrrolo ring, the tether between the PBD units, and the N10-C11 imine group (see WO 2009/016516; US 2009/304710; US 2010/047257; US 2009/036431; US 2011/0256157; and WO 2011/130598).

In some embodiments, the ADC comprises an antibody conjugated to one or more maytansinoid molecules. Maytansinoids are derivatives of maytansine, and are mitotic inhibitors which act by inhibiting tubulin polymerization. Maytansine was first isolated from the east African shrub *Maytenus serrata* (U.S. Patent No. 3,896,111). Subsequently, it was discovered that certain microbes also produce maytansinoids, such as maytansinol and C-3 maytansinol esters (U.S. Patent No. 4,151,042). Synthetic maytansinoids are disclosed, for example, in U.S. Patent Nos. 4,137,230; 4,248,870; 4,256,746; 4,260,608; 4,265,814; 4,294,757; 4,307,016; 4,308,268; 4,308,269; 4,309,428; 4,313,946; 4,315,929; 4,317,821; 4,322,348; 4,331,598; 4,361,650; 4,364,866; 4,424,219; 4,450,254; 4,362,663; and 4,371,533.

In some embodiments, the ADC includes an antibody conjugated to a dolastatin or auristatin, or an analog or derivative thereof (see U.S. Patent Nos. 5,635,483; 5,780,588; 5,767,237; and 6,124,431). Auristatins are derivatives of the marine mollusk compound dolastatin-10. Dolastatins and auristatins have been shown to interfere with microtubule dynamics, GTP hydrolysis, and nuclear and cellular division (Woyke *et al.*, *Antimicrob Agents and Chemother* 45(12):3580-3584, 2001) and have anticancer (U.S. Patent No. 5,663,149) and antifungal activity (Pettit *et al.*, *Antimicrob Agents Chemother* 42:2961-2965, 1998). Exemplary

dolastatins and auristatins include, but are not limited to, dolastatin 10, auristatin E, auristatin F, auristatin EB (AEB), auristatin EFP (AEFP), MMAD (Monomethyl Auristatin D or monomethyl dolastatin 10), MMAF (Monomethyl Auristatin F or N-methylvaline-valine-dolaisoleuine-dolaproine-phenylalanine), MMAE (Monomethyl Auristatin E or N-methylvaline-valine-dolaisoleuine-dolaproine-norephedrine), 5-benzoylvaleric acid-AE ester (AEVB), and other auristatins (see, for example, U.S. Publication No. 2013/0129753).

In some embodiments, the ADC comprises an antibody conjugated to one or more calicheamicin molecules. The calicheamicin family of antibiotics, and analogues thereof, are capable of producing double-stranded DNA breaks at sub-picomolar concentrations (Hinman *et al.*, *Cancer Res* 53:3336-3342, 1993; Lode *et al.*, *Cancer Res* 58:2925-2928, 1998). Exemplary methods for preparing ADCs with a calicheamicin drug moiety are described in U.S. Patent Nos. 5,712,374; 5,714,586; 5,739,116; and 5,767,285.

In some embodiments, the ADC comprises an anthracycline. Anthracyclines are antibiotic compounds that exhibit cytotoxic activity. It is believed that anthracyclines can operate to kill cells by a number of different mechanisms, including intercalation of the drug molecules into the DNA of the cell thereby inhibiting DNA-dependent nucleic acid synthesis; inducing production of free radicals which then react with cellular macromolecules to cause damage to the cells; and/or interactions of the drug molecules with the cell membrane. Non-limiting exemplary anthracyclines include doxorubicin, epirubicin, idarubicin, daunomycin, daunorubicin, doxorubicin, epirubicin, nemorubicin, valrubicin and mitoxantrone, and derivatives thereof. For example, PNU-159682 is a potent metabolite (or derivative) of nemorubicin (Quintieri *et al.*, *Clin Cancer Res* 11(4):1608-1617, 2005). Nemorubicin is a semisynthetic analog of doxorubicin with a 2-methoxymorpholino group on the glycoside amino of doxorubicin (Grandi *et al.*, *Cancer Treat Rev* 17:133, 1990; Ripamonti *et al.*, *Br J Cancer* 65:703-707, 1992).

In some embodiments, the ADC can further include a linker. In some examples, the linker is a bifunctional or multifunctional moiety that can be used to link one or more drug moieties to an antibody to form an ADC. In some embodiments, ADCs are prepared using a linker having reactive functionalities for covalently attaching to the drug and to the antibody. For example, a cysteine thiol of an antibody can form a bond with a reactive functional group of a linker or a drug-linker intermediate to make an ADC.

In some examples, a linker has a functionality that is capable of reacting with a free cysteine present on an antibody to form a covalent bond. Exemplary linkers with such reactive functionalities include maleimide, haloacetamides, α-haloacetyl, activated esters such as

succinimide esters, 4-nitrophenyl esters, pentafluorophenyl esters, tetrafluorophenyl esters, anhydrides, acid chlorides, sulfonyl chlorides, isocyanates, and isothiocyanates.

In some examples, a linker has a functionality that is capable of reacting with an electrophilic group present on an antibody. Examples of such electrophilic groups include, but are not limited to, aldehyde and ketone carbonyl groups. In some cases, a heteroatom of the reactive functionality of the linker can react with an electrophilic group on an antibody and form a covalent bond to an antibody unit. Non-limiting examples include hydrazide, oxime, amino, hydrazine, thiosemicarbazone, hydrazine carboxylate and arylhydrazide.

In some examples, the linker is a cleavable linker, which facilitates release of the drug. Examples of cleavable linkers include acid-labile linkers (for example, comprising hydrazone), protease-sensitive linkers (for example, peptidase-sensitive), photolabile linkers, and disulfide-containing linkers (Chari *et al.*, *Cancer Res* 52:127-131, 1992; U.S. Patent No. 5,208,020).

The ADCs disclosed herein can be used for the treatment of a CD33-positive cancer alone or in combination with another therapeutic agent and/or in combination with any standard therapy for the treatment of cancer (such as surgical resection of the tumor, chemotherapy or radiation therapy).

VI. Multi-specific Antibodies

Multi-specific antibodies are recombinant proteins comprised of antigen-binding fragments of two or more different monoclonal antibodies. For example, bispecific antibodies are comprised of antigen-binding fragments of two different monoclonal antibodies. Thus, bispecific antibodies bind two different antigens and trispecific antibodies bind three different antigens. Multi-specific antibodies can be used for cancer immunotherapy by simultaneously targeting, for example, both CTLs (such as a CTL receptor component such as CD3) or effector natural killer (NK) cells, and at least one tumor antigen. The CD33-specific monoclonal antibodies disclosed herein can be used to generate multi-specific (such as bispecific or trispecific) antibodies that target both CD33 and CTLs, or target both CD33 and NK cells, thereby providing a means to treat CD33-expressing cancers.

Bi-specific T-cell engagers (BiTEs) are a type of bispecific monoclonal antibody that are fusions of a first single-chain variable fragment (scFv) that targets a tumor antigen and a second scFv that binds T cells, such as bind CD3 on T cells. In some embodiments herein, one of the binding moieties of the BiTE (such as one of the scFv molecules) is specific for CD33.

Bi-specific killer cell engagers (BiKEs) are a type of bispecific monoclonal antibody that are fusions of a first scFv that targets a tumor antigen and a second scFv that binds a NK cell activating receptor, such as CD16.

Provided herein are multi-specific, such as trispecific or bispecific, monoclonal antibodies comprising a CD33-specific monoclonal antibody. In some embodiments, the multi-specific monoclonal antibody further comprises a monoclonal antibody, or antigen-binding fragment thereof, that specifically binds a component of the T cell receptor, such as CD3. In other embodiments, the multi-specific monoclonal antibody further comprises a monoclonal antibody, or antigen-binding fragment thereof, that specifically binds a NK cell activating receptor, such as CD16, Ly49, or CD94. Also provided are isolated nucleic acid molecules and vectors encoding the multi-specific antibodies, and host cells comprising the nucleic acid molecules or vectors. Multi-specific antibodies comprising a CD33-specific antibody can be used for the treatment of cancers that express CD33. Thus, provided herein are methods of treating a subject with cancer by selecting a subject with a cancer that expresses CD33, and administering to the subject a therapeutically effective amount of the CD33-targeting multi-specific antibody.

VII. Antibody-Nanoparticle Conjugates

The monoclonal antibodies disclosed herein can be conjugated to a variety of different types of nanoparticles to deliver cytotoxic agents or other anti-cancer agents directly to tumor cells via binding of the antibody to a tumor specific antigen (*e.g.* CD33) expressed on the surface of tumor cells. The use of nanoparticles reduces off-target side effects and can also improve drug bioavailability and reduce the dose of a drug required to achieve a therapeutic effect. Nanoparticle formulations can be tailored to suit the drug that is to be carried or encapsulated within the nanoparticle. For example, hydrophobic molecules can be incorporated inside the core of a nanoparticle, while hydrophilic drugs can be carried within an aqueous core protected by a polymeric or lipid shell. Examples of nanoparticles include, but at not limited to, nanospheres, nanocapsules, liposomes, dendrimers, polymeric micelles, niosomes, and polymeric nanoparticles (Fay and Scott, *Immunotherapy* 3(3):381-394, 2011).

Liposomes are currently one of the most common types of nanoparticles used for drug delivery. An antibody conjugated to a liposome is often referred to as an "immunoliposome." The liposomal component of an immunoliposome is typically a lipid vesicle of one or more concentric phospholipid bilayers. In some cases, the phospholipids are composed of a hydrophilic head group and two hydrophobic chains to enable encapsulation of both hydrophobic and hydrophilic drugs. Conventional liposomes are rapidly removed from the circulation via macrophages of the reticuloendothelial system (RES). To generate long-circulating liposomes, the composition, size and charge of the liposome can be modulated. The surface of the liposome may also be modified, such as with a glycolipid or sialic acid. For example, the inclusion of polyethylene glycol (PEG) significantly increases circulation half-life. Liposomes for use as

drug delivery agents, including for preparation of immunoliposomes, have been described in the art (see, for example, Paszko and Senge, *Curr Med Chem* 19(31)5239-5277, 2012; Immordino *et al.*, *Int J Nanomedicine* 1(3):297-315, 2006; U.S. Patent Application Publication Nos. 2011/0268655; 2010/00329981).

Niosomes are non-ionic surfactant-based vesicles having a structure similar to liposomes. The membranes of niosomes are composed only of nonionic surfactants, such as polyglyceryl-alkyl ethers or *N*-palmitoylglucosamine. Niosomes range from small, unilamellar to large, multilamellar particles. These nanoparticles are monodisperse, water-soluble, chemically stable, have low toxicity, are biodegradable and non-immunogenic, and increase bioavailability of encapsulated drugs.

Dendrimers include a range of branched polymer complexes. These nanoparticles are water-soluble, biocompatible and are sufficiently non-immunogenic for human use. Generally, dendrimers consist of an initiator core, surrounded by a layer of a selected polymer that is grafted to the core, forming a branched macromolecular complex. Dendrimers are typically produced using polymers such as poly(amidoamine) or poly(L-lysine). Dendrimers have been used for a variety of therapeutic and diagnostic applications, including for the delivery of DNA, RNA, bioimaging contrast agents and chemotherapeutic agents.

Polymeric micelles are composed of aggregates of amphiphilic co-polymers (consisting of both hydrophilic and hydrophobic monomer units) assembled into hydrophobic cores, surrounded by a corona of hydrophilic polymeric chains exposed to the aqueous environment. In many cases, the polymers used to prepare polymeric micelles are heterobifunctional copolymers composed of a hydrophilic block of PEG, poly(vinyl pyrrolidone) and hydrophobic poly(L-lactide) or poly(L-lysine) that forms the particle core. Polymeric micelles can be used to carry drugs that have poor solubility. These nanoparticles have been used to encapsulate a number of anti-cancer drugs, including doxorubicin and camptothecin. Cationic micelles have also been developed to carry DNA or RNA molecules.

Polymeric nanoparticles include both nanospheres and nanocapsules. Nanospheres consist of a solid matrix of polymer, while nanocapsules contain an aqueous core. The formulation selected typically depends on the solubility of the therapeutic agent to be carried/encapsulated; poorly water-soluble drugs are more readily encapsulated within a nanospheres, while water-soluble and labile drugs, such as DNA and proteins, are more readily encapsulated within nanocapsules. The polymers used to produce these nanoparticles include, for example, poly(acrylamide), poly(ester), poly(alkylcyanoacrylates), poly(lactic acid) (PLA), poly(glycolic acids) (PGA), and poly(D,L-lactic-*co*-glycolic acid) (PLGA).

Antibodies, including scFv and single-domain antibodies, can be conjugated to a suitable nanoparticle according to standard methods known in the art. For example, conjugation can be either covalent or non-covalent. In some embodiments in which the nanoparticle is a liposome, the antibody is attached to a sterically stabilized, long circulation liposome via a PEG chain. Coupling of antibodies or antibody fragments to a liposome can also involve thioester bonds, for example by reaction of thiols and maleimide groups. Cross-linking agents can be used to create sulfhydryl groups for attachment of antibodies to nanoparticles (Paszko and Senge, *Curr Med Chem* 19(31)5239-5277, 2012).

IX. Compositions and Methods of Use

Compositions are provided that include one or more of the disclosed monoclonal antibodies that bind (for example specifically bind) CD33 in a carrier. Compositions comprising ADCs, multi-specific (such as bispecific or trispecific) antibodies, antibody-nanoparticle conjugates, immunoliposomes and immunoconjugates are also provided. The compositions can be prepared in unit dosage forms for administration to a subject. The amount and timing of administration are at the discretion of the treating clinician to achieve the desired outcome. The antibody, ADC, multi-specific antibody, antibody-nanoparticle conjugate, immunoliposome or immunoconjugate can be formulated for systemic or local administration. In one example, the antibody is formulated for parenteral administration, such as intravenous administration.

The compositions for administration can include a solution of the antibody, ADC, multi-specific (such as bispecific or trispecific) antibody, antibody-nanoparticle conjugate, immunoliposome or immunoconjugate in a pharmaceutically acceptable carrier, such as an aqueous carrier. A variety of aqueous carriers can be used, for example, buffered saline and the like. These solutions are sterile and generally free of undesirable matter. These compositions may be sterilized by conventional, well known sterilization techniques. The compositions may contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents and the like, for example, sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate and the like. The concentration of antibody in these formulations can vary widely, and will be selected primarily based on fluid volumes, viscosities, body weight and the like in accordance with the particular mode of administration selected and the subject's needs.

A typical pharmaceutical composition for intravenous administration includes about 0.1 to 10 mg of antibody (or ADC, multi-specific antibody, antibody-nanoparticle conjugate, or immunoconjugate) per subject per day. Dosages from 0.1 up to about 100 mg per subject per day may be used, particularly if the agent is administered to a secluded site and not into the

circulatory or lymph system, such as into a body cavity or into a lumen of an organ. Actual methods for preparing administrable compositions will be known or apparent to those skilled in the art and are described in more detail in such publications as *Remington's Pharmaceutical Science, 19th ed.*, Mack Publishing Company, Easton, PA (1995).

Antibodies (or other therapeutic molecules) may be provided in lyophilized form and rehydrated with sterile water before administration, although they are also provided in sterile solutions of known concentration. The antibody solution is then added to an infusion bag containing 0.9% sodium chloride, USP, and in some cases administered at a dosage of from 0.5 to 15 mg/kg of body weight. Considerable experience is available in the art in the administration of antibody drugs, which have been marketed in the U.S. since the approval of RITUXAN™ in 1997. Antibodies, ADCs, multi-specific (such as bispecific or trispecific) antibodies, antibody-nanoparticle conjugates, immunoliposomes or immunoconjugates can be administered by slow infusion, rather than in an intravenous push or bolus. In one example, a higher loading dose is administered, with subsequent, maintenance doses being administered at a lower level. For example, an initial loading dose of 4 mg/kg may be infused over a period of some 90 minutes, followed by weekly maintenance doses for 4-8 weeks of 2 mg/kg infused over a 30 minute period if the previous dose was well tolerated.

Controlled release parenteral formulations can be made as implants, oily injections, or as particulate systems. For a broad overview of protein delivery systems see, Banga, A.J., *Therapeutic Peptides and Proteins: Formulation, Processing, and Delivery Systems*, Technomic Publishing Company, Inc., Lancaster, PA, (1995). Particulate systems include, for example, microspheres, microparticles, microcapsules, nanocapsules, nanospheres, and nanoparticles. Microcapsules contain the therapeutic protein, such as a cytotoxin or a drug, as a central core. In microspheres the therapeutic is dispersed throughout the particle. Particles, microspheres, and microcapsules smaller than about 1 μm are generally referred to as nanoparticles, nanospheres, and nanocapsules, respectively. Capillaries have a diameter of approximately 5 μm so that only nanoparticles are administered intravenously. Microparticles are typically around 100 μm in diameter and are administered subcutaneously or intramuscularly. See, for example, Kreuter, J., *Colloidal Drug Delivery Systems*, J. Kreuter, ed., Marcel Dekker, Inc., New York, NY, pp. 219-342 (1994); and Tice & Tabibi, *Treatise on Controlled Drug Delivery*, A. Kydonieus, ed., Marcel Dekker, Inc. New York, NY, pp. 315-339, (1992).

Polymers can be used for ion-controlled release of the antibody-based compositions disclosed herein. Various degradable and nondegradable polymeric matrices for use in controlled drug delivery are known in the art (Langer, *Accounts Chem. Res.* 26:537-542, 1993). For example, the block copolymer, polaxamer 407, exists as a viscous yet mobile liquid at low

temperatures but forms a semisolid gel at body temperature. It has been shown to be an effective vehicle for formulation and sustained delivery of recombinant interleukin-2 and urease (Johnston *et al., Pharm. Res.* 9:425-434, 1992; and Pec *et al., J. Parent. Sci. Tech.* 44(2):58-65, 1990). Alternatively, hydroxyapatite has been used as a microcarrier for controlled release of proteins (Ijntema *et al.*, *Int. J. Pharm.* 112:215-224, 1994). In yet another aspect, liposomes are used for controlled release as well as drug targeting of the lipid-capsulated drug (Betageri *et al., Liposome Drug Delivery Systems*, Technomic Publishing Co., Inc., Lancaster, PA (1993)). Numerous additional systems for controlled delivery of therapeutic proteins are known (see U.S. Patent Nos. 5,055,303; 5,188,837; 4,235,871; 4,501,728; 4,837,028; 4,957,735; 5,019,369; 5,055,303; 5,514,670; 5,413,797; 5,268,164; 5,004,697; 4,902,505; 5,506,206; 5,271,961; 5,254,342 and 5,534,496).

A. Therapeutic Methods

The antibodies, compositions, ADCs, multi-specific (such as bispecific or trispecific) antibodies, antibody-nanoparticle conjugates, immunoliposomes and immunoconjugates disclosed herein can be administered to slow or inhibit the progression of a CD33-positive cancer, or inhibit the metastasis of a CD33-positive cancer. In these applications, a therapeutically effective amount of a composition is administered to a subject in an amount sufficient to inhibit growth, replication or metastasis of cancer cells, or to inhibit a sign or a symptom of the cancer. Suitable subjects may include those diagnosed with a cancer that expresses CD33, such as AML, a lymphoma or a squamous cell carcinoma.

Provided herein is a method of treating a CD33-positive cancer in a subject by administering to the subject a therapeutically effective amount of a CD33-specific antibody, immunoconjugate, ADC, multi-specific (such as bispecific or trispecific) antibody, antibody-nanoparticle conjugate, immunoliposome or composition disclosed herein. Also provided herein is a method of inhibiting metastasis of a CD33-positive cancer in a subject by administering to the subject a therapeutically effective amount of a CD33-specific antibody, immunoconjugate, ADC, multi-specific (such as bispecific or trispecific) antibody, antibody-nanoparticle conjugate, immunoliposome or composition disclosed herein. In some embodiments, the CD33-positive cancer is AML. In other embodiments, the CD33-positive cancer is a lymphoma or a squamous cell carcinoma.

A therapeutically effective amount of a CD33-specific monoclonal antibody, ADC, multi-specific (such as bispecific or trispecific) antibody, immunoconjugate, immunoliposome or composition disclosed herein will depend upon the severity of the disease, the type of disease, and the general state of the patient's health. A therapeutically effective amount of the antibody-

based composition is that which provides either subjective relief of a symptom(s) or an objectively identifiable improvement as noted by the clinician or other qualified observer.

Administration of the CD33-specific antibodies, ADCs, immunoconjugates, multi-specific (such as bispecific or trispecific) antibodies, antibody-nanoparticle conjugates, immunoliposomes and compositions disclosed herein can also be accompanied by administration of other anti-cancer agents or therapeutic treatments (such as surgical resection of a tumor). Any suitable anti-cancer agent can be administered in combination with the antibodies, compositions and immunoconjugates disclosed herein. Exemplary anti-cancer agents include, but are not limited to, chemotherapeutic agents, such as, for example, mitotic inhibitors, alkylating agents, anti-metabolites, intercalating antibiotics, growth factor inhibitors, cell cycle inhibitors, enzymes, topoisomerase inhibitors, anti-survival agents, biological response modifiers, anti-hormones (*e.g.* anti-androgens) and anti-angiogenesis agents. Other anti-cancer treatments include radiation therapy and other antibodies that specifically target cancer cells.

Non-limiting examples of alkylating agents include nitrogen mustards (such as mechlorethamine, cyclophosphamide, melphalan, uracil mustard or chlorambucil), alkyl sulfonates (such as busulfan), nitrosoureas (such as carmustine, lomustine, semustine, streptozocin, or dacarbazine).

Non-limiting examples of antimetabolites include folic acid analogs (such as methotrexate), pyrimidine analogs (such as 5-FU or cytarabine), and purine analogs, such as mercaptopurine or thioguanine.

Non-limiting examples of natural products include vinca alkaloids (such as vinblastine, vincristine, or vindesine), epipodophyllotoxins (such as etoposide or teniposide), antibiotics (such as dactinomycin, daunorubicin, doxorubicin, bleomycin, plicamycin, or mitomycin C), and enzymes (such as L-asparaginase).

Non-limiting examples of miscellaneous agents include platinum coordination complexes (such as cis-diamine-dichloroplatinum II also known as cisplatin), substituted ureas (such as hydroxyurea), methyl hydrazine derivatives (such as procarbazine), and adrenocrotical suppressants (such as mitotane and aminoglutethimide).

Non-limiting examples of hormones and antagonists include adrenocorticosteroids (such as prednisone), progestins (such as hydroxyprogesterone caproate, medroxyprogesterone acetate, and magestrol acetate), estrogens (such as diethylstilbestrol and ethinyl estradiol), antiestrogens (such as tamoxifen), and androgens (such as testerone proprionate and fluoxymesterone). Examples of the most commonly used chemotherapy drugs include Adriamycin, Alkeran, Ara-C, BiCNU, Busulfan, CCNU, Carboplatinum, Cisplatinum, Cytoxan, Daunorubicin, DTIC, 5-FU, Fludarabine, Hydrea, Idarubicin, Ifosfamide, Methotrexate, Mithramycin, Mitomycin,

Mitoxantrone, Nitrogen Mustard, Taxol (or other taxanes, such as docetaxel), Velban, Vincristine, VP-16, while some more newer drugs include Gemcitabine (Gemzar), Herceptin, Irinotecan (Camptosar, CPT-11), Leustatin, Navelbine, Rituxan STI-571, Taxotere, Topotecan (Hycamtin), Xeloda (Capecitabine), Zevelin and calcitriol.

Non-limiting examples of immunomodulators that can be used include AS-101 (Wyeth-Ayerst Labs.), bropirimine (Upjohn), gamma interferon (Genentech), GM-CSF (granulocyte macrophage colony stimulating factor; Genetics Institute), IL-2 (Cetus or Hoffman-LaRoche), human immune globulin (Cutter Biological), IMREG (from Imreg of New Orleans, La.), SK&F 106528, and TNF (tumor necrosis factor; Genentech).

Another common treatment for some types of cancer is surgical treatment, for example surgical resection of a metastatic tumor. Another example of a treatment is radiotherapy, for example administration of radioactive material or energy (such as external beam therapy) to the tumor site to help eradicate the tumor or shrink it prior to surgical resection.

Therapeutic agents for the treatment of AML are known in the art and can be administered in combination with any of the CD33-specific antibodies or antibody conjugates disclosed herein. In some embodiments, the subject is treated with an anti-leukemic therapeutic agent, such as cytarabine, idarubicin, etoposide, methotrexate or clofarabine. In some embodiments, the patient receives a hematopoietic stem cell transplant.

B. Methods for Diagnosis and Detection

Methods are provided herein for detecting CD33 protein *in vitro* or *in vivo*. In some cases, CD33 expression is detected in a biological sample. The sample can be any sample, including, but not limited to, blood samples, tissue from biopsies, autopsies and pathology specimens. Biological samples also include sections of tissues, for example, frozen sections taken for histological purposes. Biological samples further include body fluids, such as blood, serum, plasma, sputum, spinal fluid or urine. A biological sample is typically obtained from a mammal, such as a human or non-human primate.

Provided herein is a method of determining if a subject has a CD33-positive cancer by contacting a sample from the subject with a CD33-specific monoclonal antibody disclosed herein; and detecting binding of the antibody to the sample. An increase in binding of the antibody to the sample as compared to binding of the antibody to a control sample identifies the subject as having a CD33-positive cancer.

In another embodiment, provided is a method of confirming a diagnosis of a CD33-positive cancer in a subject by contacting a sample from a subject diagnosed with a CD33-positive cancer with a CD33-specific monoclonal antibody disclosed herein; and detecting binding of the antibody to the sample. An increase in binding of the antibody to the sample as

compared to binding of the antibody to a control sample confirms the diagnosis of a CD33-positive cancer in the subject.

In some examples of the disclosed methods, the monoclonal antibody is directly labeled.

In other examples, the methods further include contacting a second antibody that specifically binds the monoclonal antibody with the sample; and detecting the binding of the second antibody. An increase in binding of the second antibody to the sample as compared to binding of the second antibody to a control sample detects a CD33-positive cancer in the subject or confirms the diagnosis of a CD33-positive cancer in the subject.

In some cases, the cancer is AML. In other cases, the cancer is a lymphoma or a squamous cell carcinoma.

In some examples, the control sample is a sample from a subject without cancer. In particular examples, the sample is a blood or tissue sample.

In some embodiments of the methods of diagnosis and detection, the antibody that binds (for example specifically binds) CD33 is directly labeled with a detectable label. In another embodiment, the antibody that binds (for example, specifically binds) CD33 (the first antibody) is unlabeled and a second antibody or other molecule that can bind the antibody that specifically binds CD33 is labeled. As is well known to one of skill in the art, a secondary antibody is chosen that is able to specifically bind the specific species and class of the first antibody. For example, if the first antibody is a human IgG, then the secondary antibody may be an anti-human-IgG. Other molecules that can bind to antibodies include, without limitation, Protein A and Protein G, both of which are available commercially.

Suitable labels for the antibody or secondary antibody include various enzymes, prosthetic groups, fluorescent materials, luminescent materials, magnetic agents and radioactive materials. Non-limiting examples of suitable enzymes include horseradish peroxidase, alkaline phosphatase, beta-galactosidase, or acetylcholinesterase. Non-limiting examples of suitable prosthetic group complexes include streptavidin/biotin and avidin/biotin. Non-limiting examples of suitable fluorescent materials include umbelliferone, fluorescein, fluorescein isothiocyanate, rhodamine, dichlorotriazinylamine fluorescein, dansyl chloride or phycoerythrin. A non-limiting exemplary luminescent material is luminol; a non-limiting exemplary a magnetic agent is gadolinium, and non-limiting exemplary radioactive labels include ^{125}I, ^{131}I, ^{35}S or ^{3}H.

In an alternative embodiment, CD33 can be assayed in a biological sample by a competition immunoassay utilizing CD33 protein standards labeled with a detectable substance and an unlabeled antibody that specifically binds CD33. In this assay, the biological sample, the labeled CD33 protein standards and the antibody that specifically bind CD33 are combined and the amount of labeled CD33 protein standard bound to the unlabeled antibody is determined.

The amount of CD33 in the biological sample is inversely proportional to the amount of labeled CD33 protein standard bound to the antibody that specifically binds CD33.

The immunoassays and methods disclosed herein can be used for a number of purposes. In one embodiment, the antibody that specifically binds may be used to detect the production of CD33 in cells in cell culture. In another embodiment, the antibody can be used to detect the amount of CD33 in a biological sample, such as a tissue sample, or a blood or serum sample. In some examples, the CD33 is cell-surface CD33. In other examples, the CD33 protein is soluble (*e.g.* in a cell culture supernatant or in a body fluid sample, such as a blood or serum sample).

In one embodiment, a kit is provided for detecting CD33 in a biological sample, such as a blood sample or tissue sample. For example, to confirm a cancer diagnosis in a subject, a biopsy can be performed to obtain a tissue sample for histological examination. Kits for detecting a polypeptide will typically comprise a monoclonal antibody that specifically binds CD33, such as any of the monoclonal antibodies disclosed herein. In a further embodiment, the antibody is labeled (for example, with a fluorescent, radioactive, or an enzymatic label).

In one embodiment, a kit includes instructional materials disclosing means of use of an antibody that binds CD33. The instructional materials may be written, in an electronic form (such as a computer diskette or compact disk) or may be visual (such as video files). The kits may also include additional components to facilitate the particular application for which the kit is designed. Thus, for example, the kit may additionally contain means of detecting a label (such as enzyme substrates for enzymatic labels, filter sets to detect fluorescent labels, appropriate secondary labels such as a secondary antibody, or the like). The kits may additionally include buffers and other reagents routinely used for the practice of a particular method. Such kits and appropriate contents are well known to those of skill in the art.

In one embodiment, the diagnostic kit comprises an immunoassay. Although the details of the immunoassays may vary with the particular format employed, the method of detecting CD33 in a biological sample generally includes the steps of contacting the biological sample with an antibody which specifically reacts, under immunologically reactive conditions, to CD33. The antibody is allowed to specifically bind under immunologically reactive conditions to form an immune complex, and the presence of the immune complex (bound antibody) is detected directly or indirectly.

The antibodies disclosed herein can also be utilized in immunoassays, such as, but not limited to radioimmunoassays (RIAs), ELISA, or immunohistochemical assays. The antibodies can also be used for fluorescence activated cell sorting (FACS). FACS employs a plurality of color channels, low angle and obtuse light-scattering detection channels, and impedance channels, among other more sophisticated levels of detection, to separate or sort cells (see U.S.

Patent No. 5,061,620). Any of the monoclonal antibodies that bind CD33, as disclosed herein, can be used in these assays. Thus, the antibodies can be used in a conventional immunoassay, including, without limitation, an ELISA, an RIA, FACS, tissue immunohistochemistry, Western blot or immunoprecipitation.

The following examples are provided to illustrate certain particular features and/or embodiments. These examples should not be construed to limit the disclosure to the particular features or embodiments described.

EXAMPLES

Example 1: Selection of CD33-Specific Monoclonal Antibodies

This example describes the identification and characterization of six anti-CD33 monoclonal antibodies.

Selection of human phage-displayed scFv and VH domain antibodies specific for CD33

A naïve human scFv phage display library (approximate diversity, 1010 unique specificities), constructed from peripheral blood B cells of 50 healthy donors, and a human VH domain library were used for selection of scFvs or VH domains specific for recombinant human CD33. Amplified libraries of 10^{12} phage-displayed scFv or VH were incubated with 5, 3, and 1, μg of coated CD33 in a 5 x 100-μl volume, distributed equally in 5 wells of a 96-well plate for 2 hours at room temperature during the first, second and third rounds of biopanning, respectively. After each round of incubation, the wells were washed 5 times for the first round and 10 times for the later rounds with phosphate-buffered saline containing 0.05% Tween 20 (PBST) to remove nonspecifically bound phage. The bound phage were mixed with TG1 competent cells for 1 hour at 37°C, and the phage were amplified from the infected cells and used in the next round of biopanning. After the third round of biopanning, 380 clones were randomly picked from the infected TG1 cells and each inoculated into 150 μl 2YT medium containing 100 μg/ml carbenicillin and 0.2% glucose in 96-well plates using the automated BioRobotics BioPick colony picking system (Genomic Solutions, Ann Arbor, MI). After the bacterial cultures reached an optical density at 600 nm (OD600) of 0.5, helper phage M13K07 at a multiplicity of infection (MOI) of 10 and kanamycin at a final concentration of 50 μg/ml were added to the medium, and the plates were further incubated at 30°C overnight in a shaker at 250 rpm. The phage supernatants were mixed with 3% nonfat milk in PBS at a 4:1 volume ratio and used for enzyme-linked immunosorbent assay (ELISA) to identify clones of phage displaying scFvs or VH domains with high CD33 binding affinity. The supernatants were incubated for 2 hours at room

temperature with recombinant human CD33 coated at 50 ng per well in 96-well plates and washed five times with PBST (after overnight incubation at 4°C it was blocked with 3% nonfat milk in PBS and washed three times with PBS containing 0.05% Tween 20). CD33-bound phage were detected using horseradish peroxidase (HRP)-conjugated goat anti-M13 antibody. After incubation with the antibody, the nonspecifically bound antibody was removed by washing wells, and the 3,3',5,5'-tetramethylbenzidine (TMB) substrate was added, and solution absorbance at 450 nm (A450) measured. Clones that bound to CD33 with A450 of >1.0 were selected for further characterization.

Expression and purification of selected soluble ScFvs or VHs

The VH and VL domains of the selected clones and the VH domain of the single-domain binders were DNA sequenced, and the scFvs or VH domains encoded by clones with unique sequences were expressed and purified as described below. Plasmids extracted from these clones were used for transformation of HB2151 cells. A single colony was picked from the plate containing freshly transformed cells, inoculated into 200 ml 2YT medium containing 100 μg/ml ampicillin and 0.2% glucose, and incubated at 37°C with shaking at 250 rpm. When the OD600 of the culture reached 0.90, isopropyl-β-d-thiogalactopyranoside at a 0.5 mM final concentration was added, and the culture was further incubated overnight at 30°C. The bacterial pellet was collected after centrifugation at 8,000 × g for 20 minutes and resuspended in PBS buffer containing 0.5 mU polymyxin B (Sigma-Aldrich, St. Louis, MO). After a 30-minute incubation with rotation at 50 rpm at room temperature, the resuspended pellet was centrifuged at 25,000 × g for 25 minutes at 4°C, and the supernatant was used for scFv purification using the Ni-NTA resin following vendor protocol (Qiagen).

ELISA binding assay

Fifty μl of diluted recombinant human CD33 in PBS at 2 μg/ml was coated in a 96-well plate at 4°C overnight. Purified scFv or VH domain (from above) with His and Flag tags were serially diluted and added into the target protein coated wells. After washing, a 1:3000 diluted HRP conjugated anti-Flag antibody was added for 1 hour at room temperature. After washing, TMB substrate was added, 1N H_2SO_4 was added to stop the reaction after incubation at room temperature for 10 minutes, and the OD was read at 450 nm to quantify the relative ability of scFv to bind CD33.

Based upon the results of the ELISA binding assays (FIGS. 1, 3, 5, 7, 9 and 11), four separate scFv clones specific for recombinant human CD33 were identified and labeled as human anti-CD33 scFv binders m1033-9 (FIG. 1), m1033-10 (FIG. 3), m1033-12 (FIG. 5) and m1033-

15 (FIG. 7). Two unique VH domain binders, referred to as m1033-2 (FIG. 9) and m1033-4 (FIG. 11), were also identified from the ELISA binding assay.

FACS binding assays

To evaluate the capacity of the selected CD33-specific antibodies to bind cell-surface expressed CD33, fluorescence activated cell sorting (FACS) assays were performed using the CD33-negative ALL cell line RS4;11, the CD33-positive AML cell line MV4-11 and either Jurkat T cells, 293T cells or CHO cells, all of which are CD33-negative. Cells were contacted with each antibody in scFv format at a concentration of 10 μg/ml. Anti-flag antibody conjugated with phycoerythrin (PE) was used as the secondary antibody for detection of antibody binding. Cells were then subject to FACS analysis. The results are shown in FIGS. 2A-2C (m1033-9), 4A-4C (m1033-10), 6A-6C (m1033-12), 8A-8C (m1033-15), 10A-10C (m1033-2) and 12A-12C (m1033-4). Significant binding to CD33-postive MV4-11 cells was detected for antibodies m1033-9 (FIG. 2B), m1033-10 (FIG. 4B), m1033-15 (FIG. 8B), m1033-2 (FIG. 10B) and m1033-4 (FIG. 12B).

In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope and spirit of these claims.

CLAIMS

1. An isolated monoclonal antibody that binds human CD33, or an antigen-binding fragment thereof, comprising:

a variable heavy (VH) domain and a variable light (VL) domain, wherein the VH domain of the antibody comprises the complementarity determining region (CDR) sequences of SEQ ID NO: 2, SEQ ID NO: 6, SEQ ID NO: 10 or SEQ ID NO: 14, and the VL domain of the antibody comprises the CDR sequences of SEQ ID NO: 4, SEQ ID NO: 8, SEQ ID NO: 12, SEQ ID NO: 16; or

a VH domain comprising the CDR sequences of SEQ ID NO: 18 or SEQ ID NO: 20.

2. The monoclonal antibody or antigen-binding fragment of claim 1, wherein the CDR sequences are determined using the IMGT, Kabat or Chothia numbering scheme.

3. The monoclonal antibody or antigen-binding fragment of claim 1 or claim 2, wherein:

the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-32, 51-58 and 97-111 of SEQ ID NO: 2 and the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 27-34, 55-57 and 94-102 of SEQ ID NO: 4;

the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-35, 53-61 and 100-117 of SEQ ID NO: 6 and the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-35, 51-53 and 90-100 of SEQ ID NO: 8;

the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-35, 53-61 and 100-113 of SEQ ID NO: 10 and the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-31, 49-51 and 88-98 of SEQ ID NO: 12; or

the VH domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 26-31, 51-58 and 97-107 of SEQ ID NO: 14 and the VL domain comprises a CDR1, a CDR2 and a CDR3 respectively set forth as residues 27-37, 55-57 and 94-102 of SEQ ID NO: 16.

4. The monoclonal antibody or antigen-binding fragment of any one of claims 1-3, wherein:

the amino acid sequence of the VH domain is at least 90% identical to SEQ ID NO: 2 and the amino acid sequence of the VL domain is at least 90% identical to SEQ ID NO: 4;

the amino acid sequence of the VH domain is at least 90% identical to SEQ ID NO: 6 and the amino acid sequence of the VL domain is at least 90% identical to SEQ ID NO: 8;

the amino acid sequence of the VH domain is at least 90% identical to SEQ ID NO: 10 and the amino acid sequence of the VL domain is at least 90% identical to SEQ ID NO: 12; or

the amino acid sequence of the VH domain is at least 90% identical to SEQ ID NO: 14 and the amino acid sequence of the VL domain is at least 90% identical to SEQ ID NO: 16.

5. The monoclonal antibody or antigen-binding fragment of any one of claims 1-4, wherein:

the amino acid sequence of the VH domain comprises SEQ ID NO: 2 and the amino acid sequence of the VL domain comprises SEQ ID NO: 4;

the amino acid sequence of the VH domain comprises SEQ ID NO: 6 and the amino acid sequence of the VL domain comprises SEQ ID NO: 8;

the amino acid sequence of the VH domain comprises SEQ ID NO: 10 and the amino acid sequence of the VL domain comprises SEQ ID NO: 12; or

the amino acid sequence of the VH domain comprises SEQ ID NO: 14 and the amino acid sequence of the VL domain comprises SEQ ID NO: 16.

6. The antigen-binding fragment of any one of claims 1-5, wherein the antigen-binding fragment is an Fab fragment, an Fab' fragment, an $F(ab)'_2$ fragment, a single chain variable fragment (scFv) or a disulfide stabilized variable fragment (dsFv).

7. The monoclonal antibody of any one of claims 1-5, wherein the antibody is an IgG.

8. The monoclonal antibody or antigen-binding fragment of claim 1 or claim 2, which is a VH single domain antibody comprising:

residues 26-33, 51-58 and 96-108 of SEQ ID NO: 18; or

residues 26-33, 51-58 and 97-102 of SEQ ID NO: 20.

9. The monoclonal antibody or antigen-binding fragment of any one of claims 1-8, which is a fully human, chimeric or synthetic antibody or antigen-binding fragment.

10. An immunoconjugate comprising the monoclonal antibody or antigen-binding fragment of any one of claims 1-9 and an effector molecule.

11. The immunoconjugate of claim 10, wherein the effector molecule is a toxin.

12. The immunoconjugate of claim 11, wherein the toxin is *Pseudomonas* exotoxin or a variant thereof.

13. The immunoconjugate of claim 10, wherein the effector molecule is a detectable label.

14. The immunoconjugate of claim 13, wherein the detectable label comprises a fluorophore, an enzyme or a radioisotope.

15. An antibody-drug conjugate (ADC) comprising a drug conjugated to the monoclonal antibody or antigen-binding fragment of any one of claims 1-9.

16. The ADC of claim 15, wherein the drug is a small molecule.

17. The ADC of claim 15 or claim 16, wherein the drug is an anti-microtubule agent, an anti-mitotic agent and/or a cytotoxic agent.

18. A multi-specific antibody comprising the monoclonal antibody or antigen-binding fragment of any of claims 1-9 and at least one additional monoclonal antibody or antigen-binding fragment thereof.

19. The multi-specific antibody of claim 18, which is a bispecific antibody.

20. The multi-specific antibody of claim 18, which is a trispecific antibody.

21. The multi-specific antibody of any one of claims 18-20, wherein the at least one additional monoclonal antibody or antigen binding fragment thereof specifically binds a component of the T cell receptor or a natural killer (NK) cell activating receptor.

22. An antibody-nanoparticle conjugate, comprising a nanoparticle conjugated to the monoclonal antibody or antigen-binding fragment of any one of claims 1-9.

23. The antibody-nanoparticle conjugate of claim 22, wherein the nanoparticle comprises a polymeric nanoparticle, nanosphere, nanocapsule, liposome, dendrimer, polymeric micelle, or niosome.

24. The antibody-nanoparticle conjugate of claim 22 or claim 23, wherein the nanoparticle comprises a cytotoxic agent.

25. A fusion protein comprising the monoclonal antibody or antigen-binding fragment of any one of claims 1-9 and a heterologous protein or peptide.

26. The fusion protein of claim 25, wherein the heterologous protein is an Fc protein.

27. A composition comprising a pharmaceutically acceptable carrier and the monoclonal antibody or antigen-binding fragment of any one of claims 1-9, the immunoconjugate of any one of claims 10-14, the ADC of any one of claims 15-17, the multi-specific antibody of any one of claims 18-21, the antibody-nanoparticle conjugate of any one of claims 22-24, or the fusion protein of claim 25 or claim 26.

28. A nucleic acid molecule encoding the monoclonal antibody or antigen-binding fragment of any one of claims 1-9, the immunoconjugate of any one of claims 10-14, the multi-specific antibody of any one of claims 18-21, or the fusion protein of claim 25 or claim 26.

29. The nucleic acid molecule of claim 28, comprising SEQ ID NO: 1, SEQ ID NO: 3, SEQ ID NO: 5, SEQ ID NO: 7, SEQ ID NO: 9, SEQ ID NO: 11, SEQ ID NO: 13, SEQ ID NO: 15, SEQ ID NO: 17 or SEQ ID NO: 19.

30. The nucleic acid molecule of claim 28, comprising:
SEQ ID NO: 1 and SEQ ID NO: 3;
SEQ ID NO: 5 and SEQ ID NO: 7;
SEQ ID NO: 9 and SEQ ID NO: 11;
SEQ ID NO: 13 and SEQ ID NO: 15;
SEQ ID NO: 17; or
SEQ ID NO: 19.

31. The nucleic acid molecule of any one of claims 28-30, operably linked to a promoter.

32. A vector comprising the nucleic acid molecule of any one of claims 28-31.

33. A method of treating a CD33-positive cancer in a subject, comprising administering to the subject the monoclonal antibody or antigen-binding fragment of any one of claims 1-9, the immunoconjugate of any one of claims 10-14, the ADC of any one of claims 15-17, the multi-specific antibody of any one of claims 18-21, the antibody-nanoparticle conjugate of any one of claims 22-24, the fusion protein of claim 25 or claim 26, or the composition of claim 27.

34. A method of inhibiting metastasis of a CD33-positive cancer in a subject, comprising administering to the subject the monoclonal antibody or antigen-binding fragment of any one of claims 1-9, the immunoconjugate of any one of claims 10-14, the ADC of any one of claims 15-17, the multi-specific antibody of any one of claims 18-21, the antibody-nanoparticle conjugate of any one of claims 22-24, the fusion protein of claim 25 or claim 26, or the composition of claim 27.

35. The method of claim 33 or claim 34, wherein the CD33-positive cancer is acute myeloid leukemia (AML).

36. The method of claim 33 or claim 34, wherein the CD33-positive cancer is a lymphoma or a squamous cell carcinoma.

37. A method of detecting expression of CD33 in a sample, comprising:

contacting the sample with the monoclonal antibody or antigen-binding fragment of any one of claims 1-9; and

detecting binding of the antibody to the sample, thereby detecting expression of CD33 in the sample.

38. The method of claim 37, wherein the monoclonal antibody or antigen-binding fragment is directly labeled.

39. The method of claim 37, further comprising:

contacting the monoclonal antibody or antigen-binding fragment with a second antibody, and

detecting the binding of the second antibody to the monoclonal antibody or antigen-binding fragment, thereby detecting expression of CD33 in the sample.

40. The method of any one of claims 37-39, wherein the sample is obtained from a subject suspected of having a CD33-positive cancer.

41. The method of any one of claims 37-40, wherein the sample is a blood sample.

42. The method of any one of claims 37-40, wherein the sample is a bone marrow biopsy.

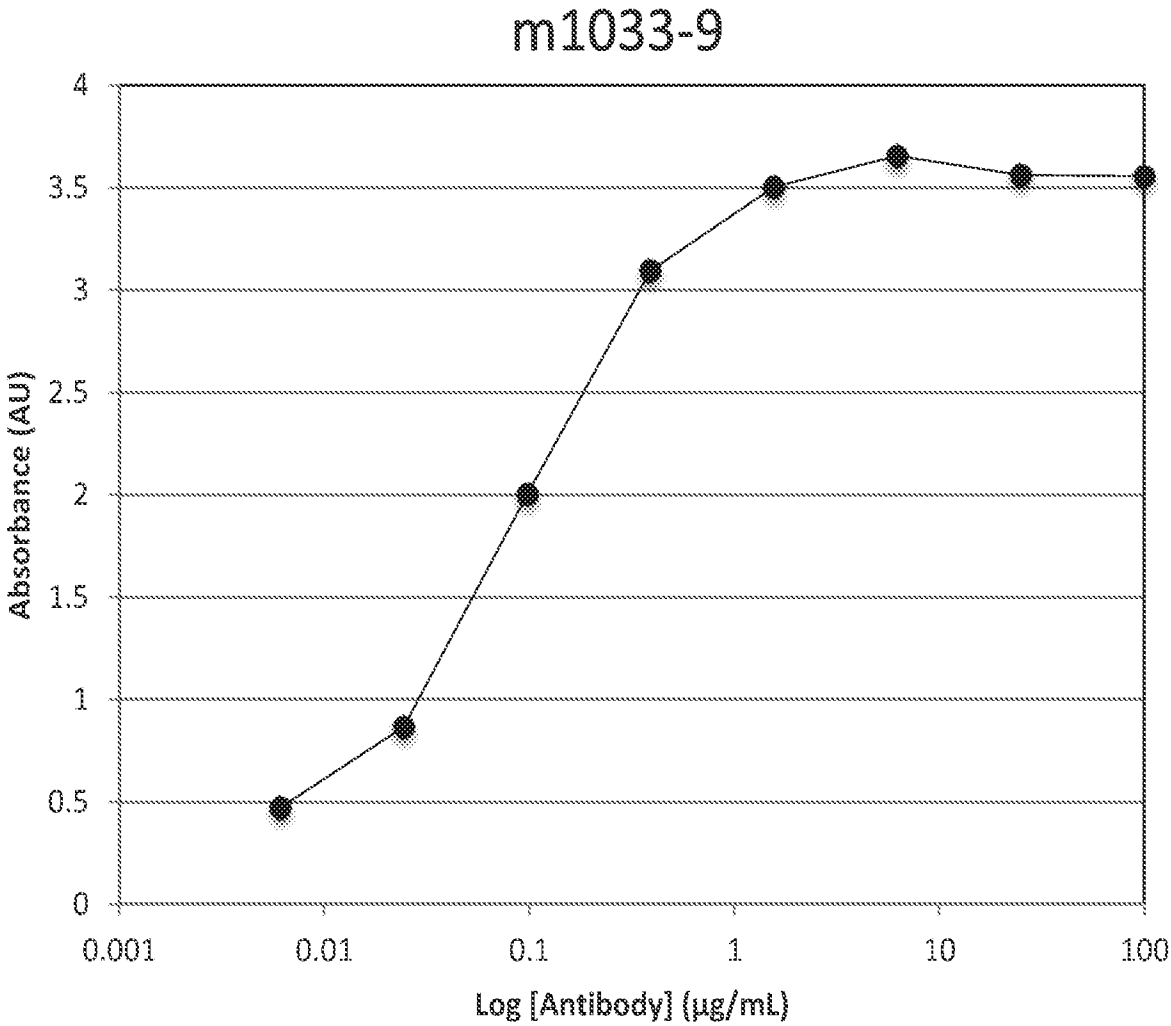

m1033-9
Absorbance (AU)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.001
0.01
0.1
1
10
100
Log [Antibody] (µg/mL)

FIG. 1

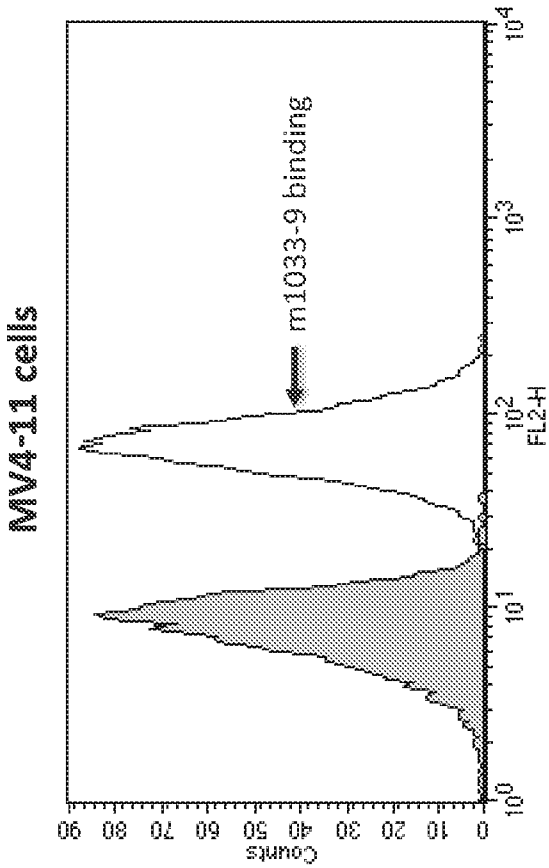


FIG. 2B

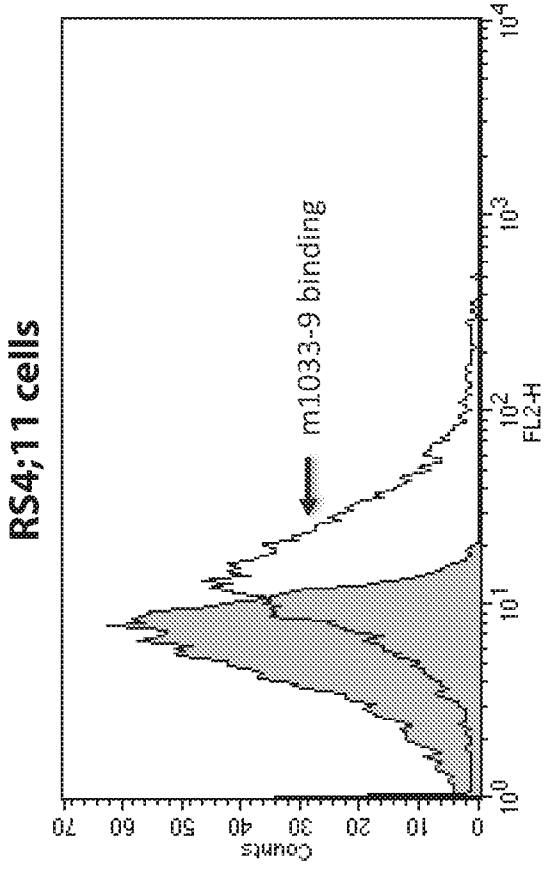


FIG. 2A

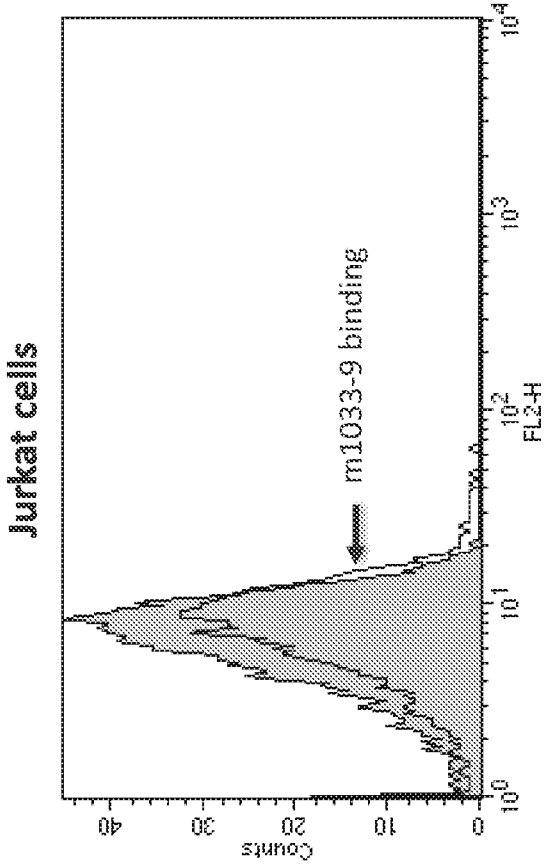


FIG. 2C

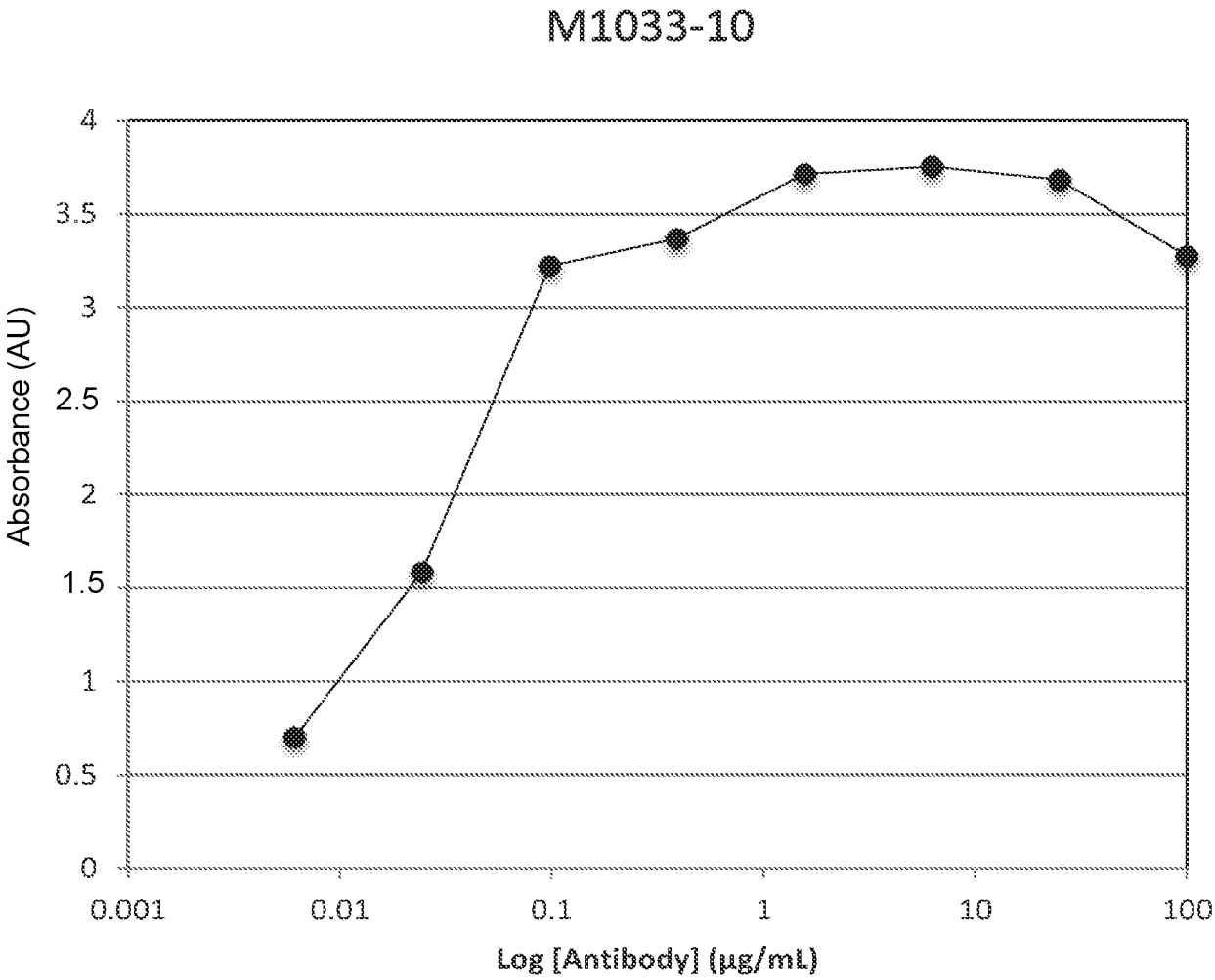

M1033-10
Absorbance (AU)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.001
0.01
0.1
1
10
100
Log [Antibody] (µg/mL)

FIG. 3

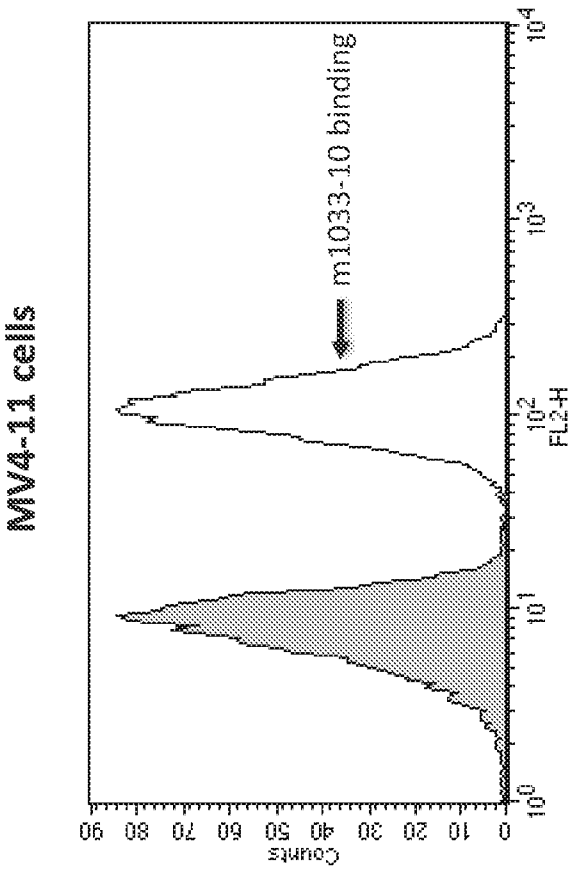


FIG. 4B

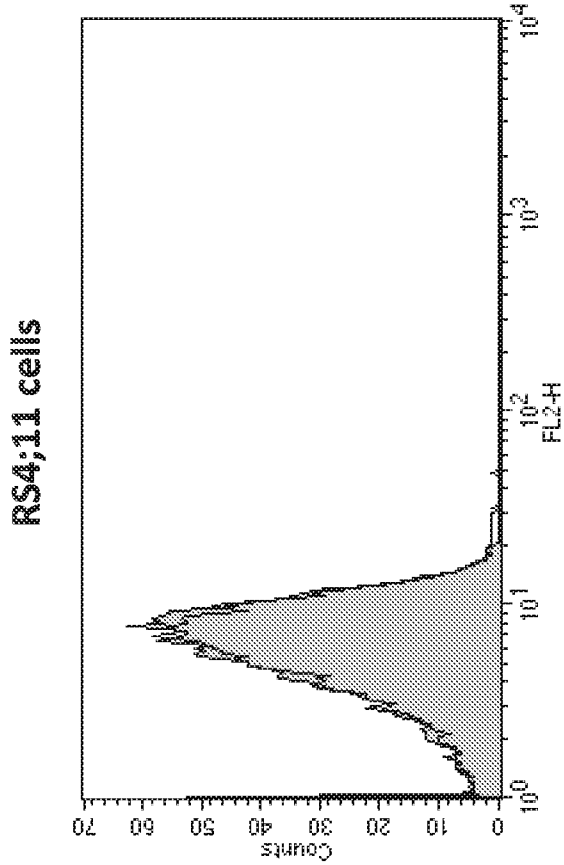


FIG. 4A

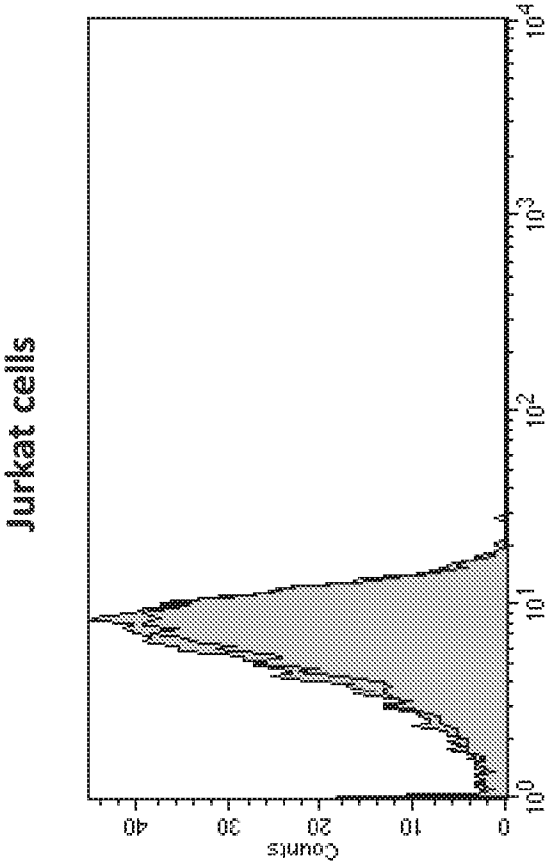


FIG. 4C

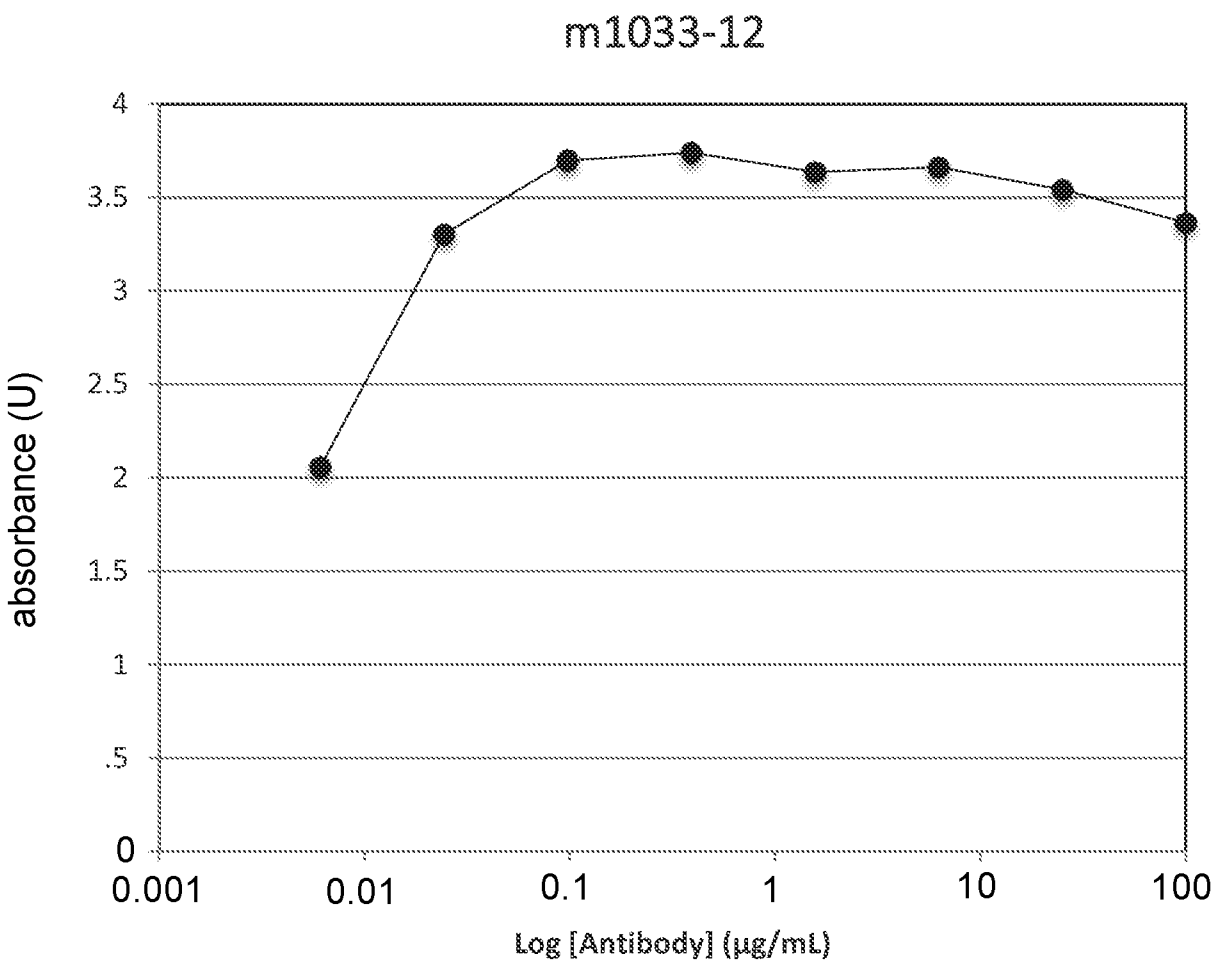

m1033-12
absorbance (U)
4
3.5
3
2.5
2
1.5
1
.5
0
0.001
0.01
0.1
1
10
100
Log [Antibody] (µg/mL)

FIG. 5

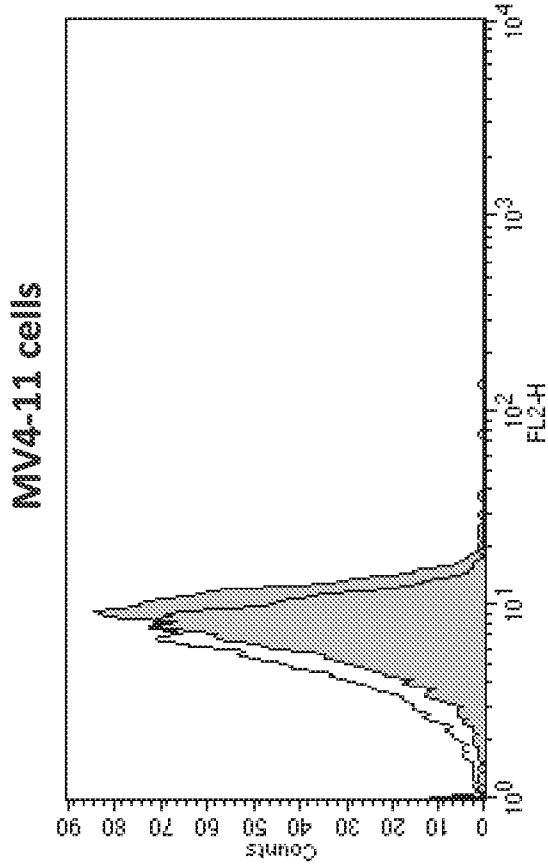


FIG. 6B

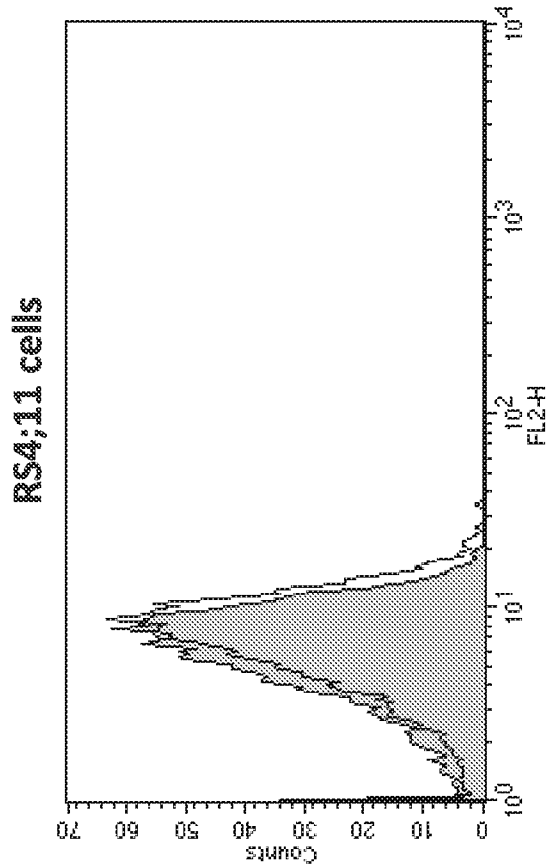


FIG. 6A

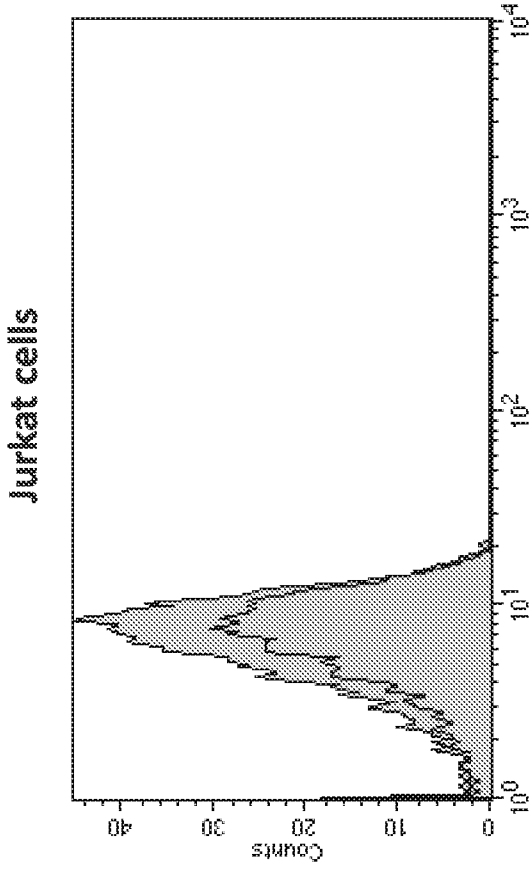


FIG. 6C

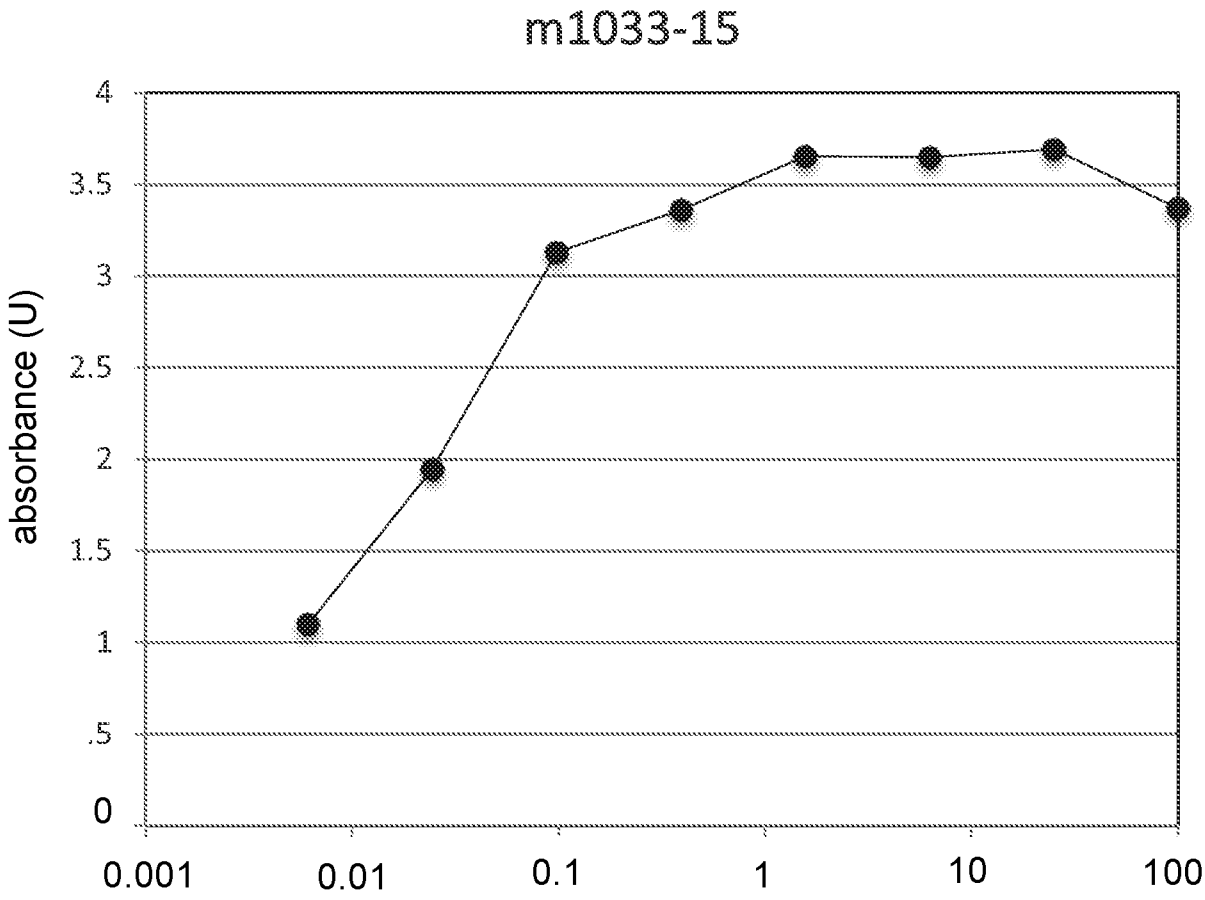


FIG. 7

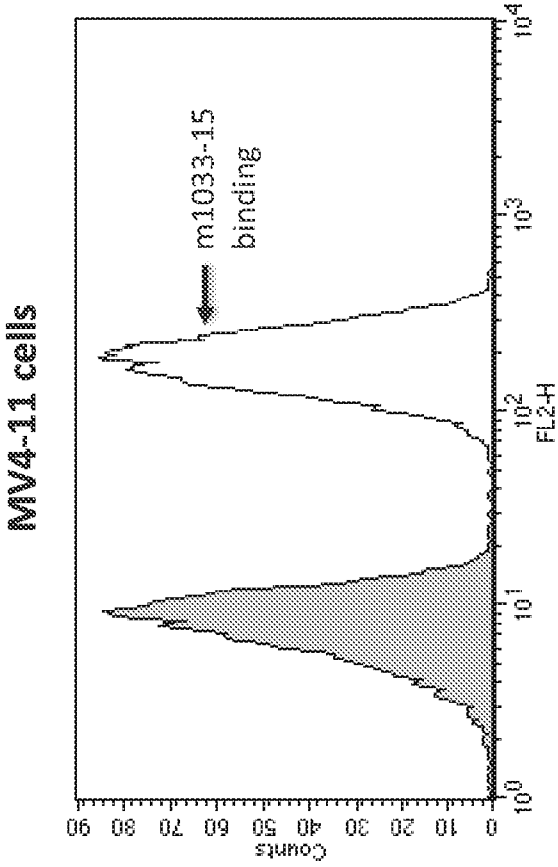


FIG 8B

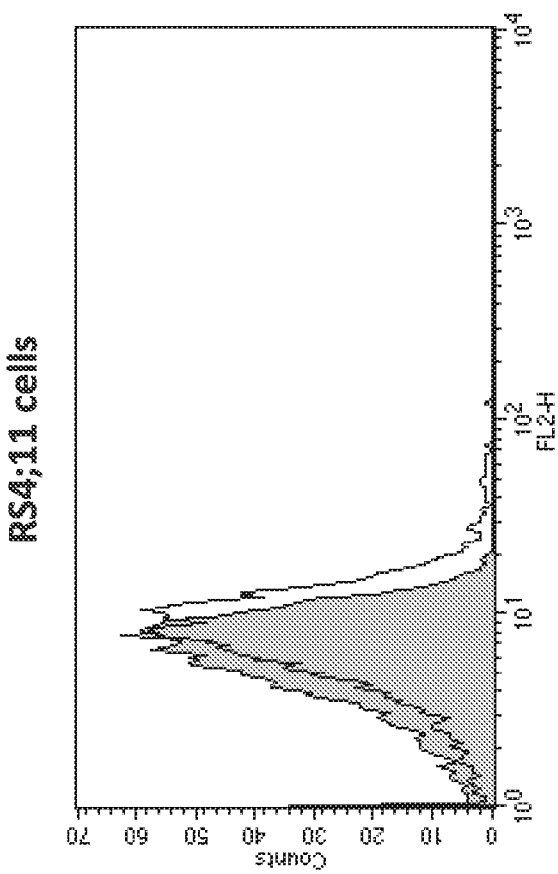


FIG. 8A

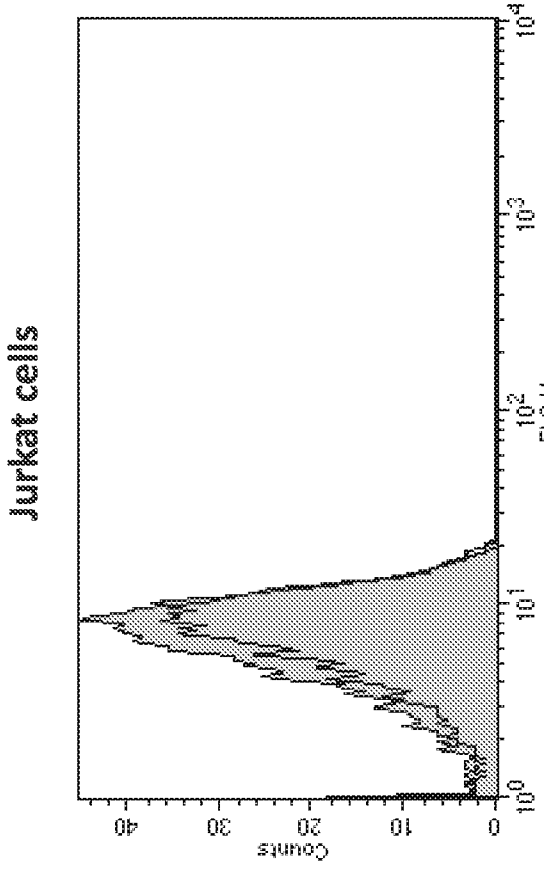


FIG. 8C

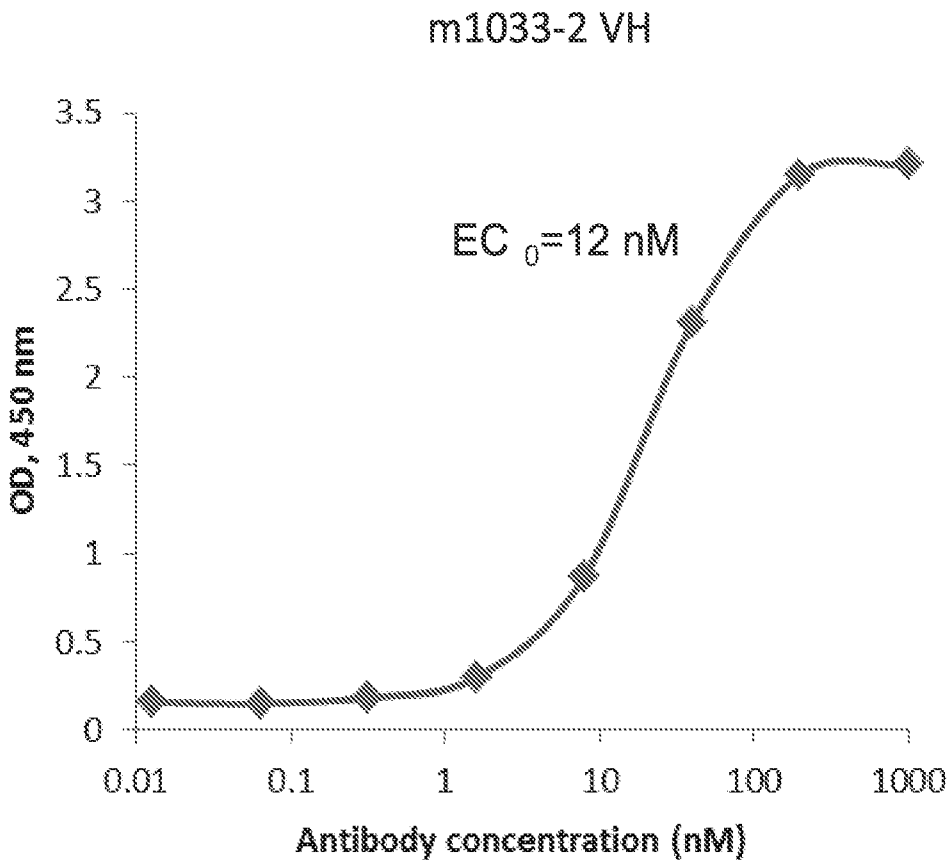

m1033-2 VH
EC 0=12 nM
OD, 450 nm
3.5
3
2.5
2
1.5
1
0.5
0
0.01
0.1
1
10
100
1000
Antibody concentration (nM)

FIG. 9

FIG. 10A

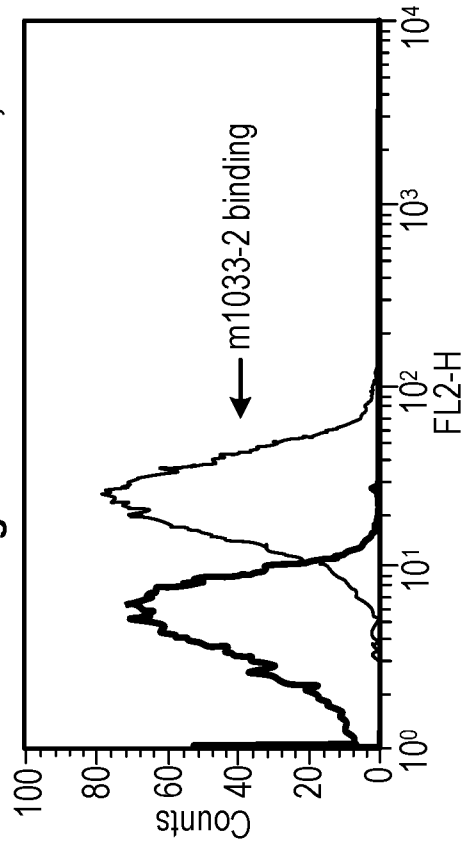


FIG. 10B

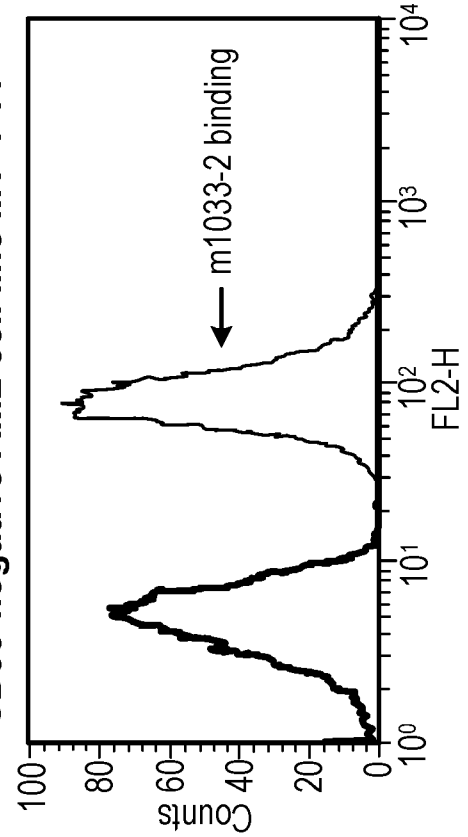
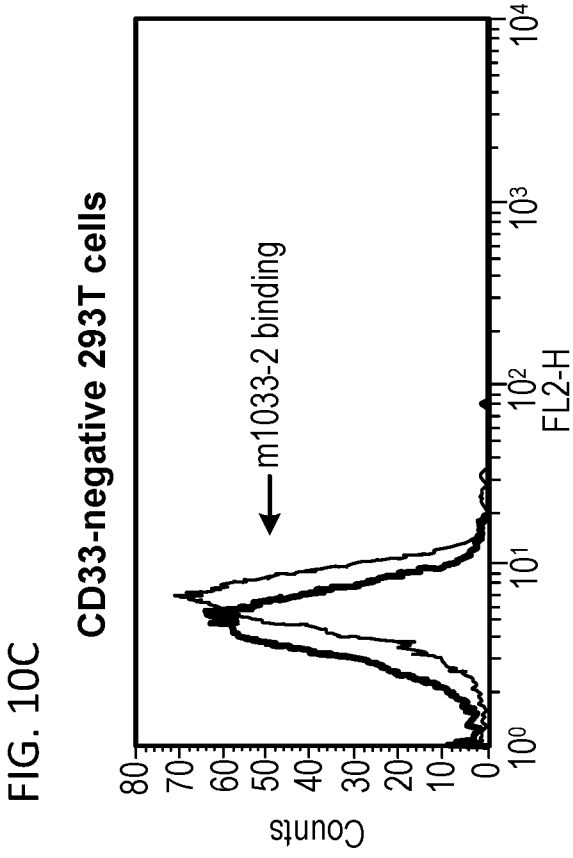


FIG. 10C



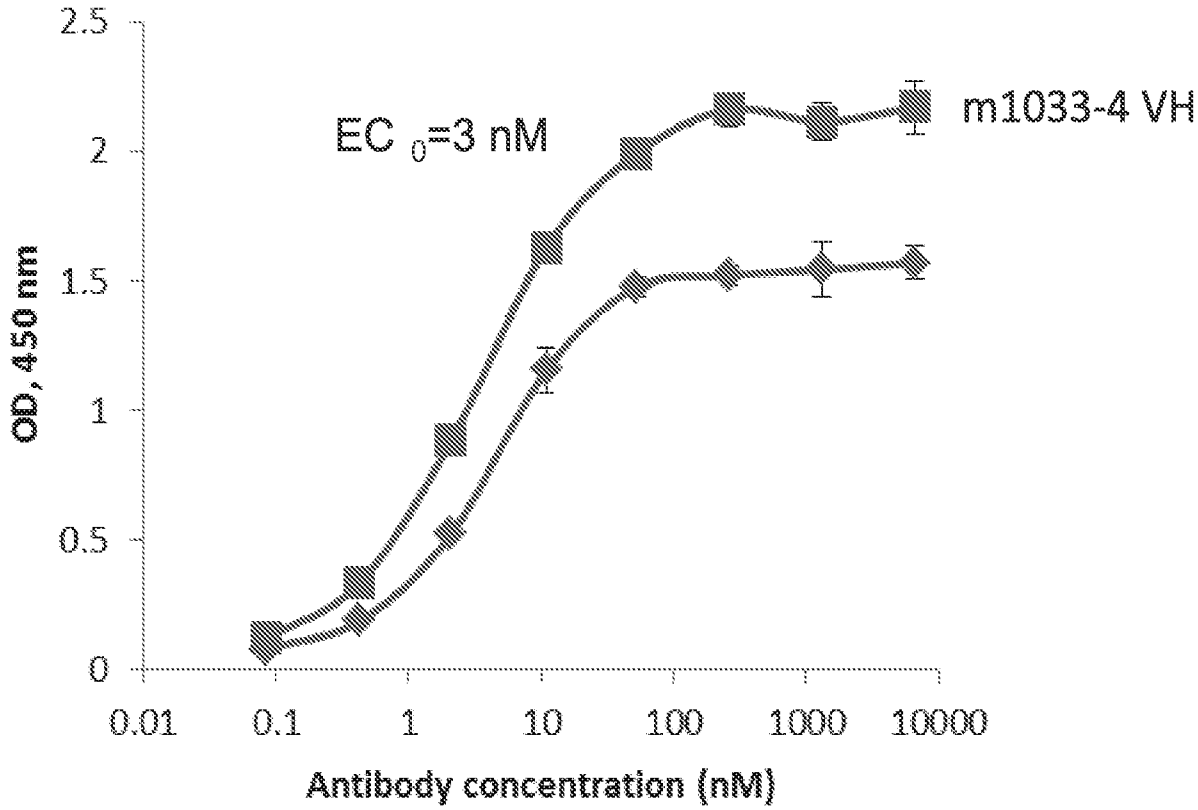

2.5
2
1.5
1
0.5
0
OD, 450 nm
EC 0=3 nM
m1033-4 VH
0.01
0.1
1
10
100
1000
10000
Antibody concentration (nM)

FIG. 11

FIG. 12A

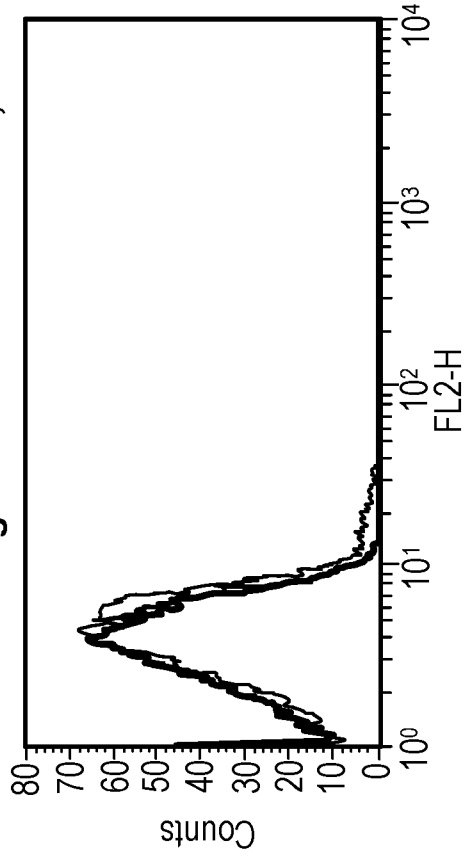


FIG. 12B

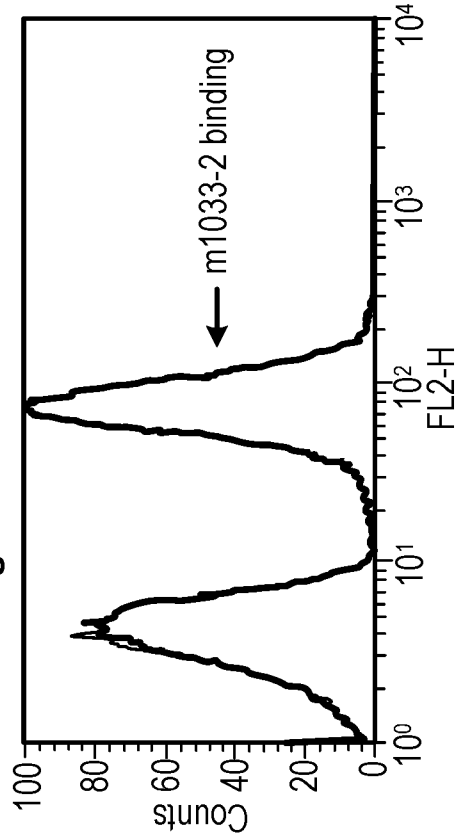
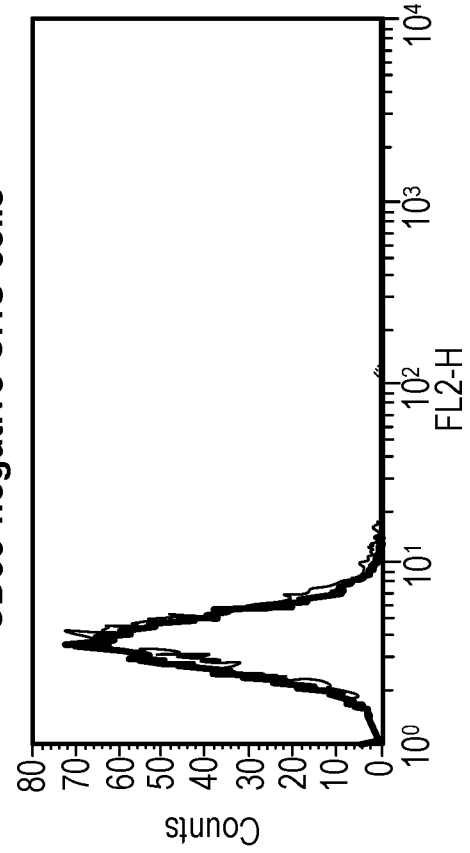


FIG. 12C



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/040257

A. CLASSIFICATION OF SUBJECT MATTER
INV. C07K16/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2015/089344 A1 (GENENTECH INC [US]) 18 June 2015 (2015-06-18) pages 1, 10, 11, 14, 106, 109, 110; claims 1, 22, 37, 38, 40, 45 -----	1-42
Y	Gautam Borthakur: "Precision 're'arming of CD33 antibodies", , 1 January 2013 (2013-01-01), XP055499788, Retrieved from the Internet: URL:http://www.bloodjournal.org/content/bloodjournal/122/8/1334.1.full.pdf?sso-checked=true [retrieved on 2018-08-14] the whole document ----- -/--	1-42

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 August 2018	24/10/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Heder, Andreas

2

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	HAMANN PHILIP R ET AL: "Gemtuzumab ozogamicin, a potent and selective anti-CD33 antibody-calicheamicin conjugate for treatment of acute myeloid leukemia", BIOCONJUGATE CHEMISTRY, AMERICAN CHEMICAL SOCIETY, US, vol. 13, no. 1, 1 January 2002 (2002-01-01), pages 47-58, XP009080679, ISSN: 1043-1802, DOI: 10.1021/BC010021Y abstract -----	1-42

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/040257

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-42(partially)

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-42(partially)

Monoclonal antibody (mAb) that binds CD33, immunoconjugate, ADC (antibody-drug conjugate), multi-specific antibody, antibody-nanoparticle conjugate, fusion protein, and composition comprising said mAb, nucleic acid encoding the same, and medical and diagnostic use thereof, wherein the mAb comprises the CDR of both SEQ ID NO: 2 and 4

2-4. claims: 1-42(partially)

Like invention 1, wherein the mAb comprises the CDR of both SEQ ID NO: 6 and 8, SEQ ID NO: 10 and 12, or SEQ ID NO: 14 and 16, respectively

---

5. claims: 1-42(partially)

Further groups of potential inventions, like invention 1, wherein the mAb comprises combinations of CDR not covered by inventions 1-4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/040257

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015089344 A1	18-06-2015	AR 098743 A1	08-06-2016
		AU 2014362238 A1	09-06-2016
		CA 2931340 A1	18-06-2015
		CL 2016001477 A1	20-01-2017
		CN 105814084 A	27-07-2016
		CR 20160257 A	22-07-2016
		EA 201691214 A1	30-12-2016
		EP 3080164 A1	19-10-2016
		JP 2017505604 A	23-02-2017
		KR 20160098328 A	18-08-2016
		MA 39095 A1	31-08-2016
		PE 07122016 A1	26-07-2016
		PH 12016501143 A1	15-08-2016
		SG 11201604784X A	28-07-2016
		TW 201533060 A	01-09-2015
		US 2017002074 A1	05-01-2017
		WO 2015089344 A1	18-06-2015